HOLISTIC CARRYING CAPACITY FOR SALMON AQUACULTURE: THE IMPLICATION OF SOCIAL VALUES

by

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DEDICATION

To my loving husband Dan,
for your patience,
your love,
your humour,
your encouragement
and your willingness to eat out.

And to my daughter Skye,
for your smiling face,
your silliness,
and your genuine curiosity about the world.

For your unwavering support,
And unconditional admiration,
which kept me grounded,
reminding me why I work so hard.

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ABSTRACT

The increasing need to consider multiple pressures and take a more holistic approach to management of aquaculture has prompted the development of the Food and Agriculture Organization (FAO)'s Ecosystem Approach to Aquaculture (EAA). Carrying capacity (CC) has been identified to support more sustainable aquaculture and inform holistic assessment of aquaculture across multiple management goals and priorities. Yet, how to integrate components holistically, i.e., how a holistic CC approach can be defined, measured, and used in policy contexts, is not fully understood. Therefore, the overall goal of this thesis was to investigate carrying capacity to support holistic assessment of salmon aquaculture in the context of an EAA. This thesis first identifies the opportunities and challenges for operationalizing carrying capacity to support more holistic management, building on a comprehensive literature review (Chapter 2) and consensus (Delphi) with international experts (Chapter 3) in CC and aquaculture. This thesis presents a research agenda to address these gaps (Chapter 2) and presents some general guidelines and recommendations to inform a holistic assessment of aquaculture (Chapter 3). In addition, this thesis also aims to close the gap in understanding social carrying capacity by investigating relevant factors for understanding social indicators and thresholds for aquaculture, focusing on salmon aquaculture in Nova Scotia. Through quantitative (Chapter 4), and qualitative (Chapter 5 and 6) perception research, this thesis identifies a suite of individual, contextual, and perceptual factors influencing social attitudes towards aquaculture. This thesis highlights that developing holistic assessments of aquaculture carrying capacity continues to be complex. The challenges and opportunities identified here present a potential role for holistic carrying capacity as an approach to planning and decision-making within an EAA. The insights, recommendations, and findings from this work advances the development of a process for holistic carrying capacity assessment and begin to close the gap on social carrying capacity based on social acceptance, values, and integration of trust and legitimacy. Finally, this thesis offers a way forward for holistic carrying capacity by outlining a series of interlinked lenses that places social values as integral to identifying social, production, physical and ecological limits.

LIST OF ABBREVIATIONS USED

Abbreviation	Description
AIC	Akaike Information Criterion
BEJ	Best Expert Judgement
EBM	Ecosystem-Based Management
EAA	Ecosystem Approach to Aquaculture
EIA	Environmental Impact Assessment
ECC	Ecological Carrying Capacity
ES	Ecosystem Services
CC	Carrying Capacity
CCC	Comprehensive Carrying Capacity
DEB	Dynamic Energy Budget
DFO	Department of Fisheries and Oceans Canada
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographic Information Systems
HCC	Holistic Carrying Capacity
ICZM	Integrated Coastal Zone Management
IUCN	International Union for Conservation of Nature
KMO	Kaiser-Meyer-Olkin
LCA	Life Cycle Assessment
MSP	Marine Spatial Planning
NEP	New Ecological Paradigm
NIMBY	Not In My Backyard
NSDFA	Nova Scotia Department of Fisheries and Aquaculture
NGO	Non-Governmental Organization
PCA	Principal Components Analysis
SA	Social Acceptance
SCC	Social Carrying Capacity
SDGs	Sustainable Development Goals
SES	Social-Ecological Systems

SLO	Social License to Operate
PrCC	Production Carrying Capacity
PhCC	Physical Carrying Capacity
UN	United Nations

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CHAPTER 1: INTRODUCTION

1.1 THE NEED FOR SUSTAINABLE AQUACULTURE

Aquaculture, defined as the controlled farming of fish, shellfish, or seaweeds, has grown dramatically over the past 30 years, and continues to rise as output from capture fisheries has declined (FAO, 2020a). Aquaculture continues to be one of the fastest growing global food industries. Aquaculture production now supplies over 50% of the fish for human consumption (FAO, 2020a), and is expected to at least double by 2050 (Pernet & Browman, 2021). This growth is met with an increase in fish consumption globally at an average annual rate of 3.1% between 1961 and 2017, a whole percentage point higher than other animal proteins (FAO, 2020a). Around the world, over 600 aquatic species were farmed in freshwater, marine, and brackish water environments in 2018. However, only a handful of species make up most of the production volume (Naylor et al., 2021). Consistent growth of the industry in recent years has been driven by strong markets for species like shrimp, bivalves, and salmon. Since 2013, salmonids like Atlantic salmon (*Salmo salar*) have been the single most important commodity traded by volume, accounting for roughly 19% of all internationally traded fish products in 2018 (FAO, 2020a). Consequently, aquaculture has become a promising industry to meet the food needs of a growing population and relieving fishing pressure on overexploited wild fish stocks.

The effective development and management of salmon aquaculture requires addressing numerous challenges across economic, social, and environmental dimensions. The rapid growth of aquaculture has generated ecological concerns over the near-field and far-field effects of finfish aquaculture including benthic and water quality effects, modification of habitat, spread of diseases and invasive species, attraction of wild fish and predators, and the reliance on wild fish for feed (Weitzman et al., 2019). Disease outbreaks can also have severe economic repercussions for industries and communities, as was demonstrated in the aftermath of a series of infectious salmon anemia outbreaks in Chile between 2007 and 2009 (Bachmann-Vargas et al., 2021).

These challenges have manifested significant public concerns in most salmon-farming countries, creating issues of public trust and challenging the social sustainability of the sector. In many parts of the world, poor social acceptance of aquaculture due to a combination of public concerns and mistrust are often considered a barrier to development (Corner et al., 2018). Nevertheless, aquaculture may promote necessary economic benefits for many areas that face economic pressures such as rural employment, youth retention and economic stability. Achieving social sustainability recognizes that aquaculture operations should improve social well-being and be acceptable to communities and public groups. The growing recognition of social sustainability has given rise to a recent discourse around social acceptance (SA) and social license to operate (SLO) (Mather & Fanning, 2019). Both terms refer to social perceptions and attitudes towards aquaculture, drawing on viewing it as positive technology. Social acceptance is broad and multi-faceted reflecting an individual-oriented measurement of how operations are viewed. In comparison, SLO is an industry-focused outcome dependent on practices necessary to be accepted by both local, regional, and market communities (for a review, see Gehman et al., 2017). In this way, understanding what shapes, and motivates social acceptance is critical for measuring and managing social impacts and informing more equitable aquaculture policy.

Persistent environmental challenges and growing social conflicts of aquaculture reinforce a recent recognition of inefficient and insufficient governance, management, and planning structures for aquaculture in many parts of the world (e.g., Bush & Oosterveer, 2019; Couture et al., 2021). While regulatory structures for aquaculture are often extensive, they are also criticized as being complex and fragmented, with multiple regulations across different departments and levels of government governing aquaculture (Davies et al., 2019; Liu et al., 2013; Sanderson & Kvalvik, 2014). This is relevant in Canada, where a complex regulatory framework (Noakes, 2018) characterized by a patchwork of governance approaches (Doelle & Saunders, 2016) creates challenges for managing a sustainable aquaculture industry (Wiber et al., 2021). As a result, a shift from traditional governance mechanisms to those that recognize the holistic nature of aquaculture becomes critical for sustainability of the sector.

1.2 THE ECOSYSTEM APPROACH TO AQUACULTURE

The increasing need to consider multiple pressures and take a more holistic approach to management of marine systems has prompted the development of several ecosystem-based management (EBM) strategies like the FAO Ecosystem Approach to Aquaculture (Arkema et al., 2006; Soto et al., 2008). The FAO's Ecosystem Approach to Aquaculture (EAA) is defined as "a strategy for the integration of aquaculture within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems." (Soto et al., 2008). The EAA represents a shift in thinking that recognizes that humans are an integral part of many ecosystems.

Part of this shift requires approaches that view aquaculture in their coastal regions as coupled, social-ecological systems (SESs) (Johnson et al., 2019). The social-ecological system framework conceptualizes the "environment" as an open system made up of ecological and social processes, integrated through management practices and resource use. Applied to aquaculture, this concept recognizes aquaculture activities as the resource use process that influences the environment's provision of ecosystem services to benefit or impact human well-being (**Figure 1.1**). Operating across multiple spatial and temporal scales and cycles, the system components are influenced by broad-scale forces (political, economic, and biogeochemical) and interact through interdependencies and feedbacks (Ostrom, 2009). Applying a more systemic worldview can help meet many modern environmental management challenges such as those seen with aquaculture (Virapongse et al. 2016).

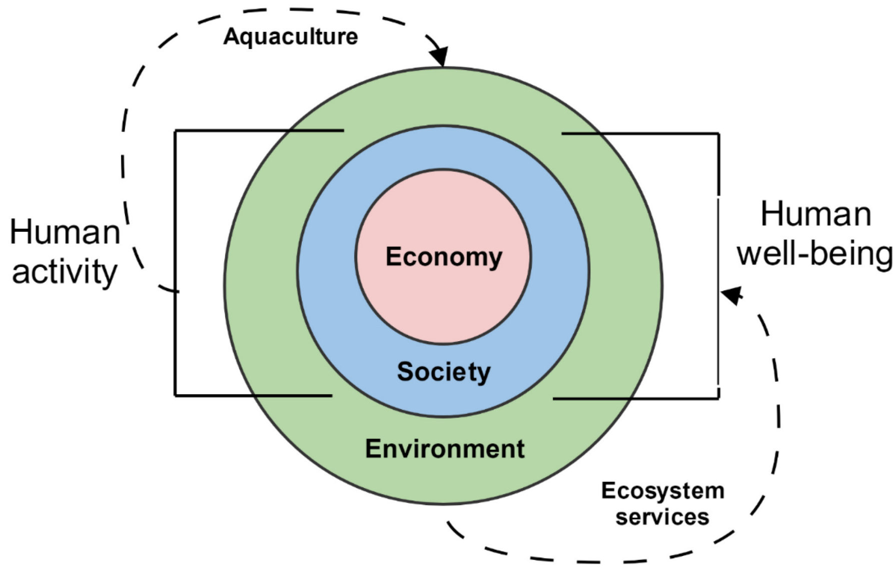

Figure 1.1 System of interactions between economic, societal, and environmental attributes of aquaculture.

The EAA presents a holistic and interdisciplinary approach to aquaculture management. EAA implementation is supported by various principles, which include adaptive and participatory approaches that consider all aspects of aquaculture across multiple temporal and spatial scales (Costa-Pierce, 2008). The EAA is guided by three main principles (Soto et al., 2008):

- Aquaculture development and management should take account of the full range of ecosystem functions and services, and should not threaten the sustained delivery of these to society
- Aquaculture should improve human well-being and equity for all relevant stakeholders
- Aquaculture should be developed in the context of other sectors, policies, and goals

Despite its inception over 10 years ago, the EAA has had varying degrees of uptake and adoption and continues to face implementation barriers and challenges (Brugère et al., 2018). Empirical data on both social and ecological processes in a system are needed for successful integrated management approaches (Plummer & Fitzgibbon, 2004). Implementing an Ecosystem Approach to Aquaculture requires developing holistic tools to help manage and develop the salmon aquaculture industry in a sustainable and socially accepted manner.

1.3 CARRYING CAPACITY AS A TOOL FOR EAA

To implement the EAA, managers and planners must consider how environmental constraints affect aquaculture, the potential socio-economic impacts, and interactions with other activities when determining new sites for development and monitoring existing aquaculture sites. In this regard, the well-known concept of carrying capacity could be mobilized for the holistic assessment of aquaculture to support an EAA (Ross et al., 2013). Within the context of the Ecosystem Approach to Aquaculture, carrying capacity (CC) describes the extent of aquaculture that could be developed in an area without causing harm to the natural, social, cultural, or economic environment beyond "unacceptable" thresholds. As a result, scholars often describe four types of carrying capacity (Mckinsey et al., 2006; Ross et al., 2013):

- *Ecological carrying capacity*: the magnitude of aquaculture production that can be supported without leading to significant changes to ecological processes, services, species, populations, or communities in the environment
- *Social carrying capacity*: the level of aquaculture that can be developed that is accepted by local communities, and does not cause adverse social effects
- *Production carrying capacity*: the magnitude of aquaculture activity at which the production biomass is maximized
- *Physical carrying capacity*: the area geographically available and physically and/or chemically suitable for an aquaculture activity

Carrying capacity has been used in a range of disciplines, including tourism and recreation (McCool & Lime, 2001; Saveriades, 2000), agriculture (Venkateswarlu & Prasad, 2012), population biology (Braithwaite et al., 2012), and aquaculture (Duarte et al., 2003; Ferreira et al., 2008; Filgueira et al., 2015a,b). Carrying capacity has become an important part of sustainable resource management in Canada and internationally. Carrying capacity can help guide the decisions of managers and planners, such as determining suitable sites for fish farming development, setting acceptable monitoring thresholds, and making sustainable resource management policies (Ross et al., 2013). Yet, a full integration of various types of CC is still lacking. Furthermore, a key question remains about how to align CC within aquaculture decision-making under the context of EAA.

1.4 GOALS AND RATIONALE FOR STUDY

Site selection, approval, and monitoring of aquaculture is supported with tools that provide guidelines to manage issues and concerns over sector development. Carrying capacity is a potentially powerful tool often considered critical to overall area management but is poorly implemented in many areas (Corner et al., 2018). Modern management frameworks recognize that sustainable and effective policy decisions should be based on an ecosystem-based approach that acknowledge challenges posed by feedback between environmental, social, and economic environments. Yet, how the CC approach can be effectively mobilized for holistic assessments of aquaculture has not been elucidated. Therefore, the overall goal of this thesis was to investigate carrying capacity in support of holistic assessment of salmon aquaculture in the context of an Ecosystem Approach to Aquaculture.

This research was guided by the following research questions and sub-questions:

1. How can carrying capacity be mobilized to support the holistic management of salmon aquaculture?
    a. How can the concepts and approaches currently used in carrying capacity research be mobilized for a more holistic assessment of aquaculture?
    b. What processes, tools, and information are most suitable for a holistic design for aquaculture carrying capacity?
2. What factors determine the socially acceptable limits of salmon aquaculture?
    a. What factors are most important drivers for public opinions of aquaculture?
    b. What factors influence community acceptance to aquaculture?

This thesis explores both the practical and theoretical challenges and opportunities for carrying capacity (CC). A holistic approach has not yet been developed for finfish like Atlantic salmon. Where social aspects of aquaculture are a major challenge and remain largely neglected in the literature, this research can foster a better understanding of the perceptions of local communities to aquaculture, identify conflicts, and help inform decision-makers about social acceptance issues (Mazur & Curtis, 2006). This work can further refine the definitions and analytical approaches for assessing social carrying capacity. An effective CC framework to support EAA principles will engage with novel adaptive and participatory approaches that consider all aspects of aquaculture across multiple temporal and spatial scales (Costa-Pierce, 2008). Therefore, this interdisciplinary research can offer decision-makers potential guidance and knowledge for more holistic decision-making and planning of aquaculture.

This work was motivated by governance challenges and social conflicts with Atlantic salmon (*Salmo salar*) farming in Atlantic Canada, which remained the underlying consideration across this research. Therefore, research conducted to investigate factors of socially acceptable limits (research question 2) drew on data from Nova Scotia. Still, this work also drew from an international panel of experts to identify more generalizable conclusions about CC opportunities and challenges. As a result, this work can have applicability to management in other areas of the world, where aquaculture is also rapidly developing and where countries are increasingly recognizing the need for adopting an Ecosystem Approach to Aquaculture. This research can improve the understanding of the approaches for estimating carrying capacity, inform planning processes, and help work towards operationalizing an EAA.

1.5 RESEARCH APPROACH AND THESIS STRUCTURE

This thesis consists of five research chapters, each of which is written as a stand-alone article that is either already published or in review in a peer-reviewed scientific journal. The research in this thesis was guided by a pragmatic theoretical perspective, drawing on a largely interpretivist philosophy, focusing on the practical implications of the work. To that end, this work applied a mixed-methods research approach, combining multiple quantitative and qualitative data collection and analysis to explore the research questions as described above. This thesis took an emergent research approach to enable the generalizability of findings to theory, whereby insights gained were considered conceptually and reflexively, and each research chapter reflects a research process that drew from the findings and conclusions of earlier research chapters (Mabry, 2008). Findings of all chapters are summarized in a concluding chapter at the end of this thesis, which also provides reflection on the role of carrying capacity within holistic aquaculture governance.

Chapter 2 presents a comprehensive review of carrying capacity concepts, applications, and measurement tools and offers theoretical insights how CC aligns with holistic ecosystem-based principles. The findings of this chapter present a research agenda that served to guide the overall design for the following chapters.

In **Chapter 3**, a panel of international subject-matter experts elicited and validated a series of guidelines and requirements for a useful CC process in light of holistic assessments of aquaculture. This resulted in the creation of holistic CC assessment principles, processes, and techniques, as well as practical challenges and opportunities for CC.

Understanding gained reflexively in early chapters (Chapter 2 and 3) identified a primary knowledge gap related to defining socially relevant indicators and thresholds for CC, motivating the development of the second research question. To answer this question, this research aimed to contribute to existing theoretical assumptions about what factors influence perceptions and attitudes towards aquaculture. Recognizing that investigating drivers of perceptions and attitudes must be bounded by specific societal contexts, this thesis explored perceptions of salmon aquaculture in Nova Scotia. This thesis applied an analytic generalization process (per Yin, 2009) whereby the main goal was to uncover causal relations by identifying the essential characteristics of the phenomenon studied. Drawing from theory in existing literature and integration of evidence across multiple studies and data sets, this work helps build theoretical premises to make assertions about situations akin to the one studied. Thus, this thesis makes no claims to generalizability to the population studied (e.g., Nova Scotia), but to advance theory on social acceptance. To that end, **Chapter 4** details a quantitative public survey in Nova Scotia that investigated how differences in demographics, values, and knowledge influence public views of salmon farming. In addition, an in-depth qualitative approach captured the perceptions and attitudes of citizens and stakeholders in three salmon farming communities in Nova Scotia on the operation, management, and development of salmon farming (Chapters 5 and 6). Multiple case-study comparisons (**Chapter 5**) present an in-depth exploration of the role of context on shaping perceptions, enabling comparative inference in support of generalization (Gobo, 2008). Drawing on the same dataset from Chapter 5, **Chapter 6** is positioned to identify common attributes between different perspectives, providing insights that may advance the conceptual understanding of what motivates attitudes towards aquaculture in salmon farming communities. The outcomes of this stage can lead to a better understanding of what may indicate social acceptance and lead to the potential identification of social carrying capacity thresholds.

Chapter 7 synthesizes findings from earlier chapters to into a comprehensive overview of the conclusions in support of my main research objectives and questions. This section highlights the main challenges and opportunities for holistic assessment of aquaculture CC, presenting the final vision for way forward for holistic carrying capacity (HCC), and identifies future research opportunities.

1.6 STATEMENT OF CO-AUTHORSHIP

The overall conceptualization of this thesis was developed by myself with the guidance of my co-authors. Across all research chapters, I designed the research, conducted all data analysis, and wrote the majority of the manuscripts. My co-authors provided valuable insight and feedback (comments, suggestions, and edits) throughout the conceptualization and writing of all research chapters and aided in the preparation of submission for publication. Published chapters and chapters in review from this thesis are as follows:

Chapter 2:

Weitzman, J., & Filgueira, R. (2019). The evolution and application of carrying capacity in aquaculture: towards a research agenda. *Reviews in Aquaculture, 12,* 1297-1322. https://doi.org/10.1111/raq.12383

Chapter 3:

Weitzman, J., Filgueira, R., & Grant, J. (2021). Development of best practices for more holistic assessments of carrying capacity of aquaculture. *Journal of Environmental Management, 287*, 112278. https://doi.org/10.1016/j.jenvman.2021.112278

Chapter 4:

Weitzman, J., Filgueira, R., & Grant, J. (2022). Identifying key factors driving public opinion of salmon aquaculture. *Marine Policy, 143,* 105175. https://doi.org/10.1016/j.marpol.2022.105175

Chapter 5:

Weitzman, J., Filgueira, R., & Grant, J. Context matters: Understanding how local context influences perceptions of aquaculture. *Ecology & Society* [In Review]

Chapter 6:

Weitzman, J., Filgueira, R., & Grant, J. Dimensions of legitimacy and trust in shaping social acceptance of marine aquaculture: an in-depth case study in Nova Scotia, Canada. *Journal of Environmental Science and Policy* [In Review]

CHAPTER 2: THE EVOLUTION AND APPLICATION OF CARRYING CAPACITY IN AQUACULTURE

The overall goal of this chapter was to provide the theoretical foundation for comprehensive notions of carrying capacity. In this sense, this chapter clarifies the research to help set priorities and goals for subsequent chapters. To do so, a comprehensive literature review of the carrying capacity concept across disciplines was conducted. This was then put in the context of the Ecosystem Approach to Aquaculture to identify challenges and opportunities of the concept and identify future research areas. The outcomes from this chapter included a theoretical understanding of the relevant concepts and information to apply to a holistic carrying capacity framework and research gaps.

Citation:

Weitzman, J., & Filgueira, R. (2019). The evolution and application of carrying capacity in aquaculture: towards a research agenda. *Reviews in Aquaculture, 12,* 1297-1322. https://doi.org/10.1111/raq.12383

Please note that this chapter appears exactly as it did in the published journal article.

2.1 ABSTRACT

Carrying capacity has become a fundamental concept within the context of environmental management. Carrying capacity for aquaculture has been studied since the 1960s and has attracted a dedicated literature focused on measuring the environmental and production limits of aquaculture developments. Nevertheless, management and policy face emerging challenges across environmental and social aspects and the growing need to manage multiple objectives in increasingly crowded aquatic ecosystems. Therefore, promoting more sustainable aquaculture development should consider how the tools, methods, and research used to support management and decision-making should advance to meet such challenges. Here, the conceptual and practical applications of carrying capacity are reviewed and future prospects discussed. Carrying capacity for aquaculture has developed a range of models, indicators, and approaches to study the relationships between aquaculture and ecosystem components. Carrying capacity supports diverse management objectives to support physical, production, ecological and social goals, although greater emphasis has focused on ecological and production capacities. This review introduces research needs and strategies to advance methods and tools and improve carrying capacity utilization for more holistic, ecosystem-based aquaculture decision-making. This paper presents a five pillar research agenda for carrying capacity that 1) recognizes system complexity and is 2) policy-relevant, 3) adaptive, 4) interdisciplinary, and 5) meaningful. By promoting knowledge uptake and addressing literature gaps, the proposed agenda could help operationalize a holistic approach to managing for aquaculture sustainability.

2.2 INTRODUCTION

Carrying capacity (CC) can be broadly described as the maximum level of use an area can tolerate before unacceptable degradation occurs. However, a single overarching definition may be inappropriate due to the divergence in applications of the concept across disciplines (Sayre, 2008). Carrying capacity has become a widely popularized concept in modern environmental politics; notably, CC has been considered both the basis for, and a tool to operationalize, sustainable development (Daily & Ehrlich 1992; Daly, 1990; Graymore et al., 2010; Sala et al., 2015). Over the years, the carrying capacity concept has been used to describe the growth limits of natural populations, account for resource use by rising human populations, and make environmental management decisions within fields such as tourism, agriculture, and aquaculture (Chapman & Byron, 2018).

Within the last 30 years, the global production of aquaculture has rapidly expanded, surpassing fisheries in terms of seafood for human consumption for the first time in 2014 (FAO, 2016). Aquaculture has become a promising industry to address growing food demands around the world (Naylor, 2016). However, industry growth has also been associated with recognition of environmental externalities and social conflicts that may influence the capacity of environments to provide goods and services in a sustainable manner (Edwards, 2015; Primavera, 2006). Regulators and other groups have thus become increasingly interested in understanding and evaluating the carrying capacity of aquaculture to support diverse decision-making goals and management applications, including reducing the industry's environment impact and optimizing production characteristics. Carrying capacity has also been proposed as a promising tool to advance holistic ecosystem-based aquaculture management (Ross et al., 2013). Nevertheless, ecosystem-based approaches to aquaculture have had varying degrees of uptake and adoption by groups (Brugère et al., 2018). Furthermore, there remains a lack of clear frameworks for operationalizing carrying capacity into holistic decision-making.

The purpose of this review is to critically examine the carrying capacity literature for aquaculture and highlight CC methods and capabilities in supporting ecosystem-based decision-making. By reviewing the primary and secondary literature, this paper examines the theoretical underpinnings and carrying capacity applications across the broader literature and explores how carrying capacity has been defined and measured in aquaculture contexts. This comparative approach provided the basis to identify common challenges and themes and to propose a research agenda to advance carrying capacity utilization in decision-making.

2.3 BACKGROUND AND HISTORY

2.3.1 Conceptual evolution and applications of carrying capacity

The carrying capacity (CC) concept evolved concurrently across multiple disciplines, which have independently applied the concept to study a range of applications from biology, population ecology, human demography, wildlife and resource management, and more recently sustainable development (**Figure 2.1**). Contemporary definitions of carrying capacity are often thought to have ancestry in Thomas Malthus' 1798 *Essay on the Principle of Population* (Malthus, 1986). In 1838, mathematician Pierre Verhulst first defined Malthus' ideas to fit what is popularly known today as the "logistic growth equation" or "logistic growth curve". While Malthus laid the conceptual foundation for CC and Verhulst assigned its mathematical formulation, neither ever used the term "carrying capacity" (Sayre, 2008), which was simply represented as the upper limit of population growth (*K*). The earliest articulation of the term carrying capacity has been attributed to an 1845 U.S. Secretary of State to the Senate report whereby carrying capacity was used to describe the maximum load that a cargo ship could carry. According to a review by Sayre (2008), it is likely that the CC concept as a function of mechanical attributes of manufactured objects likely predates Malthus. While this literal and quantitative application of carrying capacity to physical infrastructure has largely been replaced by the term payload in the modern literature (Sayre, 2008), there remain a range of engineering and physics literature dedicated to calculating the load-carrying capacity of manufactured objects (e.g., Rajput & Sharma, 2018; Su et al., 2009) or current-carrying capacity of physical materials (e.g., Kim et al., 2010; Yu et al., 2012). This literal definition is also applied today to living systems in biological and medical research, for example, to describe how the oxygen capacity of blood relates to animal or human physiology (Dabruzzi & Bennett, 2014; Salazar Vázquez et al., 2008; Tufts et al., 2013).

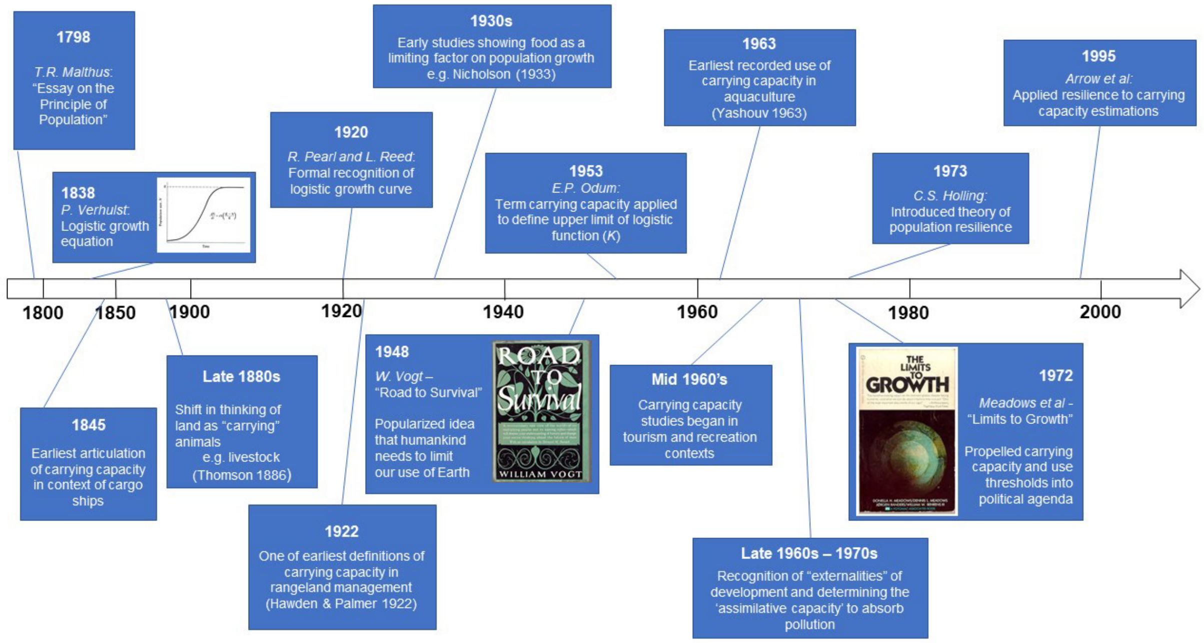

Figure 2.1 Timeline of major developments in the evolution of carrying capacity concepts and applications.

In the 1880s, studies began regularly applying carrying capacity to attributes of living systems (Chapman & Byron, 2018). Early studies in livestock and rangeland management (e.g., Thomson, 1886) represent a shift in thinking away from quantitative physical applications towards linking carrying capacity to notions of productivity and the capacity of the land to "carry" a population. Since then, carrying capacity has become a popular concept in managed environments to support the farming or harvesting of wildlife. In 1922, Hawden & Palmer presented the first definition of carrying capacity in the context of rangeland management, described as "the number of stock which a range will support for a definite period of grazing without injury to the range." (Hawden & Palmer, 1922). This and other similar definitions were applied by other rangeland and livestock management scholars (Seidl & Tisdell, 1999), including prominent ecologist Aldo Leopold, whose fundamental textbook *Game Management* (1933) influenced a generation of game managers to manipulate and/or increase the number of wildlife an area could produce to remain below carrying capacity (Sayre, 2008). Many CC studies are interested in understanding how species use available resources and determining the quality of the habitat as proxies for the environment's capacity (Chapman & Byron, 2018). In marine environments, carrying capacity has been studied in the context of fisheries biology to estimate catch quotas, investigate how the stocks respond to fishing levels, and understand how close a stock is to biological thresholds (e.g., Myers et al., 2001; Vasconcellos & Gasalla, 2001).

During the early 1930s, ecologists further refined concepts of carrying capacity in a related, but separate application more related to conservation and population biology. In 1933, Nicholson proposed density dependence as a limiting factor restricting the size of populations to fit the logistic growth equation. The concept of limiting factors driving ecosystem processes and population growth were refined throughout the following few decades by ecologists and wildlife biologists such as Smith (1935), Errington (1934), and Lack (1954). While CC concepts had become well established within ecological texts by the 1950s, its popularization as a mathematic expression was not officially recognized until Eugene Odum formally linked the term carrying capacity to describe *K*, the upper limit of the logistic growth curve (Odum, 1953). Since then, carrying capacity has become popular vocabulary and is today a basic assumption of population biology. These applications are often concerned with modelling the growth trends of wild populations, including determining the factors limiting growth. For example, carrying capacity has been used to understand species evolution and population dynamics (e.g., Hurlbert & Stegen, 2014). It has also become relevant in conservation biology to evaluate natural and anthropogenic pressures on vulnerable populations and determine appropriate protection measures (e.g., Plumb et al., 2009).

Throughout the 1940s and 1950s, Malthus's ideas on carrying capacity continued to influence generations of Neo-Malthusians concerned with human population growth and the consequences of economic development. Vogt's famous book *Road to Survival* (1948) captured the strains of World War II and popularized the idea that humankind is reaching environmental limits imposed by Earth (Sayre, 2008), helping build a distinct paradigm of carrying capacity in the context of human populations. At a local level, many studies are interested in estimating urban carrying capacity (e.g., Xu et al., 2010; Oh et al., 2005), defined comprehensively as "the limit of urban development from environmental impacts and natural resources, infrastructure and urban services, public perception, institution setting, and society supporting capacity." (Wei et al., 2015). On a regional level, much research focuses on investigating the availability of and constraints on natural resources (particularly food resources) to support human populations (Peters et al., 2016; Suweis et al., 2015; Venkateswarlu & Prasad, 2012). As early as the mid-1960s, adoption of CC by social scientists also prompted decades of applications in recreation and tourism at both local and regional scales (McCool & Lime, 2001). In this application, thresholds for carrying capacity are commonly measured as a function of the services needed to support tourists and by tourist satisfaction (e.g., Saveriades, 2000; Navarro Jurado et al., 2012).

During the 1960s, prominent Neo-Malthusian ecologists warned of the dangers of human overpopulation including Garrett Hardin's "Tragedy of the Commons" (1968) and Paul Ehrlich's *Population Bomb* (1968). In 1972, Meadows and colleagues propelled human carrying capacity into the political agenda in their report *Limits to Growth*. Since then, carrying capacity concepts have shaped, and become central to the field of ecological economics (Sagoff, 1995). In a global context, scientists have attempted to calculate the maximum number of humans the Earth can support (e.g., Cohen, 1995; Daily & Ehrlich, 1992; Van Den Bergh & Rietveld, 2004). This application of carrying capacity has become politically endorsed with concepts such as planetary boundaries framework (Rockström et al., 2009; Steffen et al., 2015) and the Ecological Footprint (Rees, 1996; Wackernagel & Rees, 1997).

2.3.2 Carrying capacity in aquaculture

The earliest published study referencing carrying capacity in aquaculture was traced to a study on fish ponds in 1963 whereby the addition of fertilizer increased the carrying capacity of ponds to hold fish (Yashouv, 1963). Early studies were heavily focused on production aspects such as determining the optimal stocking density of ponds (e.g., Latapie et al., 1972). Carrying capacity was not applied at the ecosystem-level until 1981 (Incze et al., 1981), but started to become a mainstay of aquaculture research in the late 1990s (Chapman & Byron, 2018). Since then, carrying capacity approaches have been particularly well-developed by aquaculture scientists and managers and applied to a variety of production systems, species, and contexts around the world.

Carrying capacity tools and methods have been most extensively developed for bivalve aquaculture (e.g., Ferreira et al., 2008; Filgueira et al., 2015a; Kluger et al., 2016ab; Silva et al., 2011). Several studies have also measured carrying capacity for finfish (e.g., Geček, & Legović, 2010; Karakassis et al., 2013), although these approaches are most often focused on benthic interactions. Much of the focus on bivalves emerged due to their dependence on food sources from a healthy environment to support production, which is a lot less emphasized for finfish species such as salmon, which rely on the addition of feed to support production. Until recently, major concerns for finfish focused on deposition of wastes, which are easier to measure than ecosystem-scale interactions like disease transmission and wild fisheries interactions. Recent publications have also emerged that deal with multi-species cultures, or integrated multi-trophic aquaculture systems (e.g., Duarte et al., 2003; Ferreira et al., 2012; Nunes et al., 2003).

Carrying capacity has moved beyond the research arena into practical application in management, and has been used by farmers, regulators, and other groups to improve aquaculture practices for sustainability (**Table 2.1**). In different cases, carrying capacity is used as both a tool to support decisions (e.g., when measured alongside a larger Environmental

Impact Assessment - EIA), or as a process and guiding approach to make decisions about development (e.g., to set limits on production). For example, several studies in freshwater and brackishwater pond-farming contexts aim to promote fish health by determining production levels or site suitability to maintain water quality to account for increased nutrient loads due to intense production (e.g., Montanhini Neto et al., 2017; Lorenzen et al., 1997; Triyatmo et al., 2018). The thresholds, indicators and outcomes of carrying capacity assessments have also been promoted to support both farm-scale and ecosystem-scale policy and decision-making. The concept is incorporated into modern management frameworks (i.e., Ecosystem Approach to Aquaculture (Ross et al., 2013)), spatial planning (Aguilar-Manjarrez et al., 2017), and industry best practices (e.g., ASC, 2017). Carrying capacity estimations are currently most often involved in early stages of aquaculture planning and site selection to determine environmental suitability and cultivation limits within areas (e.g., DFO, 2015). However, it also supports ongoing monitoring programmes by setting thresholds or informing sustainability indicators (Cranford et al., 2012; Fernandes et al., 2001). Thresholds can guide licensing decisions; for example, siting regulations regarding setbacks and buffers for salt pond aquaculture in in Rhode Island, United States were informed by carrying capacity assessments (Dalton et al., 2017). Additionally, carrying capacity can help reduce environmental effects (for example, by feed-related aquaculture effluents) by limiting site licences issued based on assimilative capacity (Tacon & Forester, 2003). Various decision-making approaches and management options thus deal with carrying capacity for aquaculture development, management, and monitoring (Smaal & van Duren, 2019).

Table 2.1 Various pathways supporting the practical application of carrying capacity for aquaculture management and decision-making

Pathway	Examples
Informing farming practices	
Maximize production yield	Assess costs and externalities
Farm design and layout	Selecting growing sites Inform culture layouts
Selection of production characteristics	Determine choice of species Select stocking densities
Promote species health	Optimize water quality Reduce risk of disease
Support for policy and management	
Data support for management frameworks	Ecosystem Approach to Aquaculture (EAA) Integrated coastal zone management (ICZM)
Integration with other decision-support tools	Life Cycle Assessments (LCA) Environmental Impact Assessments (EIA)
Inform site selection and planning	Determine environmental suitability Choose cultivation limits
Support monitoring efforts	Determining thresholds, setting Environmental Quality Standards Selecting ecological/sustainability indicators
Inform best practices	Best Management Practices Performance standards Certification standards
Guide relevant legislation	Policy Regulations
Guide licensing criteria	Planning areas (e.g., Allowable Zone of Effect) License issuing

2.4 DEFINING CARRYING CAPACITY FOR AQUACULTURE

In the field of aquaculture, carrying capacity can be understood as the level of aquaculture that can be supported without violating the maximum acceptable limits of the farmed stock or environment (adapted from Stigebrandt, 2011). This can be measured as a function of either biomass, area for aquaculture, number of cages, or number of farms, depending both on the relevant CC type and decision-making objectives. The definition of carrying capacity has evolved into a more comprehensive four pillar approach that includes physical, production, ecological, and social carrying capacities to reflect varying management objectives (Inglis et al., 2000; McKindsey et al., 2006). Other authors have recognized the nuances of socio-economic and environmental trade-offs, leading some authors to independently define *economic carrying capacity* as the biomass investors are willing to offer or maintain (e.g., Gibbs, 2009). Finally, governance factors have been recognized through the addition of a definition of regulatory carrying capacity (Byron & Costa-Pierce, 2013; Ferreira et al., 2013). The various components reflect different attributes that humans have decided to value as relevant; as such, all CC components reflect to some degree social values. Thus, each CC component has discrete inputs into decision-making as each describes different management objectives, scales, and interactions between aquaculture and its surroundings, and are thus driven by unique sets of forces and measured against distinct indicators (**Table 2.2**). The following section describes how each component has been defined within the aquaculture literature.

Table 2.2 Examples of indicators, data requirements and spatial scales (areas affected) relevant to each of the carrying capacity components for aquaculture. Modified from Ross et al., (2013).

Carrying capacity / Management objectives	Data requirements	Indicators	Relevant spatial scale
Physical carrying capacity			
Assess development potential Avoid critical habitats Manage space conflicts	Critical habitats Space uses Hydrodynamics	Water availability and quality Hydrography Water access	Inlet (bay scale)
Production carrying capacity			
Optimize production yield and species growth	Temperature Diet Feed regime Infrastructure Yield costs Wind, waves, currents	Production biomass Growth rate Food availability Investment Yield and market factors	Local (cage or farm scale)
Ecological carrying capacity			
Minimize environmental impacts	Feed regime Critical habitats Wind, waves, currents Hydrodynamics	Community structure Biodiversity metrics Waste deposition Eutrophication (nutrient levels) Organic enrichment Dissolved oxygen concentration	Local – Inlet – Regional (wider ecosystem) - Global
Social carrying capacity			
Reduce social conflicts Measure social acceptance	Workforce Perceptions Access rights Access to capital	Employment and income rate Acceptability Space conflict Community values	Inlet (communities) - Regional (market) - Global

2.4.1 Physical carrying capacity

The physical carrying capacity of a site is often represented as the geographic area that is both available and suitable for aquaculture. It is often expressed either as the number of farms or amount of geographic area occupied, sometimes as a percentage of a given area (e.g., Teixeira et al., 2018). It is most useful for determining the area available for aquaculture production but does not inform on the limits of production. Physical capacity is thus determined largely by the physical factors driving the suitability of a site to meet the specific needs of the cultured species or production technique (McKindsey et al., 2006). Physical factors may include physical properties such as depth, temperature, substrate type, salinity, or oxygen concentrations, among others (Ross et al., 2013). Physical carrying capacity is traditionally measured by combining hydrographic information (e.g., topography, bottom morphology) from available hydrographic charts or models with other physical parameters (e.g., depth, salinity, temperature) collected through remote sensing or field sampling (McKindsey, 2013). Other authors interject diverse socio-economic properties such as access to resources and transportation (e.g., Teixeira et al., 2018) or other uses in the area (e.g., Triyatmo et al., 2018) into their physical CC assessments.

Physical carrying capacity is often considered one component of broader site selection criteria during early phases of aquaculture development projects. This means that physical carrying capacity is often included as a first step before other CC measures, although it can sometimes be measured alongside other components (McKindsey et al., 2006; Ross et al., 2013). Physical carrying capacity may also be integrated into larger coastal zone management and area planning schemes which deal with wider social conflicts and competition among users.

2.4.2 Production carrying capacity

Production carrying capacity is best described as the stocking density at which production biomass is maximized (McKindsey et al., 2006). Since the earliest applications of carrying capacity for aquaculture were aimed at optimizing yield, production CC has been the most well-studied and relevant for economic and farm-scale management (Ross et al., 2013). Some interpretations prioritize growth and productivity, defining production CC rather as the magnitude of activity that does not negatively affect growth rates (Carver & Mallet, 1990; DFO, 2015). Production CC is thus highly linked to hydrodynamics, food regimes, and the physical carrying capacity of an area (Ferreira et al., 2013). Accordingly, many studies aim to understand the factors that are relevant to the growth and productivity of the target cultured species. For bivalves, this is predominantly addressed by exploring factors influencing food availability and/or depletion (e.g., Cranford et al., 2014; Grant & Filgueira, 2011) and the resulting potential growth changes (e.g., DFO, 2015). Other studies search for optimal densities based on environmental conditions, food requirements (e.g., chlorophyll availability for bivalves), and/or hydrographic characteristics (e.g., Shi et al., 2011). Likewise, production carrying capacity estimations for finfish have been based on searching for optimal holding capacity of cages based on biological and physical parameters such as oxygen concentration, water flows, and food conversion, among others (Halide et al., 2009; Tookwinas et al., 2004).

Since production is dependent on the technology and infrastructure of different production systems (Gibbs, 2009), some authors include economic parameters that influence yield such as investment costs and market factors into their assessments of production CC (Ross et al., 2013). For example, Halide et al., (2009) supplement production capacity calculations with economic appraisals that measure return on investment and break-even points based on holding capacity, feed conversion ratio, costs, and fish prices. However, the integration of economic factors is not widely practiced and often limited to simple calculations of revenue and cost metrics (e.g., Ferreira et al., 2007).

2.4.3 Ecological carrying capacity

Ecological carrying capacity (ECC) describes the maximum density of cultured species that does not cause unacceptable ecological impacts (McKindsey, 2013). When defined as the ability of the environment to support a given activity without unacceptable change to the localized ecosystem, Elliot et al., (2018) argue that carrying capacity can also be considered synonymous to the term assimilative capacity. Ideally, ECC should be determined by significant changes to ecological processes, species, or communities (Gibbs, 2009). Predicting ecological carrying capacity is crucial to assessing and minimizing the potential impact of aquaculture development and expansion and can also help identify relevant sustainability indicators to evaluate the performance of farms (Gibbs, 2007). Key to this is determining the thresholds and criteria that define the level of "unacceptable" environmental change. Several scholars have argued that these thresholds should be ideally based on the ecological resilience and tipping points of natural ecosystems (Filgueira et al., 2015ab; Kluger et al., 2017) but are more often based on established regulatory or private standards (e.g., Bakar et al., 2016; Cai et al., 2010). This is often because measuring resilience or tipping points is challenging and sometimes impossible without baseline information (Filgueira et al., 2013; Filgueira et al., 2014).

The definition of ecological carrying capacity infers a focus on recognizing and quantifying the interactions of the farming activity with the receiving environment. Compared to production carrying capacity which only focuses on the target species, ECC should consider the whole ecosystem and the various stages of production (McKindsey et al., 2006). This is largely due to the complexity of aquaculture-environment interactions that are relevant at the farm, or cage scale, but may also interact with the wider ecosystem beyond the vicinity of the farm, producing effects at the far-field (Weitzman et al., 2019). Different production systems also face unique challenges relevant at multiple spatial and temporal scales. For example, pond-based farming systems consist of clear system boundaries with an emphasis on point-source ecological interactions within the farm. Alternatively, decisions regarding open ocean net-pen aquaculture require consideration of a wider geographic area since net-pen operations are influenced by hydrographic processes throughout the coastal area or bay. In addition, the environmental effects of aquaculture may be affected by the timing and length of production cycles, which can vary based on the species and receiving environment. Studies informing ECC should thus consider the spatial extent of effects and the interactions at both the farm scale and include wider, bay-scale or regional effects.

Since the production of cultured organisms may use available resources and add wastes, chemicals, or disease agents into the receiving environment, research on ecological carrying capacity is thus broadly divided into benthic or pelagic interactions (Geček & Legović, 2010; Gibbs, 2009). This research is often carried out by relying on models to run hypothetic scenarios or empirical studies conducting field measurements on aquaculture-environment interactions. Pelagic interactions include dispersion of wastes that can cause eutrophication or impacts of cultured species on energy flows and other trophic levels. For example, many studies estimate or measure the phytoplankton depletion caused by grazing of cultured bivalves (e.g., Cranford et al., 2008; Filgueira & Grant, 2009). For bivalves, food-web approaches have been developed to predict changes in energy fluxes between trophic levels (e.g., Byron et al. 2011a; Jiang & Gibbs, 2005; Kluger et al., 2016ab). While research on interactions with other trophic levels has been conducted for species like finfish and invertebrates (e.g., Callier et al., 2018; White et al., 2017), these studies are not framed specifically around the CC concept. For finfish, water quality is determined as a function of both oxygen and nutrient concentrations found within and near farm cages (Stigebrandt, 2011; Tett et al., 2011). In freshwater environments, phosphorous loading is often considered the limiting factor affecting water quality (e.g., Buyupkapar & Alp, 2006; Montanhini Neto et al., 2017; Pulatsü, 2003). Benthic interactions are primarily concerned with increased organic loading due to biodeposition or excess feed in the case of fish. Research in this area has largely focused on modelling patterns of waste dispersion and deposition and their impacts on benthic communities (e.g., Corner et al. 2006; Cromey et al., 2002; Weise et al., 2009). Field measurements in this area often involve testing the benthic response to different levels of organic matter supply and subsequently on different levels of production (e.g., Callier et al., 2009; Hargrave 2010; Sanz-Lázaro et al., 2011).

Despite the large body of work developing models and indicators of ecological carrying capacity, monitoring and modelling for ECC is often limited to few interactions with the environment (McKindsey et al., 2006). Carrying capacity modellers often restrict the interactions in a need to reduce model complexity and scientific uncertainty (Filgueira et al., 2013). This is partly because ECC can have wide spatio-temporal variabilities and depend on numerous factors unique to specific areas or culture systems, including but not limited to, diet of cultured species (Bueno et al., 2016), patterns of primary and secondary production, and variations in physical oceanography and limnology (Byron & Costa Pierce, 2013). Certain issues such as the spread of disease can greatly affect production and ecological carrying capacities but are extremely difficult to model and thus not currently incorporated into ECC assessments (Ferreira et al., 2013). While there are recent research efforts in modelling sea lice dispersion in aquaculture (e.g., Sandvik et al., 2016), decision-making often relies on other a posteriori mechanisms such as monitoring to address these issues. Nevertheless, these limitations result in policy applications and interpretations of ECC that often do not represent the whole ecosystem.

2.4.4 Social carrying capacity

Social carrying capacity (SCC) has been defined as the level of aquaculture development that can be supported without adverse social effects (Inglis et al., 2000). However, this definition does not expand on what defines "adverse" or expands to explain what uses are included in this assessment. Dalton et al., (2017) further define SCC as the level of aquaculture beyond which environmental and social impacts exceed acceptable levels, measured by community or stakeholder satisfaction, desirability, or preferences. Alternatively, social carrying capacity has been measured as the agreed-upon level of aquaculture that does not inhibit social uses by relevant stakeholder groups (e.g. Byron et al., 2011b). While there has yet to be an agreed-upon definition for SCC, it certainly involves quantifying both perceived and actual social impacts, as well as determining social acceptance of different levels of use or impact.

Social carrying capacity reflects a recognition that aquaculture operates as aquaculture ecosystems ("aqua-ecosystems") that are embedded within a larger social context (Costa-Pierce, 2010). In this way, aqua-ecosystems operate as complex social-ecological systems (SES; Ostrom, 2009) that involve multiple subsystems such as the resource system (e.g., aquaculture), resource units (e.g., fish), users (e.g., fish farmers), and governance systems that operate at multiple scales. Theoretically, the relevant spatial scale for social carrying capacity often emphasizes social interactions within the communities adjacent to aquaculture operations, or within the spatial extent of the farm where uses can interact. This is because many ecological impacts, user conflicts, and pushback are often felt at the farm and local community level. However, due to the governance structures and far-field influences of actors throughout the value chain, aquaculture influences social linkages beyond the production system (Bailey, 2008). Social and economic contribution to national Gross Domestic Product (GDP) or global food security illustrates how benefits are dispersed beyond the farm scale or local communities. Several stakeholders including government, environmental groups, and research are often disconnected from the potential impacts, but may play important roles in management. Nevertheless, there is no consensus within the literature as to the relevant spatial scale for SCC assessments. It is therefore likely that the relevant scale for SCC will depend on the objectives and local characteristics of each assessment.

SCC for aquaculture has only gained popularity within the last 15 years, and the models, tools, and assessments designed specifically to evaluate aquaculture SCC are poorly developed. Broadly, assessing the social carrying capacity of an area requires addressing the interests of all stakeholders (e.g., shipping, recreation, tourism, fisheries) (Byron & Costa-Pierce, 2013; McKindsey et al., 2006). This is especially relevant since Dalton et al., (2017) found variations on the estimate for social carrying capacity among stakeholder groups. Where SCC has been strongly established in recreation and tourism since the 1960s (Graefe et al., 1984), it is often measured against impact indicators such as levels of crime or tourist spending (Navarro Jurado et al., 2012), or by indicators related to perceptions and enjoyment (e.g., "encounter norms"; Needham et al., 2011). Dalton et al., (2017) also apply a normative evaluation approach to infer SCC by measuring perceptions, attitudes and preferences for different types of shellfish development in Rhode Island, United States. Most evaluations of social carrying capacity in an aquaculture context is currently focused on measuring perceptions and conflicts (Kluger et al., 2019) or adjusting ecological models by following a precautionary approach (Melaku Canu et al., 2011). Other models have been more economically oriented including income, profits, and production costs (e.g., Byron & Costa-Pierce 2013; Melaku Canu et al., 2011; Nobre et al., 2009). The use of fuzzy expert systems (McKindsey et al., 2006) or assigning monetary values to impacts (NRC, 2009) have been proposed as ways to measure social carrying capacity for aquaculture but have yet to be formally studied or applied. In conclusion, the critical limits of social change and social carrying capacity indicators in the context of aquaculture have not been well defined (Ross et al., 2013).

Previous studies have highlighted some of the complexities of understanding and assessing social carrying capacity. For example, social effects can exert downstream and upstream effects across multiple users and value-chains, involving potentially large number of stakeholders (Little et al., 2013). Studies exploring the support for aquaculture to measure SCC have found that perceptions vary based on waterbody, scale of operation, and how the activity is carried out (Dalton et al., 2017; Kluger et al., 2019). External forces such as community values, economic conditions of the time, and performance of other industries may also influence perceptions and acceptance (e.g., Banta & Gibbs, 2009; Kaiser & Stead, 2002). Finally, social carrying capacity depends on managing trade-offs between a range of stakeholders to meet social and economic demands (e.g., employment, recreation) and environmental concerns (e.g., protected species) (McKindsey, 2013).

While social carrying capacity has been the least well-studied carrying capacity component for aquaculture, it has also been considered the most critical for management. Social impacts and conflicts are often the limiting factor in development scenarios (Banta & Gibbs, 2009) and at the forefront of decision-making in the European Union, the United States and Canada (Ferreira et al., 2013). Therefore, defining and incorporating social carrying capacity for aquaculture management has been considered an ongoing challenge and priority (Byron et al., 2011b; Filgueira et al., 2015a; Gibbs, 2009).

2.5 ESTIMATING CARRYING CAPACITY IN AQUACULTURE

Estimating carrying capacity encompasses determining the relationship between the farming activity and the quality of the ecological, social, or economic environment. When used to inform decision-making, there are often several steps before the assessment of CC begins, such as determining objectives and priorities with stakeholders. Beyond that moment, the operationalization of carrying capacity comprises three primary steps (**Figure 2.2**). The first step involves determining agreed-upon indicators that identify changes to the state of the ecological, social, or economic environment that are then to be measured against the pressures that aquaculture exerts upon them. This involves choosing from a suite of possible interactions by focusing on the most salient, often limiting factors (e.g., food availability for production CC). The second step consists of understanding and quantifying the relationship between the farming activity and state indicators. This information can then be fed into predictive models or empirical studies to determine what levels of production correspond to the aforementioned aquaculture activities. The third step includes calculating the maximum safe pressure of activities (biomass, stocking density, or size and number of farms) that maintains state indicators below or above a given level or threshold. Across these steps, researchers and planners employ a suite of tools, approaches, and methods to determine these relationships and indicators, and ultimately calculate carrying capacity.

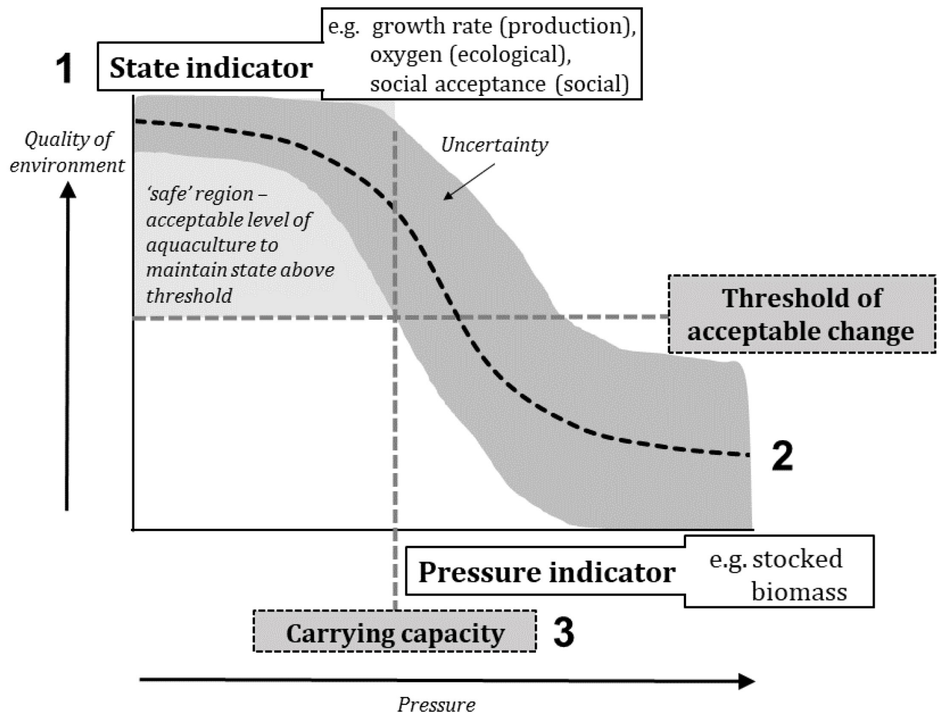

Figure 2.2 Conceptual framework for carrying capacity, depicting the relationship between pressure and state changes, with numbers denoting the major steps involved in estimating carrying capacity for aquaculture (modified from Tett et al., 2011).

2.5.1 Indicators

Sustainability indicators provide a quantifiable metric against which public policy issues can be measured (Hezri & Dovers, 2006). They are generally simplified to imply a set of assumptions or modelled behaviour representing a wider phenomenon (Valenti et al., 2018). Sustainability indicators for aquaculture can be used to navigate different development choices and evaluate the effectiveness of choices (Valenti et al., 2018). Indicators are also necessary in threshold-based management because they help determine progress towards unwanted tipping points (Foley et al., 2015). Consequently, long-term monitoring programmes rely on indicators to measure effectiveness, environmental quality, and compliance with regulations.

Managers and decision-makers can use indicators in the determination of carrying capacity, or use carrying capacity research to develop environmental indicators for valued ecosystem components. For example, Pearson & Rosenberg (1978) modelled benthic community changes along a gradient of organic enrichment, leading Hargrave et al. (2008) to propose biogeochemical indicators (such as pH, redox potential, and free S^{2-}) to measure thresholds of benthic health. Management frameworks in several countries such as Canada, New Zealand, and the United States now rely on free S^{2-} to monitor and evaluate benthic health (Wilson et al., 2009). Other studies rely on functional indicators to directly measure carrying capacity. Numerous indicators related to ecosystem health, production performance, and socio-economic considerations have also been developed for aquaculture (Cranford et al., 2012; see Table 2.2). For example, Karakassis et al. (2013) developed an indicator for production CC based on distance from shore, depth, and exposure of the farm site. Easy to use indicators are especially relevant where extensive long-term studies are not feasible (Gibbs, 2007).

While indicators are essential to monitoring efforts, reliance on indicators alone has been criticized. Ideally, indicators should be chosen that are relevant to the system and effects, proven effective and accurate, quantifiable, feasible, and policy-relevant (Cranford et al., 2012). In the context of carrying capacity, indicators should explicitly link to processes that operate at the thresholds of systems. However, there may be measurement errors or ambiguity with proposed indicators (Gibbs, 2007). Managers should be careful relying on too few CC indicators, as no single indicator can represent the complexity of natural systems (Cranford et al., 2012). Furthermore, there is a lack of CC indicators for important processes, as well as operational thresholds for many indicators (Cranford et al., 2012). In particular, the lack of social carrying capacity indicators and the need for social monitoring systems has been raised throughout the literature and is a continued challenge (Costa-Pierce, 2008). This will pose limitations to effective ecosystem-based management (EBM) which will need indicators that describe the status of multiple SES components (Borja et al., 2016).

2.5.2 Models

Models are simplified representations of the variables, relationships, and processes in the environment. CC models for aquaculture range from simple mathematical expressions to farm-scale models of production, to complex processes involving multiple interactions at the ecosystem-scale. Model complexity revolves around both the type of information (e.g. variations in biogeochemistry and hydrodynamics) and how models handle space and time (variations across both scale and resolution). Models are especially useful in carrying capacity studies since they can define ecological thresholds and indicators (Cranford et al., 2012) and run simulations to depict hypothetical scenarios related to different levels of production or environmental conditions (Byron & Costa-Pierce, 2013; Nobre et al., 2010). Models may also be used to run optimization tools to explore facets of resilience and thresholds that are integral to decision-making (Filgueira et al., 2013). While models must be carefully validated through case studies and trials, models are particularly relevant since they allow decision-makers to determine thresholds and test the limits of production without needing to manipulate the real environment.

The least complex models are static mathematical expressions that depict simple relationships between cultured organisms and the surrounding environment. They include indices that reflect a combination of indicators against which aquaculture activities may be compared (Cranford et al., 2012). For example, many studies use "Dame indices" for food depletion (Dame & Prins, 1997) to explore ecological and production carrying capacities (e.g., Cranford et al., 2008; Gibbs, 2007). Their popularity is largely due to their practicality, simplicity, and low data requirements (Cranford et al., 2012; Filgueira et al., 2015a). Other mathematical models include simple energy budget models that reflect production characteristics and focus on growth in relation to food supplies and consumption patterns at the individual and farm-scale (e.g., Grant & Bacher, 1998). This category of models also includes widely used growth functions such as the thermal-unit growth coefficient (Iwama & Tautz, 1981) often applied to production of pond aquaculture (Jobling, 2003). Despite their wide application, indices and simple growth models have limited relevance since they do not provide information on spatial or temporal variability (Cranford et al., 2012; Filgueira et al., 2015), representing snapshots in time of a single homogenous area.

However, the dynamic nature of the ecosystems in which aquaculture is embedded has driven to the development of dynamic models at both the farm- and wider ecosystem-scales. Farm-scale models are often concerned with individual growth and production carrying capacity. Production models ("bio-energetic" models) have been well developed to predict individual growth of cultured species based on food supplies, following either the empirical scope for growth approach (Winberg, 1960) or more mechanistic dynamic energy budget (DEB) approach (Kooijman, 2010). These farm-scale models often include a hydrodynamic sub-model to account for the effects of water circulation on food supplies (Bacher et al., 2003; Ferreira et al., 2007). While most farm-scale models are concerned with production CC, several depositional models have been applied to estimate ECC at the local scale. Depositional models have been applied consistently and considerably developed since the 1990s to predict the fate of organic materials from culture sites to the benthos, and consequently to explore benthic impacts (Chen et al., 1999; Cromey et al., 2002; Silvert 1992). These include the finfish waste model DEPOMOD (Cromey et al., 2002), which has also been adapted for shellfish (Shellfish-DEPOMOD) in Canada (Weise et al., 2009). These models can be coupled with hydrodynamics to explore the fate and dispersion of particulate wastes (e.g., Corner et al., 2006; Pérez et al., 2002) and quantify local assimilative capacity (e.g., Bravo & Grant, 2018). Despite growing concerns over potential far-field dispersion of wastes, far-field finfish depositional models are uncommon (Ferreira et al., 2013).

To manage increasingly complex interactions of cultured species and their aquatic environments, modelling the interrelations of multiple processes over wider regional or ecosystem-scale has become increasingly common. For example, the popular EcoPath with Ecosim has been used to calculate the energy transfer between cultured organisms and other trophic levels (Byron et al., 2011abc; Jiang & Gibbs, 2005; Kluger et al. 2016ab; Xu et al., 2011). In freshwater environments, phosphorous budget models such as the one proposed by Dillon & Rigler (1975) has been applied to predict the impact of aquaculture on water quality and estimate ecological carrying capacity (e.g., Buyukcapar & Alp, 2006; Pulatsü, 2003). EcoPath with Ecosim and budgets lack spatial resolution, neglecting spatial variability within the model domain, which has been criticized (Grant & Filgueira, 2011). New developments such as Ecospace, a spatial and temporal dynamic module for EcoPath, could overcome these limitations. In general, ecosystem models can be differentiated based on their spatial resolution into simple box-models which divides the study area into few large homogeneous areas, or fully spatial models which divide the area into hundreds or thousands of separate areas (Filgueira et al., 2015a). Fully spatial models are considered desirable to inform site selection and marine spatial planning since they can more accurately describe complex hydrographic patterns (DFO, 2015). The fine-scale resolution of fully-spatial models is particularly important since it enables the investigation of both local and ecosystem-scale effects, and the feedbacks between cultured species and their environment (Guyondet et al., 2010).

Many models to support ecosystem-scale CC estimations are spatially-resolved, including a hydrodynamic component to capture both the bathymetric and morphological features of the seabed, as well as patterns of water circulation. Ecosystem-scale models include dispersion models adapted at the wider bay-scale to explore dispersal patterns of nutrients, organic wastes, and chemicals for aquaculture (Bakar et al., 2016; Tett et al., 2011). Many shellfish models predict changes in food depletion, namely phytoplankton (Bacher et al., 1997; Filgueira & Grant, 2009), or complex biogeochemical models which include wider effects on nutrients, phytoplankton and zooplankton, sometimes including detritus (Filgueira et al., 2014; Grant et al,. 2008). In recent years, bioenergetic models such as DEB models have been coupled with biogeochemical and hydrodynamic models to predict the interactions and feedbacks between cultured species and wider ecosystem-scale dynamics (Bueno et al., 2017; Dabrowski et al., 2013; Guyondet et al., 2010). Coupling individual growth models to ecosystem functioning and hydrodynamics can help estimate optimum production yield (Dowd, 1997) and predict the impacts of aquaculture on the wider ecosystem (Dowd, 2005). Therefore, many complex ecosystem-models are relevant for supporting both production and ecological carrying capacity, given their shared hydrodynamic and biogeochemical processes (McKindsey, 2013).

2.5.3 Spatial tools

For the last 20 years, aquaculture decision-making and development have progressively applied spatial tools such as Geographic Information Systems (GIS) (Aguilar-Manjarrez et al. 2010; Nath et al. 2000). Production and ecological carrying capacity models can be integrated within spatial analysis and GIS to varying degrees (Aguilar-Manjarrez et al., 2010). Spatial tools have been particularly relevant to visualize results from particulate waste dispersion models, hydrodynamic models, and growth models. In these applications, the model is often run offline and the GIS platform is used to visualize results and integrate with other layers of information (e.g., Triyatmo et al., 2018). Spatial modelling environments that integrate multiple models onto a Graphical User Interface have been developed that can be used by non-experts to estimate carrying capacity and guide site selection, optimize yield, or determine production densities (McKindsey, 2013). In this way, these tools are key in the context of aquaculture site selection (e.g., Gimpel et al., 2018; Longdill et al., 2008) and physical carrying capacity (e.g., Silva et al., 2011). Coupling carrying capacity information with GIS platforms can support coordinated planning and enable integration with wider decision-criteria (Teixeira et al., 2018). Silva et al. (2011) created a GIS site selection approach specifically designed to integrate carrying capacity with other suitability criteria. In this way, GIS platforms have enabled CC models to be incorporated into Environmental Impact Assessment (EIA) processes, site planning, and production monitoring (Corner et al., 2006; Pérez et al. 2002).

Incorporating spatial dimensions into social CC has been challenging since it is often difficult to define the spatial boundaries of many social issues related to aquaculture (McKindsey et al., 2006). As a result, applying spatial tools like GIS to help define social use limits and identify SCC criteria has not yet been extensively applied in aquaculture (Kapetsky et al., 2013), or even in more well-developed SCC disciplines (e.g., recreation – Beeco & Brown, 2013). Nevertheless, spatial analysis of socio-economic changes due to aquaculture could help quantify space and use conflicts to support multiple-use planning (e.g., Michler-Cieluch et al., 2009) and lead to a better understanding of stakeholder values with regards to resource use (e.g., Joyce & Canessa, 2009).

2.5.4 Stakeholder involvement

In the context of aquaculture carrying capacity, stakeholder involvement can refer to participation of interest groups (industry, locally affected communities, relevant government agencies, etc.) within either relevant research or decision-making processes. Engagement with a diversity of stakeholder perspectives is essential for effective environmental management of social-ecological systems (Virapongse et al., 2016). Broadening stakeholder participation in aquaculture decision-making can promote more sustainable and equitable development by favouring vision sharing and stakeholder interaction (Byron & Costa-Pierce, 2013; Reed, 2008; Soto et al., 2008). Methods to involve stakeholders can take many forms, but often rely on consultation with experts, assessing stakeholder or community perceptions, or developing working groups with stakeholders. These approaches are seldom explicit to the determination of CC but are rather conducted alongside and incorporated into site selection or decision-making frameworks (e.g., Teixeira et al., 2018; Vianna & Filho, 2018).

Within aquaculture CC, stakeholders are primarily involved during the design of CC research and assessments. For example, some research has measured expert and local community priorities and understandings to identify relevant indicators and criteria (Melaku Canu et al., 2011; Teixeira et al., 2018; Vianna & Filho, 2018). Participation with experts in a range of disciplines can also help researchers better understand the processes relevant to the proposed area and determine relevant assessment criteria. Stakeholder participation to gather ideas and expectations about aquaculture development has been used to select scenarios to be compared in carrying capacity modelling and to understand potential conflicts and considerations for CC assessments (e.g., Byron et al., 2011b; Ferreira et al., 2008; Melaku Canu et al., 2011; Nobre et al., 2010). Approaches to measure perceptions can also identify stakeholder values related to definitions of "acceptable" thresholds, which are relevant for all components of CC (Ferreira et al., 2013).

Stakeholders are less often involved in CC research as the subject of study. This type of social research is especially relevant in the context of social carrying capacity. Measuring perceptions about the impacts of development or activity are the foundation of SCC assessments in tourism management (e.g., Leujak & Ormond, 2007) but have also been applied in a few cases in aquaculture. For example, Dalton et al. (2017) applied a normative approach to determine stakeholder perceptions about different levels of aquaculture development in Rhode Island. Stakeholder perceptions are not frequently measured as part of the calculation of physical, ecological, or production carrying capacity with few exceptions. For example, Triyatmo et al. (2018) combined physical factors with land uses identified from stakeholder interviews and surveys for determining the suitability of the area for aquaculture, which they use to define carrying capacity. Nevertheless, understanding the needs, conflicts, and perceptions of all relevant stakeholders is considered essential to measuring carrying capacity (McKindsey et al., 2006).

While participatory approaches seldom contribute to calculations of carrying capacity in aquaculture, stakeholder participation can support the integration of CC assessments into wider decision-making and site selection processes. For example, Karakassis et al. (2013) applied a stakeholder approach to make management decisions based on production carrying capacity scenarios for fish farming decision-making in Greece. Others have gathered feedback on models and carrying capacity to assemble information on acceptance in decision-making processes (Byron et al., 2011b; Vianna & Filho, 2018). This type of early involvement of stakeholders with modelling efforts can increase understanding and acceptance of CC results (Byron et al., 2011a). When uncertainty is large or when data availability is limited, relying on expert judgement (Best Expert Judgement (BEJ) approaches; Elliot et al., 2018) can offer an interesting alternative to intensive data collection. While BEJ could help identify the severity of the effects of aquaculture on CC indicators in the absence of adequate data, there is currently little research on the usefulness or credibility of BEJ methods to inform CC for aquaculture.

2.5.5 Integrated approaches

Integrated approaches describe methods, frameworks, or tools that aim for interdisciplinarity, addressing multiple components of carrying capacity or considering several driving forces. The integration of ecological, social, and economic components in management contexts is often approached in a simplified way, or part of a larger decision-making process (e.g., Pastres et al., 2001; Solidoro et al., 2003). In the context of aquaculture, there have been efforts to create integrated site selection frameworks (e.g., Benetti et al., 2010) that relate multiple components, but not necessarily exclusively in the context of carrying capacity. Nevertheless, integrated CC approaches could promote vision sharing, support more comprehensive scenario analysis, and help understand system complexity (Melaku Canu et al., 2011).

In the context of carrying capacity, integrated frameworks have primarily dealt with assimilating ecological and socio-economic considerations (e.g., Byron et al., 2014; Melaku Canu et al., 2011) within models (Ferreira et al., 2007) or broader site selection frameworks (Silva et al., 2011; Teixeira et al., 2018). At the farm-scale, the FARM model (Ferreira et al., 2007) has been applied to numerous shellfish species and culture systems (Ferreira et al., 2008; Saurel et al., 2014) to estimate growth, predict ecological impacts of eutrophication, and integrate economic considerations for production. Likewise, the MARKET model combines the demand for products, production and cost factors, species growth parameters, and environmental conditions (Nobre et al., 2009). Comprehensive approaches that integrate multiple carrying capacity components are extremely relevant for site selection and decision-making but have only been attempted in few studies (e.g., Byron et al., 2011b; Silva et al., 2011). Integrated approaches have been developed beyond the context of aquaculture (e.g., Borja et al., 2016). For example, the Natural Capital Project developed a multi-tiered modelling tool called InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs – Tallis & Polasky, 2009) to inform management and policy about alternative development scenarios on economy, environment, and human well-being. While not oriented towards carrying capacity per se, these types of tools could fill the gap by addressing similar issues and support for ecosystem-based management.

2.6 ALIGNING CARRYING CAPACITY WITH EAA

Effective environmental management increasingly relies on monitoring and measuring social-ecological systems to avoid crossing tipping points under the context of carrying capacity (Kelly et al., 2015). Carrying capacity supports numerous decision-making processes (**Table 2.1**) and is often seen as a practical entry point to operationalizing the ecosystem approach to aquaculture (Aguilar-Manjarrez et al., 2017). In 2006, the FAO proposed the Ecosystem Approach to Aquaculture (EAA) as an ideal management approach to reach sustainable aquaculture development. The EAA is defined as "a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems." (Soto et al., 2008). The EAA builds off other ecosystem-based management (EBM) frameworks and shares several guiding principles (Arkema et al., 2006; Long et al., 2015). Three principles are fundamental to the EAA, which proposes that aquaculture should be developed to a) provide sustained delivery of ecosystem services to society, b) improve human well-being and equity and c) consider other sectors and goals. The harmonization of environmental, social, and multi-sectoral planning objectives fundamental to EAA can effectively be mapped onto the four carrying capacity components (**Figure 2.3**).

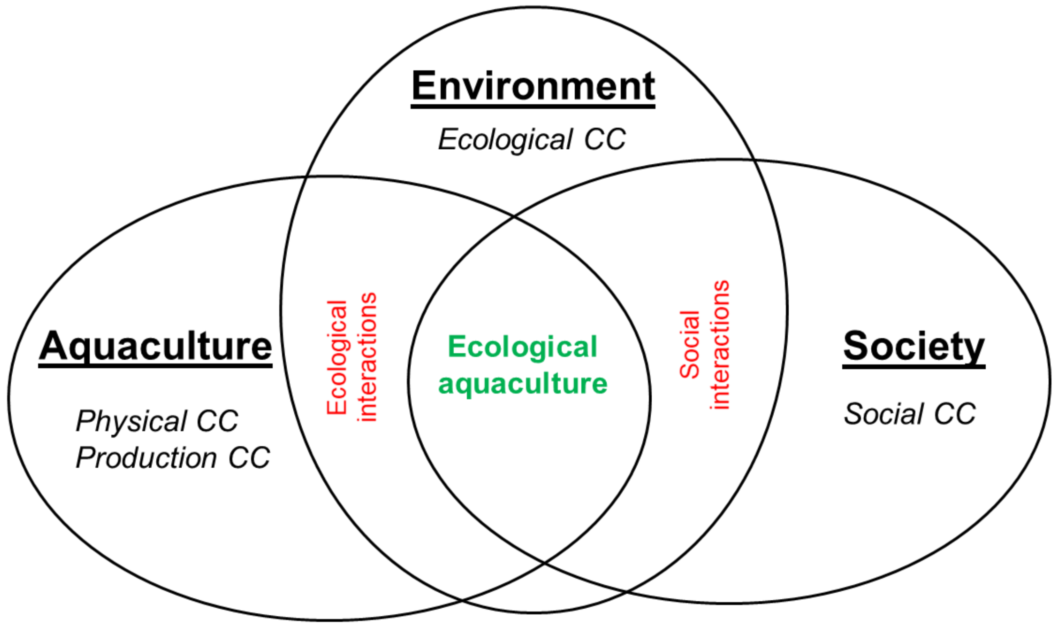

Figure 2.3 Harmonization of four types of carrying capacity to the ecosystem approach to aquaculture (green) (modified from Ferreira et al., 2013).

While various studies and evaluation methods have quantified carrying capacity, many approaches only focus on a single CC component and are not optimized for specific decision-making processes, challenging successful implementation of modern management frameworks (McKindsey et al., 2006). For example, despite its inception 10 years ago, the EAA has had varying degrees of uptake and adoption and continues to face implementation barriers and challenges (Brugère et al., 2018). To date, only a few studies have attempted to adapt CC models and frameworks to support EAA principles (Byron et al., 2011ab; Kluger et al., 2016b), or integrate within broader decision-support systems (e.g., Hermawen, 2018; Silva et al., 2012). Furthermore, few jurisdictions explicitly include carrying capacity as a necessary step in their regulatory frameworks (Holmer et al., 2008).

From the review of the carrying capacity literature, five research areas are proposed to address knowledge gaps and foster more useful CC information to support EBM objectives. This research agenda should also promote credibility, legitimacy, relevance, and iterativity to encourage carrying capacity effectiveness and uptake in decision-making (Sarkki et al., 2015). This section thus reflects on the five pillars and identifies strategies and actions to address the challenges and operationalize carrying capacity for aquaculture decision-making.

2.6.1 Recognizing system complexity

EBM approaches like EAA recognize aquaculture as dynamic and complex systems (Soto et al., 2008). Estimating aquaculture carrying capacity is complex in part due to the many poorly-understood interactions between components in the social-ecological system (SES). For example, the interactions between cultivated and non-cultivated species, as well as between cultivated species and their physical and chemical environment are not well understood (Duarte et al., 2003). Carrying capacity evaluations of a SES are also influenced by interactions between aquaculture and other users and industries within the same water body. For example, few studies consider the competition or interactions between activities (Teixeira et al., 2018). Nevertheless, integrating aquaculture into the planning of increasingly crowded spaces will require knowledge of the effects of aquaculture with other aquatic users (Dempster & Sanchez-Jerez, 2008).

The complexity of an aquaculture SES also is partly due to spatial and temporal variations with both ecosystem processes and components. Due to both regulatory and ecological processes, CC components often operate over multiple spatial scales (**Table 2.1**). Since aquaculture can interact with the environment in both the near-field and far-field, a complete assessment of carrying capacity should thus account for both local and system scales (e.g., Ferreira et al., 2008; Guyondet et al., 2010). Carrying capacity research has suggested a greater need to evaluate and incorporate far-field effects (Ferreira et al., 2013) and account for interactions between local and remote forcings (Dowd, 2005). Spatial resolution is also important for carrying capacity estimation; while local farms may produce effects at the bay-scale, whole-system approaches may ignore important variabilities at smaller scales (Duarte et al., 2003). However, ignoring wider interactions with approaches that only consider the farm-scale may miss important external forces and may make carrying capacity a less useful concept for inclusion in regional planning. Wider scales become integral to assess the interactions and cumulative effects of multiple farms in an area (Symonds, 2011). Temporal variations may also exist due to the natural effects of seasonality on patterns of food availability, temperature, and hydrodynamics, or production effects due to variations in harvesting schedules (McKindsey et al., 2006). Interactions with other coastal users may also have temporal variabilities due to seasonality of activities (e.g., tourism, fisheries). Adequate consideration of space and time variations have only been explicitly considered in a few studies in the context of both aquaculture (e.g., Dabrowski et al., 2013; Thomas et al., 2011) and the wider CC literature (Chapman & Byron, 2018).

Recognizing system complexity will require moving beyond current carrying capacity estimates which often prioritize few interactions and single CC components. Participatory working groups and BEJ approaches can help decision-makers understand the impacts of aquaculture activities on the wider area, including multiple users and activities (Elliot et al., 2018; Singh et al., 2017). To help decision-makers better understand system functioning and more accurately evaluate trade-offs between alternative development scenarios, Nunes et al. (2011) and Ferreira et al. (2008) propose running multiple models that operate at different space, time, and complexity scales. This could be supported by advancing virtual technologies and GIS to define spatial boundaries and incorporate multiple spatial scales (Kapetsky et al., 2013). Yet, incorporating complexities into CC assessments can be challenging; for example, it often requires a greater understanding of the biology of other species and diverse potential driving forces. This may often not be practical as remote sensing and field studies can be expensive, and models often require specific expertise and data that may not be available. Since many of these interactions remain unknown or difficult to quantify, applying precautionary limits to tipping points can help decision-makers account for system complexity without directly measuring it (Filgueira et al., 2013).

2.6.2 Responding to policy needs

Leveraging carrying capacity for decision-making means that assessments should respond to policy needs and priorities, therefore increasing the relevance of both knowledge and decision-making (Sarrki et al., 2015). The policy context includes incorporating local regulatory regimes into carrying capacity assessments to account for a wider range of governance factors that can influence carrying capacity. For example, overarching planning and zoning regulations can limit where activities can be placed, restrict stocking densities, and guide culture practices, even before completing any formal carrying capacity assessment. Regulations and private eco-certification standards can also set environmental thresholds and criteria integrated in CC assessments (Ferreira et al., 2013). These sometimes indiscriminate thresholds and criteria may limit carrying capacity below calculations of ecological or production carrying capacities (Montanhini Neto et al., 2017). This can happen when environmental quality standards set by policy makers are based on not only scientific and environmental considerations, but also political and social trade-offs (Bermudez, 2013). Therefore, management-oriented CC should recognize that carrying capacity knowledge, models, and indicators depends on local policy realities including available infrastructure and resources, priorities, and understandings (Turnhout et al., 2007). This requires carrying capacity indicators, thresholds, and criteria that are not only ecologically relevant but also align with management objectives.

Understanding policy needs and priorities will rely on meaningful stakeholder engagement throughout the carrying capacity assessment process. While decision-making often involves setting priorities and values before pursuing CC issues, participatory processes are not yet widely applied to carrying capacity assessments, despite the recognized benefits to decision-making. Enhancing the use and development of policy-relevant indicators and methods will require both continued quality control, but also stakeholder acceptance (Turnhout et al., 2007). Carrying capacity indicators should therefore be developed by a joint process involving both scientists and policy stakeholders (Hezri & Dovers, 2006; O'Ryan & Pereira, 2015). Stakeholder engagement is often recognized as a priority within modern ecosystem-based management and effective marine spatial planning policies (Pomeroy & Douvere, 2008). Ultimately, stakeholder engagement can improve the perceived credibility and legitimacy of carrying capacity estimations and the associated decision-making or site selection process (Sarkki et al., 2015).

2.6.3 Applying adaptive framework

Environmental decision-making must often deal with great uncertainty, especially given data scarcities, complex and dynamic systems, and emerging concerns such as climate change (Polasky et al., 2011). Adaptive management and the precautionary approach are highly promoted to address sustainability of aquaculture and promote ecosystem-based management (Soto et al., 2008) and coastal marine planning (Halpern et al., 2012). Likewise, the concept and application of carrying capacity has been previously criticized due to its common interpretation as a static, fixed value (Arrow et al., 1995; Seidl & Tisdell, 1999).

Carrying capacity seldom accounts for cumulative or long-term temporal changes that influence the estimation of carrying capacity (Gibbs, 2009). For example, long-term environmental responses due to climate change or other factors may influence the susceptibility of CC components to altered production levels or methods (e.g., Melaku Canu et al., 2010; Guyondet et al., 2015). In addition, technological and scientific developments in aquaculture feed, infrastructure, and equipment continue to improve resource efficiency and profitability and reduce many environmental impacts (Edwards, 2015; Murray & Munro, 2018). Finally, changing environmental and socio-economic conditions, shifting priorities, and new knowledge on aquaculture can shift social perceptions (Gibbs, 2009). As thresholds for the acceptability of changes relevant to SCC and ECC will be set by those making decisions and relevant societal values, these may also change with changes in political parties, individuals in power, or shifting views. This means that thresholds for carrying capacity may change over time. Adjusting carrying capacity through an adaptive lens can thus develop CC as a variable concept, accounting for dynamic changes in the socio-economic and biophysical environment. This could develop carrying capacity as a variable concept needed to promote a revitalized EAA (Brugère et al., 2018), and help align aquaculture decisions to future environmental and climate change scenarios.

Tailoring CC to adaptive decision-making should involve consideration of uncertainties, predicted long-term changes, and new information and environmental changes. One potential way to account for these long-term changes would be applying thresholds of potential concern that operate along a continuum of change rather than a fixed value to allow for adjustments (Cranford et al., 2012). Ideally, carrying capacity estimations should be re-run throughout development stages rather than limited to original site selection processes prior to development. This recognizes that certain environmental and social interactions will not be evident before farms are established (Dempster et al., 2005). However, re-running CC assessments is often impractical due to financial, infrastructural, or data constraints. Therefore, the dynamic nature of carrying capacity can rather be addressed by adding precautionary limits around CC parameters (Filgueira et al., 2013; Gibbs, 2009). While this has been addressed in few studies (e.g., Filgueira et al. 2015b), there is the need for a more consistent application and thorough analysis of uncertainty in the context of adaptive management. Another strategy to support an adaptive approach to CC is more common application of stakeholder involvement methods or BEJ approaches to gather information in areas with paucity of data or uncertainty (Elliot et al., 2018). Stakeholder engagement and participation are integral to adaptive management frameworks (Williams, 2011) and thus necessary components of adaptive carrying capacity. Finally, future research on long-term or cumulative changes in the context of carrying capacity (e.g., Guyondet et al., 2015) can also help prepare adaptive responses that can be integrated in the context of a wider coastal planning or ecosystem management.

2.6.4 Embracing interdisciplinarity

Integrated approaches can promote a holistic perspective addressing healthy natural and social system within which aquaculture operates (Borja et al., 2016). Operationalizing EAA will thus require not only multi-component carrying capacity but rather an integration of components. This acknowledges that aquaculture management should recognize the interaction of multiple dimensions of SES including species biology, environment, policy, and surrounding markets (and perceptions) (Broitman et al., 2017).

One of the most challenging aspects of CC lies in understanding, recognizing, and integrating interactions between the four CC components (**Figure 2.4**; Gibbs, 2009). Carrying capacity components may be linked by shared data requirements and indicators due to broader environmental dynamics. As a result, practitioners often model production and ecological carrying capacity together. For example, the Norwegian MOM system (Modelling-Ongrowing fish farms-Monitoring) helps decision-makers set production limits based on the preservation of the supporting water quality and benthic integrity (Ervik et al., 1997; Stigebrandt et al., 2004). However, connections between CC components can create strong feedbacks which are seldom explicitly considered in CC assessments. For example, it has long been recognized that determinations of thresholds and what constitutes “acceptable change” inherent to all CC components are a function of social values and cultural considerations (McKindsey et al., 2006; Wagar, 1974; Whittaker et al., 2011). Integrated carrying capacity is thus an enduring challenge due to complex relationships between ecological processes, social development goals, policies, and economic activities (Ma et al., 2017). Creating integrated approaches is also difficult due to scale mismatches between environmental, social, and political drivers and priorities

(Virapongse et al., 2016). One necessary step is advancing integrated CC frameworks that combine multiple tools, indicators, and disparate data types of various CC components (Borja et al., 2016; Ferreira et al., 2013). An integrated approach should also consider external drivers such as markets and climate change (Gibbs, 2009). Integration will thus require interdisciplinary approaches and tools that quantify ecological and social carrying capacity in tandem, recognizing feedback loops to other components (Filgueira et al. 2015a; Ferreira et al., 2008). This can help build a platform that meets the computational needs to support an EAA (Nunes et al., 2011).

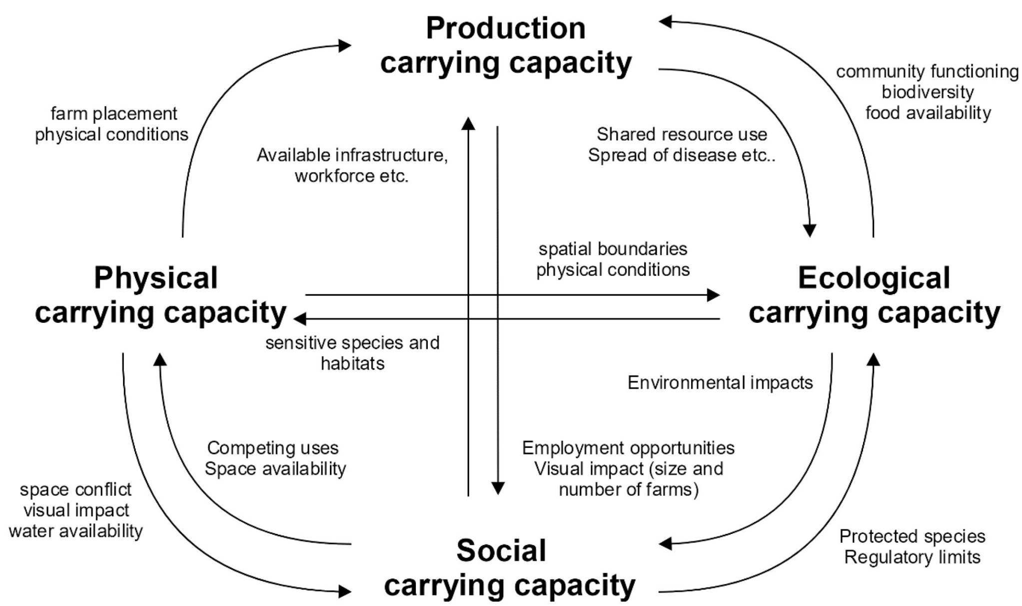

Figure 2.4 Examples of the interactions between carrying capacity components, highlighting specific feedbacks/guidance between components.

Beyond the field of aquaculture, recent research in urban and coastal planning has investigated frameworks for comprehensive carrying capacity, although they remain mostly conceptual (e.g., Liu & Borthwick, 2011; Zhiming et al., 2018; Tian & Sun, 2018). A potential lens to integrate multiple components of carrying capacity is through an ecosystem services (ES) approach, which accounts for a diverse range of impacts of activities on human well-being. Within the last decade, the ES approach has witnessed a rich and evolving literature within environmental management and sustainability (McDonough et al., 2017). It is regularly supported as a tool for integrated coastal management and ecosystem-based management (e.g., Arkema et al., 2015). The ES framework has also been considered to integrate economic and social components into carrying capacity estimations, although methodologies to do so are not yet well-developed (Wengpeng et al., 2018). Liu and Borthwick (2011) proposed a comprehensive CC model by adding "ecosystem services capacity" as one component of a holistic "carrying capacity of the environment" to account for changes in the environment's goods and services. In an aquaculture context, studies are starting to incorporate ES evaluations linked to carrying capacity estimations. For example, Teixeira et al. (2018) estimated the change in the value of provisioning services given different development scenarios and physical CC. Measuring the carrying capacity beyond which ES flows are degraded could be a fundamental next step in linking ecosystem services with overarching sustainability goals (Schröter et al., 2017).

2.6.5 Curating meaningful information

An expanding range of policy fields including medicine, social policy, environmental management, and conservation recognize the need to base decisions on sound science (Dicks et al., 2014). Despite progress in this area, curating meaningful information will require filling knowledge gaps relevant to the aforementioned research pillars. One recurring challenge across the CC literature is the misrepresentation of important ecosystem processes and lack of indicators that reflect the complexity of SES (Borja et al., 2016; Ferreira et al., 2013; Gibbs, 2009; Goss-Custard et al., 2002). Most research has been developed in the context of bivalve aquaculture, with limitations for finfish species. Carrying capacity for bivalve aquaculture has predominantly focused on food availability, despite other prominent factors that can influence carrying capacity. For example, few food-web approaches (e.g., Sequeira et al., 2008) consider appropriate temporal and spatial aspects of wild species interactions (Ferreira et al., 2018). Species like bivalves can also play multiple roles in the ecosystem by altering nutrient dynamics in such a way that could be to the benefit or detriment of other trophic levels (Gibbs, 2007). Carrying capacity approaches should thus consider ways to incorporate both "positive" and "negative" feedbacks from aquaculture (Smaal & van Duren, 2019). Other interactions such as the spread of disease, harmful algal blooms, and invasive species are politically relevant issues but are lacking within the carrying capacity literature.

More importantly, despite recurring calls to incorporate social factors in aquaculture (Teixeira et al., 2018), few studies aim to understand social limits of aquaculture (Needham et al., 2011). Furthermore, in many cases, empirical data on SCC is not currently used to set regulatory limits for aquaculture (Dalton et al., 2017). While numerous studies in recent years focus on the human dimensions of aquaculture, few studies focus on the concepts of "limits" or "thresholds", which are the foundation of carrying capacity. Nevertheless, social studies that measure priorities, uses, and perceptions can serve to incorporate social factors such as multi-use conflicts into CC assessments (e.g., Triyatmo et al., 2018) and can help identify relevant CC indicators (e.g. Kluger et al., 2019). Furthermore, social carrying capacity will require a better defined and standard approach as none currently exist (Byron & Costa Pierce, 2013). This is important given the growing relevance of aquaculture's contributions to the economy, food security, and social development within sustainable development policies (Béné et al., 2016).

"Evidence-based" policy relies on meaningful and credible science that is perceived to be technically and scientifically accurate by relevant stakeholders (Cash et al., 2003). Achieving effective evidence-based policy has been challenging because the information and models available are often insufficient to accurately describe the suite of potential social and ecological interactions (Dempster & Sanchez-Jerez, 2008). Many monitoring and assessment methods require large environmental data sets which are often time-consuming and costly to acquire. These methods should thus be optimized for data poor environments (Filgueira et al., 2013; Silva et al., 2011). Greater adoption of virtual technologies like GIS and remote sensing can support more informed decision-making processes in data-scare environments through cost-effective data gathering (Ferreira et al., 2013). To respond to data scarcity, drawing from expert opinion and diverse stakeholder knowledge (including local and traditional knowledge) can enable decisions even without the adequate information (Bermudez, 2013). In data-poor areas, due to the lack of information, BEJ could indeed become a very relevant tool.

2.7 DISCUSSION

Questions about the limits of the natural and social environment have long been important in guiding discussions around how to achieve accountable resource management and sustainable development (Haines-Young et al., 2006). Carrying capacity's popularity as both a theoretically simple and quantifiable concept has incited its indiscriminate application across almost every level of biological organization and system scale (Chapman & Byron, 2018; del Monte-Luna et al., 2004). Throughout the years, the continued influence of carrying capacity concepts on multiple scholars across a range of academic disciplines attests to the concept's flexibility, robustness, and conceptual strength. Carrying capacity for aquaculture is now a relatively mature field of study and use. The last 40 years have witnessed a suite of definitions, tools, and methods for estimating CC in aquaculture. Carrying capacity has been developed considerably within aquaculture to quantify the potential biomass of species for culture, determine optimal sites for production, and understand the impacts of culture production on the surrounding environment. Carrying capacity for aquaculture recognizes multiple management objectives and offers methods to evaluate ecological, social, governance, and economic interactions. These strengths highlight a promising role for carrying capacity to guide planning, management, and monitoring processes that respect limits of aquaculture's complex social-ecological system.

Despite these strengths, this paper has identified gaps in both the study and application of CC to inform holistic decision-making. For example, most CC research has prioritized environmental and production aspects of bivalve aquaculture, with a large focus on developing environmental models. Partly due to data limitations and usability issues, carrying capacity is less often applied in policy contexts than popular management tools like Environmental Impact Assessments. Given the research gaps and challenges with knowledge uptake, this research has proposed a 5-pillar research agenda. The operationalization of this agenda will be based on selecting strategies to improve knowledge utilization and focus on a shift in thinking that frames CC around a holistic, systems perspective that is amendable to the Ecosystem Approach to Aquaculture (see Appendix A). Notably, research on social use limits and advancing methods for BEJ are important areas of focus needed to support a holistic perspective of CC. Due to information scarcity and data limitations, advances in GIS and participatory processes like BEJ can also offer cost-effective approaches to gather information. Nevertheless, it is essential to recognize that CC should only be one of many tools to support holistic management and development decisions. This research agenda rather seeks to provide a guide for decision-makers and scientists to advance the knowledge and tools to support more holistic management that considers limits of complex social-ecological systems.

While the proposed agenda offers a way forward for CC to better support decision-making, defining the specific decision-support role for CC is not straightforward. The literature revealed quite often a degree of vagueness in the definitions of CC and differences in interpretations of the concepts. For example, both environmental capacity, and assimilative capacity have all been used to describe specific aspects of ecological carrying capacity, leading some authors to merge definitions into a single ECC definition (e.g., see Elliot et al., 2018). Additionally, physical carrying capacity is often used interchangeably with suitability of the site for the purposes of informing site selection (e.g., Triyatmo et al., 2018). While this vagueness can be interpreted as intentional to enable flexibility to support diverse socio-economic and environmental contexts, it also raises questions about the methods and criteria used to assess different components. Ultimately, definitions and measures of CC are intrinsically intertwined within social values. Since CC is often used to inform "thresholds" for management, what people consider "acceptable thresholds" are ultimately founded on social values which can vary with diverse stakeholder groups (Dalton et al., 2017). This can create challenges and can raise important questions regarding biases of interest groups in areas. Indeed, setting acceptable thresholds, selecting relevant definitions and criteria likely reflect societal understanding of the concept, and may reflect how it is needed and applied in different areas. In this paper, we have shown that in many contexts, CC has been applied as both a tool to understand natural limits, and as a conceptual guide to make management decisions. It becomes apparent that the role of CC is likely a question of wider decision-making and governance and should reflect societal objectives and values.

Nevertheless, the role of CC in decision-making contexts should be made explicit to reduce confusion and encourage consistency. Its use in decision-making contexts should be predicated on clear delineation of the wider management objectives as well as the specific definitions related to different CC aspects. In particular, it will become increasingly important to clarify the definitions and uses for social carrying capacity, as it is the least well-defined CC component. Selecting specific tools, criteria and strategies are also likely to be contingent and context-specific. Around the world, aquaculture developments face unique issues and challenges, leading to different prioritization of CC components for decision-making. It is also important to recognize likely trade-offs between research actions. For example, policy needs may demand trade-offs between complexity, data requirements, and ease of use. Still, decision-makers and researchers can prioritize certain actions to address multiple pillars simultaneously (**Table 2.3**). For example, CC processes that include stakeholder perceptions and expert opinion can help generate meaningful information, respond to policy needs, and support adaptive carrying capacity. Ultimately, moving forward with the presented strategies could help align CC to guide the development of the aquaculture industry in a societally endorsed and environmentally responsible way.

Table 2.3 Summary of research actions that could support the proposed research agenda for aquaculture carrying capacity.

Research actions	**Research pillars**				
	Recognizing system complexity	*Responding to policy needs*	*Applying adaptive framework*	*Embracing interdiscipl-inarity*	*Curating meaningful information*
Wider stakeholder involvement		x	x	x	x
Coupled assessments with GIS	x			x	x
Advancement of fully-spatial dynamic models	x		x		x
Running multiple models at different (space/time) scales	x			x	
Coupling CC within the decision-context using multiple knowledge sources (e.g., BEJ)	x	x	x	x	x

2.8 CONCLUSION

This paper presents an historical overview of the carrying capacity literature and its uses in aquaculture to better understand how it has developed and identify challenges and opportunities for holistic decision-making. Carrying capacity's varied applications across diverse fields, as well as its conceptual simplicity and flexibility, and its recent attention in aquaculture offer opportunities to capture multiple objectives related to sustainable resource management. This paper presents a specific research agenda to operationalize EBM that focuses on previously established principles and knowledge uptake. Advances in GIS and participatory processes like expert judgement offer cost-effective approaches to gather information. The literature also identified key conceptual challenges related to the conflation of definitions and the inherent linkage to social values, leading to broader questions on the use of CC as a tool or a wider decision-making framework. Indeed, the debates on carrying capacity for holistic aquaculture decision-making point to tensions on how CC is understood and applied, and on its ability to be practically used in management or decision-making contexts. These tensions could be partly resolved by engaging with the proposed research agenda.

CHAPTR 3: DEVELOPING HOLISTIC CARRYING CAPACITY BEST PRACTICES

This chapter presents the findings from expert-consensus research aimed at gathering perspectives from global aquaculture and carrying capacity experts to develop a set of best practices and guidelines in support of holistic carrying capacity assessment. This work identifies the practical and theoretical challenges and opportunities of tools, methods, and CC concepts for holistic assessments. The outcomes of this chapter were used to inform the development of research carried out in subsequent research chapters.

This research was approved by Dalhousie Research Ethics Board (REB file # 2019-4756) and followed all ethical protocols, including participant anonymity and confidentiality. Research documents, including consent forms, interview schedule, questionnaires, and detailed results from each round can be found in Appendix B.

Citation:

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Please note that this chapter appears exactly as it did in the published journal article.

3.1 ABSTRACT

Carrying Capacity (CC) has emerged as a potential tool to sustainably manage human activities such as aquaculture. However, interdisciplinary and integrated frameworks for holistic CC assessments are still missing. The goal of this study was to generate expert consensus on best evaluative practices for holistic CC assessments of ocean-based salmon aquaculture. To achieve this goal, a 3-round Delphi study was conducted with 21 aquaculture and carrying capacity experts from around the world. Experts emphasized that the holistic CC process should i) engage all stakeholders in the process, ii) consider the combination of social, political, ecological, and economic aspects, iii) respond to changes over time, iv) consider multiple spatial and temporal scales, and v) be understandable and clear to all stakeholders involved. Furthermore, the expert panel emphasized the need for a cyclical and dynamic process that allows for the incorporation of feedback in the planning stages, embracing adaptive management. Due to the early stages of truly holistic assessments, the experts recognized challenges related to knowledge uncertainties and lack of approaches to integrate socio-economic data with ecological and physical data, potential conflicts arising from a multi-stakeholder process, and ill-equipped governance structures. The proposed guidelines and framework could help address some of the conceptual and procedural barriers to implementing holistic assessments into decision-making and may position CC as a useful decision-support tool for governments seeking sustainable aquaculture management.

3.2 INTRODUCTION

With rapidly growing aquaculture production around the world (FAO, 2020a), increased recognition of environmental, economic, and social consequences and challenges of farming practices has promoted shifts towards more holistic approaches to managing for sustainability (Costa-Pierce, 2010; Johnson et al., 2019; Krause et al., 2015). Modern holistic approaches recognize marine aquaculture systems as integrated social-ecological systems (SESs) requiring multi-scale, interdisciplinary, and adaptive management strategies (Johnson et al., 2019; Partelow et al., 2018). Management approaches that embrace holistic thinking like the FAO Ecosystem Approach to Aquaculture (EAA) (Soto et al., 2008) have been supported as the optimal way forward. These approaches, however, have faced implementation barriers, in part due to challenges over competing development objectives, poor governance structures, and insufficient knowledge to assess and manage aquaculture in a more holistic way (Brugère et al., 2018).

To advance the EAA, carrying capacity (CC) has been recognized as an important tool for assessing the ecological, production and social sustainability of aquaculture (Ross et al., 2013). Broadly, the concept of carrying capacity recognizes the presence of limits to growth, both for our ecological and social environment. Carrying capacity has long been applied to test for unsustainable ecosystem effects across a range of disciplines (for a review, see Chapman & Byron, 2018), for example to measure the effects of rising human populations (e.g., Świąder et al., 2020) and environmental resource use (e.g., Liu et al., 2020) and emissions across value and supply chains of products, companies and cities (e.g., life cycle assessment (LCA); Bjørn et al., 2020). Carrying capacity has become an encompassing approach that can reflect varying components of the SES. Four main "types" of carrying capacity are often reported (McKindsey, 2006), including: physical (limits set by the physical space required for marine farms), production (the stocking density to achieve maximum production levels), ecological (the level of aquaculture above which unacceptable environmental impacts become apparent), and social (the level of farm development above which unacceptable social impacts manifest) carrying capacity. Other authors have proposed other types, such as regulatory CC (Byron & Costa-Pierce, 2013; Ferreira et al., 2013) or economic CC (Gibbs, 2009) to recognize the role of other factors in the aquaculture SES. These varying definitions reflect the flexibility of the CC concept and its potential application to a range of decision-making contexts and objectives. Thus, CC could theoretically be invoked to assess aquaculture operations with a more holistic view of the range of impacts on the environment and society.

Indeed, carrying capacity has been widely applied in aquaculture to serve a range of research and decision-making contexts (Weitzman & Filgueira, 2020). Yet, CC assessments for aquaculture are rarely implemented in a systematic or consistent way. It is a diverse concept that has been traditionally applied to assess production and ecological aspects of aquaculture, such as whether potential or current practices are operating at levels to optimize cultured species health, favorable water quality, or adequate production yield (for a review see Weitzman & Filgueira, 2020). Only recently has carrying capacity research aimed to define social and economic aspects (Ruiz-Chico et al., 2020a,b; Kluger et al., 2019; Krause et al., 2019; Johnson & Hanes, 2019). Yet, assessments rarely integrate multi-stakeholder and participatory approaches that would be essential for incorporating social carrying capacity (Kluger & Filgueira, 2020). Furthermore, despite recognition of the multiple types of carrying capacity, existing frameworks often suggest a hierarchical structure for determining carrying capacity (e.g., McKindsey et al., 2006). These approaches treat different aspects as independent, and few existing CC approaches consider the feedbacks and interdependencies of ecological, biophysical, and socio-economic factors (Weitzman & Filgueira, 2020). Such interdisciplinary and multi-stakeholder approaches naturally increase the complexity of CC estimations, making holistic approaches conceptually and logistically challenging (Anaïs et al., 2020; Kluger & Filgueira, 2020). While previous work suggested that CC could help operationalize the EAA (Weitzman & Filgueira, 2020), research on how a holistic approach to CC assessment can be put into practice does not yet exist.

This study seeks to develop a set of general principles and best practices to form the basis for a shared framework of holistic carrying capacity assessments of aquaculture as it relates to ocean-based salmon aquaculture. Salmon aquaculture was chosen as it represented 46% of the farmed finfish produced in the ocean in 2018 (FAO, 2020b). Given the diversity of ways that carrying capacity has been applied to aquaculture, a framework could serve as a general reference document for decision-makers and stakeholders, providing guidance on how CC can act as a tool to operationalize the EAA. To do so, this research applied a 3-stage Delphi consultation exercise to determine what experts in aquaculture research and management consider best practice for a holistic assessment of carrying capacity. The objectives of this work were to: 1) identify essential principles for guiding a more holistic vision of CC; 2) generate recommendations and considerations for key features of the assessment process and methods; and 3) discuss challenges and opportunities for the effective implementation of CC in aquaculture decision-making. Holistic CC has been previously explored through reviews (e.g., Anaïs et al., 2019; Weitzman & Filgueira, 2020), or specific applications for bivalve aquaculture (e.g., Byron et al., 2014), yet this is the first to rely on the expertise of practitioners and researchers to develop common best practice. By drawing on known expertise, this research can help identify practical challenges and opportunities develop recommendations that would be more useful in decision-making contexts.

3.3 METHODS

A Delphi study was used to develop best practices for holistic carrying capacity assessments based on expert opinion. In classic Delphi designs, experts undergo multiple rounds of questionnaires to reach a consensus (McKenna, 1994). Summaries of group findings are provided to participants between subsequent rounds. The Delphi technique is an iterative consensus-based technique considered useful for complex multi-faceted problems in sustainability (MacMillan & Marshall, 2006; Martin et al., 2011). It has been used in ecology and conservation issues to help identify indicators, develop policies, and aid in decision-making (Mukhergee et al., 2015). The Delphi technique has also been applied to aquaculture to investigate potential for specific aquaculture technologies (Bunting, 2008) and to evaluate the overall constraints and opportunities for the aquaculture industry (Hishamunda et al., 2009). The iterative nature of the method means questions can be formulated based on earlier responses, exposing experts to potential topics they may have not considered before (McKenna, 1994). Due to its anonymous nature, Delphi is also advantageous to other group decision-making techniques since it is comparatively free from social pressures that can lead to biased conclusions such as groupthink, halo effect, and dominance effects (Mukhergee et al., 2015).

This study conducted a modified Delphi approach comprising one round of semi-structured interviews (scoping round) and two subsequent rounds of questionnaires (convergence rounds) with experts between May 2019 and August 2020 (Dalhousie University Research Ethics Board file # 2019-4756). Compared to classical Delphi studies, this study applies a modified design (Hasson & Keeney, 2011) where the wording of questions and lists evolved across rounds in response to expert feedback. This precludes systematic assessment of changes in consensus but was chosen to reflect more relevant outcomes for management.

3.3.1 Selecting expert participants

Purposive sampling was used to assemble a heterogeneous panel of experts with aquaculture and carrying capacity. Participants selected were at least one (or more): (i) subject-matter experts or experienced researchers with knowledge of carrying capacity methods and/or assessing aquaculture, (ii) experienced practitioners involved in assessments of aquaculture systems or conducting carrying capacity assessments, or (iii) individuals working for, or with, governance/decision-making agencies relevant to aquaculture management and development. In this way, experts were involved with either producing or using carrying capacity knowledge and information to inform aquaculture decision-making.

Initially, 45 experts were identified through a detailed search of relevant literature, key membership associations and through referrals from known content specialists. Snowball sampling was used to identify additional participants. Twenty-one experts agreed to participate in Round 1, including experts from four sector groups (academia, private research groups, government, and consulting) across North America, Western Europe, and Latin America (Appendix B.10). While no participants were from Asia or Africa, participants from all major salmon-producing countries including Canada, Norway, United Kingdom, and Chile were represented (FAO, 2020a). Of the original twenty-one participants, sixteen completed Round 2 and thirteen participants completed Round 3, resulting in a minimum 75% participant retention rate between each round. It can be difficult to retain participants due to the time commitments, but this study sustained participation above a recommended 70% retention rate (Hasson et al., 2000). Participants were most representative of research and academic sectors, although over 80% of participants expressed high levels of expertise on decision-making. Participants also consisted balanced interests and expertise, with greater experience of environmental than social interactions with aquaculture (Appendix B.10).

3.3.2 Data collection

Broadly, questions were based on existing literature (Round 1) and participant responses (Rounds 2 and 3). Round 2 sought expert consensus and Round 3 was used to ask further questions on emerging themes not considered in the original set of questions. The first round consisted in person and telephone semi-structured interviews designed to gather detailed views on carrying capacity and holistic decision-making for salmon aquaculture. Questions covered a variety of carrying capacity themes aimed at soliciting opinion and open comment based on expert's knowledge and experience with aquaculture management and carrying capacity. The first round asked experts: 1) to consider the role of carrying capacity within a holistic decision-making context, and the challenges to implementation; 2) to list issues and relevant information needed to assess different components of CC; and 3) to suggest methods and approaches to measuring information relevant to the CC process. Several major themes emerged from responses provided in Round 1 interviews, which were organized into subthemes and synthesized into a list of considerations that provided the basis for Round 2.

The second round consisted a questionnaire containing 19 questions, divided into four sections: guidance for framework and evaluation process of CC, relevant information and issues, selecting indicators and defining thresholds, and tools and approaches for measuring CC. Most questions asked experts to state their level of agreement, importance, suitability, or relevance to a list of considerations based on a 5-point Likert-scale. Open-ended questions asked experts to offer comments or expand on their responses. Responses were synthesized to generate a series of generalized recommendations and specific considerations for Round 3.

The questionnaire for the third round summarized a completed list of guiding principles, recommendations, and considerations for a holistic carrying capacity framework. The questionnaire contained both closed- (Likert scale and agree/disagree) and open-ended questions. The questionnaire was divided into four sections: 1) re-assessment of elements unclear from Round 2 (3 questions); 2) editing suggestions on recommendations that reached a high level of consensus in Round 2 (14 recommendations); 3) opinions on elements that did not achieve high consensus in Round 2 (15 recommendations); and 4) preference for a shared framework design.

3.3.3 Data analysis

Interviews from the first round were electronically transcribed and qualitative analysis using NVivo qualitative data analysis software [version 12 PRO] identified overarching themes and sub-themes. Themes were identified using inductive coding from transcripts. Themes and sub-themes were then translated into lists of options for rating in subsequent rounds.

In Rounds 2 and 3, rankings were analyzed, and consensus determined to extract recommendations and considerations that were the most relevant or important. Since best practices were drawn from Round 1 responses, there is an underlying assumption that all considerations will be relevant. This study thus defined consensus a-priori to be achieved when the ratings of 75% or more experts fell within a 2-point rating on the 5-point Likert scale. In this context, only those recommendations and considerations which experts rated in the "high" category (ratings 4 or 5 on Likert-scale) were included. There is no universal measure or definition of consensus in Delphi studies. When based on percentage agreement or proportion of ratings within a range, authors have recommended proportions ranging from 50% to 90%, but the median threshold for consensus often lies at 75% (Diamond et al., 2014). A cut-off point of 75% was selected to generate a synthesized set of best practices representing only the most relevant, important considerations. Quantitative analysis used the R statistical software [version 4.0.0] to provide descriptive statistics including central tendencies, frequencies, and proportions.

3.4 RESULTS AND DISCUSSION

Based on expert suggestions and opinions, this paper presents a shared framework for holistic CC assessments, defined as a set of guiding principles, recommended best practices and broad implementation steps that can help guide decision-makers evaluate aquaculture's carrying capacity for more holistic management. First, five guiding principles are proposed for successful application of holistic assessments of aquaculture CC. To implement these guiding principles, a series of best practices and a step-wise process are proposed to help CC evaluators and decision-makers conduct holistic CC assessments. Finally, this paper discusses the overall opportunities and challenges of implementing holistic CC assessment within current decision-making regimes.

3.4.1 Guiding principles for holistic carrying capacity assessment

During Round 2, experts identified five key principles as the most important for effective holistic CC processes (**Table 3.1)**. First, holistic CC assessments should be interdisciplinary by considering all aspects of the social-ecological system. This is a pillar of a holistic management and for adopting the EAA, acknowledging that aquaculture management should recognize the interaction of multiple dimensions including the surrounding environment, policy, and socio-economic contexts (Broitman et al., 2017; Soto et al., 2008). This has been an enduring challenge with CC assessments, which have struggled to define and evaluate social and economic aspects of aquaculture (Weitzman & Filgueira, 2020).

Table 3.1 Experts perceptions on the principles to guide a framework for holistic carrying capacity assessment, organized according to frequency of expert rating.

Principles	Description	% of experts rating "highly important" (Round 3)
Being interdisciplinary	consider all aspects: physical, ecological, social, economic, political, governance	100.0
Being adaptive and iterative	respond to changes over time	92.3
Being transparent and clear	understandable and includes all necessary information for all relevant stakeholders	92.3
Consider multiple scales	space and time	84.6
Being inclusive/participatory	engaging all relevant stakeholders in process	76.9

Second, adopting integrated perspectives into CC begets the need for an inclusive and participatory approach that engages a range of relevant stakeholders in the CC process. Experts expressed that having stakeholders become a part of the process can help stakeholders understand the process, increasing the chance for success and uptake. Participatory methods were also emphasized when thinking about social carrying capacity, as experts noted that social limits can only be evaluated through a discursive process that discusses trade-offs. Participatory approaches have been considered essential for more accountable and sustainable resource management, increasing the quality and legitimacy of environmental decisions (Reed, 2008).

Third, a more holistic, systems-approach to CC necessitates considering multiple spatial and temporal scales. During interviews, several experts firmly held that evaluating CC of a single site is insufficient to consider the full range of impacts or interactions of aquaculture within the wider SES. Other management approaches based on ecosystem perspectives have similarly recognized that ecosystem processes operate over a range of spatial and temporal scales (Arkema et al., 2006; Kirkfeldt, 2019). Addressing the impacts of multiple farms in an area has been a consistent challenge for environmental assessments of aquaculture operations, sometimes resulting in a failure to recognize operations that have reached or exceeded the regional area's carrying capacity (King & Pushchak, 2008). Furthermore, the dynamic nature of the marine environment entails that changes over time and the effects of aquaculture on wider spatial scales are required for a holistic view of aquaculture's impacts to the social-ecological system.

Given the existing temporal dynamics relevant to CC, the fourth principle was for CC assessments to be adaptive and iterative, meaning that a framework ensures processes for feedback and adaptation in response to changes. Experts agreed (84.6%) that CC assessments should be re-evaluated following initial site development (for example, with lease renewals). This reflects the criticism of the CC assessment as a "static" process which is often only conducted to show a snapshot of the ecosystem conditions at early site selection or original leasing procedures (e.g., Smaal & Van Duren, 2019). Adaptive management, and similar applications of the precautionary approach, have been staple principles of ecosystem-based management deemed essential for incorporating uncertainties and dynamic changes of ecosystems (Long et al., 2015).

The four above principles reflect some common key principles that have emerged in the literature for more holistic, ecosystem-based management (e.g., Long et al., 2015). In addition, when considering the role of implementing CC assessments into decision-making contexts, experts highlighted the need for the process to be transparent and clear. It was considered important for creating a common understanding of the goals and outcomes of such an assessment, and establishing adequate buy-in for a complex, multi-stakeholder process. Coherent procedures and transparency about the processes can build participant trust and improve the credibility and legitimacy of the assessment process (Sarkki et al., 2015). In conclusion, these five guiding principles can help guide the use and design of a holistic framework for more consistent application of carrying capacity to aquaculture decision-making.

3.4.2 Best practices for holistic carrying capacity assessments of salmon aquaculture

Implementing the guiding principles requires embracing best practices for successful holistic assessment of aquaculture carrying capacity. Experts agreed that best practices should advise on four main aspects related to the evaluation of CC within holistic assessments:

1. Definitions of concepts and terms (87.5%)
2. Inclusion of relevant scale(s) (81.3%)
3. Depth and breadth of stakeholder involvement (92.3%)
4. Identifying and assessing carrying capacity (93.8%)

Based on a synthesis of findings from Round 2 and 3, experts agreed on a series of guiding recommendations (bolded in text) and specific considerations (italicized in text) that support the implementation of recommendations. A final list of 10 recommendations fitting within the four aspects all achieved consensus by experts and represent the synthesized list of most important best practices to guide CC assessment (**Table 3.2**; see Appendix B.11 for more description). These best practices set the specific roadmap for how CC assessments can adhere to the general guiding principles (**Table 3.1**).

Table 3.2 Recommendations for designing holistic carrying capacity assessments for aquaculture based on expert consensus. See Appendix B for details.

Aspect of CC	Recommendation	Consensus
Definitions of concepts and terms		
1	It is essential to define and refer to concepts related to the assessment, including carrying capacity, indicator, and acceptable change (threshold)	Round 2 - 87.5%
Inclusion of relevant scale(s)		
2	Assessments should include all scales relevant to the social-ecological system.	Reached in Round 2*
3	The scales included in the assessment should be determined by the specific goals and contexts of the carrying capacity assessment	Round 3 - 92.3%
Depth and breadth of stakeholder involvement		
4	Carrying capacity assessments should be designed to engage the relevant stakeholders to participate throughout the CC process as appropriate	Round 2 – 75.0%
5	Carrying capacity assessments should clearly define the roles and responsibilities of each stakeholder, recognizing that not all stakeholders will have the same responsibilities.	Round 2 – 81.0%
Identifying and assessing carrying capacity		
6	Carrying capacity assessments should focus on selecting as few, important indicators as relevant to the assessment objectives and priorities	Round 2 - 76.9%
7	Indicators to include should be selected by balancing trade-offs in cost, relevance, reliability, and complexity	Round 2 – 80.0%
8	Carrying capacity assessments should use both a combination of universal indicators and context-specific indicators	Round 3 - 92.3%
9	Multiple types of thresholds are potentially relevant for CC assessment, but will vary depending on the indicator chosen	Round 3 - 92.3%
10	A holistic assessment of carrying capacity requires using a combination of quantitative and qualitative tools and information	Reached in Round 2*

*Based on consensus on multiple items

3.4.2.1 Definitions of concepts and terms

To ensure CC assessments are clear and understood by stakeholders, experts agreed (87.5%) that it was highly important **to define and refer to the essential concepts related to the**

assessment. Four terms emerged as most important, including carrying capacity (87.5%), types of carrying capacity (75.0%), acceptable change (81.3%), and indicator (87.5%). In interviews and open-ended comments, experts suggested that other terms may be relevant, including sustainability and scale. In part, the various uses and applications of the CC concept over the years has led to much of the confusion and lack of consistency in applications of CC (Chapman & Byron, 2018; Weitzman & Filgueira, 2020). A common understanding of what exactly we are measuring the carrying capacity "of", and how "acceptable" is defined can help decision-makers provide more consistent CC assessments suited to particular management contexts.

Based on agreement of experts (84.6% agreement) during Round 3, a common definition for holistic carrying capacity assessment for aquaculture was proposed as: "an evaluation of proposed and/or current aquaculture operations against the acceptable limits, as defined through consultation with stakeholders, of the components of the social, ecological, and economic environment in which aquaculture is embedded.". Likewise, expert consensus was not reached as to the appropriateness of any of the proposed overarching definitions for different types of aquaculture carrying capacity (e.g., physical, production, social, ecological) adapted from the existing literature (Appendix B.12). In particular, the panel prominently disagreed on the suitability of an overarching definition for carrying capacity, as well as defining physical CC, and social CC. Experts highlighted that the definitions provided were too vague, requiring more detailed explanation and further specificity. This precludes a shared set of definitions at the framework level; rather, contending that relevant terms should be defined on a case-by-case assessment basis. However, including critical assessment-specific aspects goes against mainstream thinking of providing strong and rigid definitions that can be extrapolated to multiple contexts (e.g., DFO, 2015). As a result, this suggests that a holistic CC assessment would not necessarily produce a single calculation expressed explicitly in terms of stocking density or area, as has been traditionally expressed in many CC definitions (e.g., McKindsey et al., 2006). In this way, modifications to the definitions are likely needed to reflect the purpose of the CC assessment and suit different user-groups involved in the assessment.

3.4.2.2 Delineation of appropriate scale(s)

While most traditional CC assessments for salmon farming have focused only on evaluating aquaculture at the farm-scale using the concept of assimilative capacity (e.g., Bravo & Grant, 2018; Yokoyama et al., 2004), considering multiple scales was a critical guiding principle towards a holistic CC assessment. This study proposes defining different types of scales into scale "domains" including local, large, regional, national, and global areas (**Table 3.3**). Given the interdisciplinary nature of a holistic assessment, the specific units or boundaries of these domains will vary. For example, the "local" domain for production aspects considers operations at the farm or individual cage scale, while "local" in terms of social carrying capacity may rather involve political jurisdictional boundaries that define a community. As a result, it may be most appropriate for holistic assessments to define relative scales based on area "domains" rather than to apply a specific absolute scale in geographic or ecological units.

Table 3.3 Different ways that scales may be defined for salmon aquaculture for five major scale domains.

Type of scale	Local area	Large area	Regional area	National area	Global
Ecological scale	Salmon cage or farm	Basin, bay ("ecosystem")	Multiple bays	Industry-wide	
Jurisdictional scale	Community or municipality	Cluster of communities, county etc.	Large zone for aquaculture, or province	Country	
Geographic scale	< 1km^2	10 - 20 km^2	100s - 1000s km^2		

During Round 2, experts were asked to comment on the relevance of each scale domain for evaluating the different aspects of carrying capacity (**Figure 3.1**). Both the local and large area domains were considered highly relevant to assessment of all carrying capacity types. The local area has traditionally been the focus of carrying capacity assessments and remains eminent for many aquaculture issues. For example, social conflicts are often particularly localized, dealing with issues around user conflicts, provision of local employment, property rights, community well-being, and effects on local environments (Billing, 2018; Salgado et al., 2015). In addition, studies have demonstrated that benthic impacts are most relevant right near the farms, and generally only observed within 20-50m of cages (Filgueira et al., 2017; Kalantzi et al., 2013). Including the large area domain was also highly important across all CC types, since aquaculture activities at the farm-level can have repercussions at the ecosystem-level

(Weitzman et al., 2019), for example by facilitating spread of disease to wild populations (e.g., Krkošek, 2017) or increasing coastal nutrient enrichment (e.g., Sarà et al., 2011). Setting the boundary at the large area domain is often necessary to include many relevant stakeholders who else would be left out with a restricted local focus. Experts also saw a role for carrying capacity assessments at the regional area domain, although consensus was only achieved for its high relevance for social carrying capacity. For social aspects, the scale may extend further than ecological aspects since discussions of what is acceptable and how benefits or impacts are distributed may be relevant at both the community and the wider policy context (e.g., regional and/or national level) (Kluger & Filgueira, 2020). In summary, in addition to the local area scale (farm, cage, community etc.), the physical, production, social, economic, and ecological aspects of the large area domain (at the wider basin or bay-scale) need to be considered in CC assessments. As a result, experts agreed that **assessments should include all scales relevant to the contexts of the particular social-ecological system.** Furthermore, experts agreed that **evaluators should rather select scales for assessment as determined by the specific goals and local contexts** (92.3% agreement). In conclusion, this study suggests that local and large area scales are key, but depending on local settings and goals of the assessment, these aspects should rather be flexible, and properly defined in a given CC assessment.

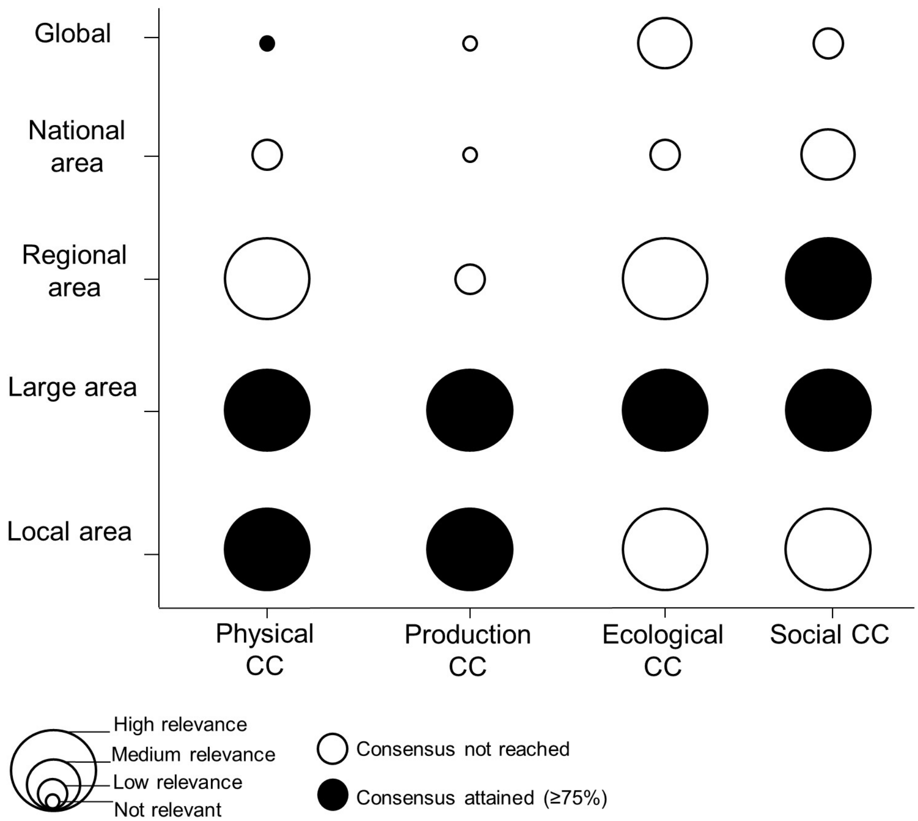

Figure 3.1 The expert ratings with the highest number of responses for the relevance of scale domains to different aspects of carrying capacity. Larger bubbles represent higher levels of relevance, with filled circles (black) representing ratings where consensus where consensus was reached.

3.4.2.3 Including and engaging stakeholders

Stakeholder involvement is an integral part of various stages of an inclusive and participatory CC assessment process. Stakeholders can include anyone with an interest in the outcomes of the project, entities leading the assessment, CC evaluators, experts and scientists, special interest groups and local communities. Experts highlighted that **carrying capacity assessments should be designed to engage stakeholders to participate throughout the carrying capacity process as appropriate** (75.0% of participants). This means that CC assessments should be designed to include processes to ensure the participation and engagement of all stakeholders at each stage and step of the process. This reflects a growing desire to adopt participatory processes and stakeholder engagement recognized for more accountable aquaculture and marine planning (Galparsoro et al., 2020; Tiller & Richards, 2015; Tompkins et al., 2008). Often, CC evaluators and decision-makers need to follow engagement procedures outlined in existing legislation and consider factors such as time and resources. As a result, any standardized guidance for who and how to engage would need to be developed when adapting a CC framework for more national or regional governance levels.

This study identified several considerations for selecting relevant stakeholders in holistic CC assessments. First, a high level of consensus was reached (94.0% of participants) that *actors involved in the carrying capacity process should represent diverse knowledge forms and disciplines.* Incorporating complex social-ecological dynamics will ultimately require interdisciplinary research teams to adequately consider all necessary components. This means that CC assessments should include input and expertise from a balanced distribution of social, economic, and ecological disciplines, relevant to the goals of the assessment. In addition, where applicable, experts noted that this may include knowledge gained by locals and/or indigenous groups, recognizing that managing complex social-ecological systems can benefit from incorporating multiple knowledge systems (Armitage et al., 2009). Second, the selection and engagement of stakeholders should include *consideration for their individual stakes, as well as their demonstrated investment and interest in participating* (92.3% agreement). Including considerations of "why" and "for whom" the assessed aquaculture activities are taking place has been suggested as important for socially-sound and equitable aquaculture decision-making (Krause et al., 2015). Third, experts agreed (84.6% agreement) that *stakeholders included in carrying capacity assessments should correspond to the relevant scale(s) of the assessment.* For example, if an assessment is more heavily focused on local area processes, engagement should emphasize local stakeholders. This is important as not to miss principal stakeholders, which can help re-orient aquaculture expansion for community well-being and equity (Campbell et al., 2021) by potentially reducing potential power inequalities between groups, such as reducing the influence of large vocal groups. Together, these considerations suggest that the identity of stakeholders and their involvement in the CC process will be highly context-dependent and ultimately relate to the goals of the assessment.

Recognizing that not all stakeholders will have the same responsibilities, experts agreed (81.0% agreement) that **carrying capacity assessments should clearly define the roles and**

responsibilities of each actor and stakeholder group. Clearly defining the roles and responsibilities early in the process can help identify where power differences may exist and provide clarity to stakeholders about the intended outcomes of the process. This can also help develop a well-designed, context-specific approach to engagement important for project support and successful implementation (Reed et al., 2018). However, experts expressed different opinions on the involvement stakeholders should have related to different roles and responsibilities in the CC process (**Figure 3.2**). Experts expressed difficulties selecting the specific degree of involvement of each stakeholder, since the way that stakeholders are involved, and their roles and responsibilities will vary depending on the contexts, purpose of the CC assessment, and/or indicators chosen. As a result, consensus on the specific roles and responsibilities of individual stakeholder groups was only achieved in a few cases. Experts agreed that government and researchers should have high degree of involvement, and particularly so related to leading CC assessments and monitoring and evaluation. This would suggest that experts highly endorse the primary role of CC being to support legislative activities like site selection and obtaining or renewing leases and licenses. While experts suggested in Round 2 that all stakeholder groups should be highly involved in both selecting indicators, as well as setting acceptable thresholds, in Round 3, experts only reached consensus that consultation and discourse among all stakeholders was highly important for two parts of the CC assessments: first, while setting assessment goals and priorities, and second, when selecting relevant indicators. Involving variety of stakeholders and interests during indicator selection can help ensure that aspects that have important social or ecological consequences are adequately considered and incorporated (Anaïs et al., 2020), but the lack of consensus highlights the difficult task of stakeholder engagement (Reed, 2008; Reed et al., 2018). As a result, stakeholders should be identified and engaged early and throughout the CC process, but not necessarily to the same degree at all stages.

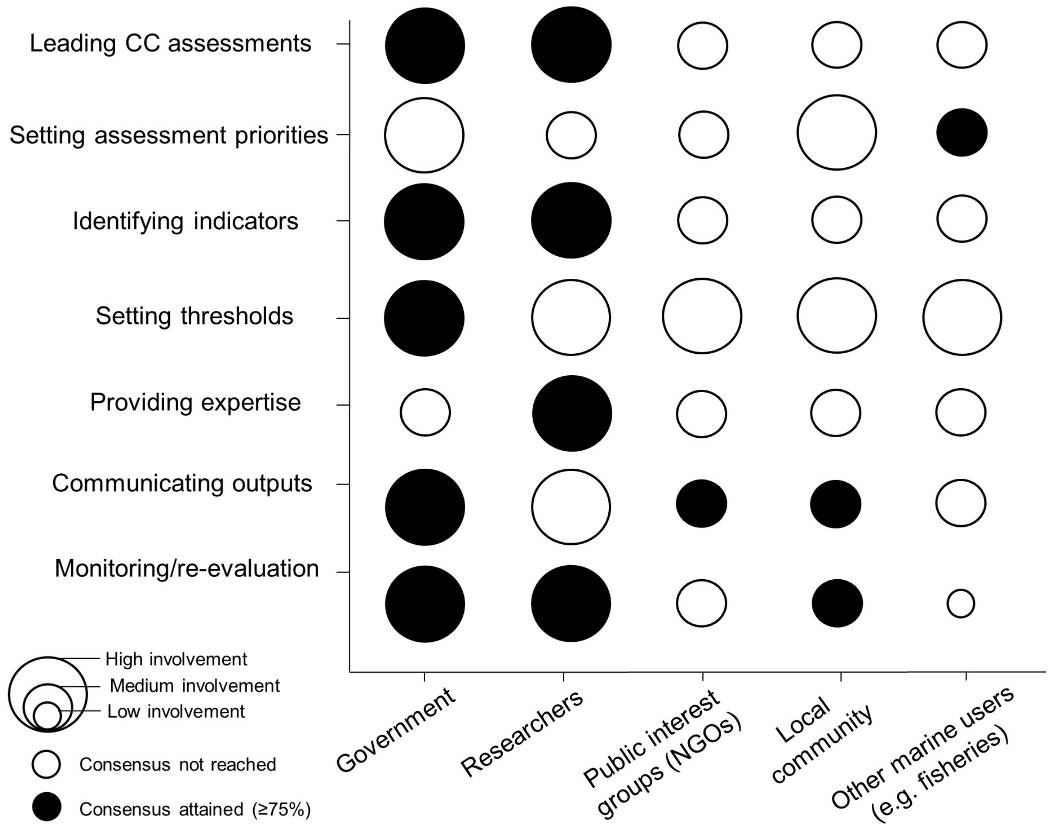

Figure 3.2 The expert ratings with the highest number of responses for the degree of involvement regarding how each stakeholder group should be involved in various roles regarding CC assessment. Larger bubbles represent higher levels of involvement, where filled circles (black) are those ratings where consensus was reached.

3.4.2.4 Identifying and assessing carrying capacity

During carrying capacity assessments, indicators reflect either the pressures or condition of key variables and are measured to identify a violation of carrying capacity limits. Identifying these pressures and issues is the first step in defining which indicator or indicators will be assessed during CC evaluation (Tett et al., 2011). During Round 2, experts identified a variety of issues and pressures highly important for understanding production, physical, ecological, and social carrying capacities in relation to ocean-based salmon farming (Appendix B.12). However, experts highlighted that factors and issues (especially those for social and ecological CC) will likely be different depending on whom is consulted and the specific circumstances, such as the definition of acceptability and purpose of the CC assessment, reinforcing the idea of the relevance of local settings. As a result, individual CC assessments may benefit selecting from a large list of potential indicators on a case-by-case basis through a participatory process involving a variety of stakeholders and interests.

Recognizing that a holistic assessment could potentially include a variety of indicators, experts agreed that **assessments should practically focus on selecting few important (or key) indicators** to reduce complexity of assessments. Experts agreed that it was highly important that the selection of indicators consider four main considerations. First, indicators should *focus on issues that are predicted to be higher risk or impact* (85.7% agreement). To some degree, this consideration assumes the need for a process to define and understand the risk factors (likelihood and severity of impact) of given indicators. Second, indicators selected should prioritize *changes that can be directly attributable to aquaculture* (86.7% agreement). This acknowledges that indicators should ideally be sensitive to the change they are measuring (Rice, 2003), and specific to link to aquaculture operations in the given area. Third, experts also considered it moderately important that the set of indicators *allow measurements across large areas* (80.0% agreement). This is consistent with the importance of both the local and large area scale domains for holistic assessment. Fourth, carrying capacity assessments should ensure that indicators chosen *link to the management objectives and societal priorities* relevant to the given context (80.0% agreement). This final consideration recognizes that useful indicators need not only be scientifically robust, but also relevant to policy and management (Cranford et al. 2012). In this way, experts have highlighted that good indicator selection criteria include both scientific and systematic relevance and credibility, with the addition of the relevant spatial scale, a consideration which is not usually included in the selection of indicators (Rector et al., 2022). In addition to these most salient considerations, other criteria may be applied, recognizing that a wide series of criteria and frameworks have been applied to indicator selection (Niemeijer & de Groot, 2008; Rice, 2003).

While the criteria above help guide the selection of individual indicators, experts also agreed that **a complete set of indicators for any given CC assessment must also balance features such as cost, relevance, reliability, and complexity** (80% agreement). Trade-offs in these features and the above-mentioned criteria may sometimes be necessary given constraints on the availability of data, expertise, time, and money. Identifying these types of trade-offs are important for generating useable scientific knowledge in decision-making

(Sarkki et al., 2014). The relative weights of each of these features will thus be an important part of the CC assessment scoping.

In Round 3, experts reached a consensus (92.3% agreement) that **carrying capacity assessments should use a combination of universal and context-specific indicators**. Universal indicators include those well-established and are generally applicable to multiple contexts and areas (e.g., unemployment rate). Universal indicators may be considered reliable and measurable since they have a proven track record. For example, the level of free sulfides in the sediment is a well-established indicator of benthic health linked to aquaculture (Hargrave, 2010) that is frequently used in environmental monitoring programs (Wilson et al., 2009) and certification standards (e.g., ASC, 2019). Universal indicators are useful to compare assessments and can help assessments draw from existing data being regularly collected and monitored. However, experts remarked that universal standards may not acknowledge local conditions or socio-economic contexts. For example, indicators developed to measure soft-bottom sediment community health may not be appropriate in hard-bottom substrates (e.g., Hamoutene et al., 2016). As a result, context-specific indicators that can be developed iteratively with stakeholders may be necessary to capture the specificities of the local context.

Once relevant indicators have been selected, carrying capacity evaluations will calculate whether the measured indicator level is acceptable or not, indicating a potential violation of carrying capacity (Tett et al., 2011). Different types of thresholds can be applied, ranging from "absolute" thresholds, which reflect a natural (or biological) tipping point in the system, to "relative" thresholds, which reflect what is acceptable, as determined by societal norms, perceptions, or goals. Both absolute and relative thresholds may also be further categorized as dynamic "flexible" thresholds presenting a range of values for indicators (e.g., Thresholds of Potential Concern; see Cranford et al., 2012), or "precautionary" thresholds as a level lower than calculated threshold (e.g., Hargrave, 2002). Experts recognized that **all types of thresholds could be highly suitable for evaluating carrying capacity but would differ depending on the indicator in question and assessment goals and objectives**. Where data and knowledge may be lacking, experts highlighted that precautionary thresholds were highly suitable for holistic CC assessments (80.0% agreement) since they can allow carrying capacity estimations to incorporate uncertainties or errors in data. During Round 1 interviews, experts highlighted that what is determined as thresholds, regardless of the type, must ultimately be based on what is "acceptable", and thus a product of societal values relative to the local context, and the goals and objectives of the assessment. In this way, stakeholder engagement at this stage is critical, as Kluger and Filgueira (2020) suggest that local limits should be constructed based on joint societal discourse.

Over the years, various tools and approaches have been utilized to assess and evaluate diverse indicators and thresholds relevant to aquaculture carrying capacity (Weitzman & Filgueira, 2020). Experts were asked to comment on a number of these methods, and rate how suitable each was for assessing some, or multiple CC components of salmon aquaculture (**Table 3.4**). Experts identified ecological modelling as a key tool for assessing environmental effects, as several models have already been well-developed for production and ecological carrying capacity (Filgueira et al., 2015). In recent years, dynamic models have become particularly relevant to account for temporal changes in the ecosystem (for a review, see Ross et al., 2013). On the social side, both qualitative and quantitative social research tools were often highlighted as critical for evaluating social and economic impacts of aquaculture. While some models and tools to determine socio-economic aspects of carrying capacity have been developed, they are rarely applied to aquaculture systems or carrying capacity (Kluger & Filgueira, 2020; Smaal & Van Duren, 2019). As a result, experts agreed the need for research to advance the qualitative and quantitative methods to determine social aspects of CC to support comprehensive CC assessments (93.3% agreement, and 86.7% respectively). This supports recent efforts to quantify the social dimensions of aquaculture in efforts to operationalize social and economic pillars of sustainable aquaculture (Krause et al., 2015; Krause et al., 2020). Finally, experts identified the relevance of risk management, expert judgement, and scenario building, which can be applied to different aspects of the SES. Experts identified risk assessments as a good step to identify relevant indicators during the indicator selection process. Risk assessments are also a method for easily incorporating precautionary measures, such is being done in the risk assessment procedures of Canada's FARM aquaculture management plan (DFO, 2019). Scenario-building was highly suitable for holistic CC to both evaluate different management scenarios (Filgueira et al., 2014) and incorporate stakeholder participation (Tiller et al., 2013) for more comprehensive planning outcomes. Expert judgement approaches which rely on expert and stakeholder input can enable decisions in paucity of data (Elliot et al., 2018), and was consistently emphasized as a critical part of CC assessments to identify needs and indicators and validate data.

Table 3.4 Examples of benefits and drawbacks of various tools for use in holistic assessment of carrying capacity assessment of aquaculture.

Tool	Benefits	Drawbacks	Suitability (% agree)
Models – production and ecological models	• Good tools to understand repercussions of impacts on some parts of the system • Can be visually explicit • Offer clear messages for decision-makers • Useful to develop and evaluate management scenarios	• Data intensive • Often static (e.g., EcoPath) • Many complex and not readily applied or understood • Often require substantial expertise to apply and interpret	Production - High (80.0%) Ecological - High (93.3%)
Risk assessment	• Can help identify relevant indicators and limiting factors • Good for low data availability	• Requires expertise and subjective judgement	High (93.3%)
Scenario building	• Build and reassess different scenarios • Potential for participatory interaction and evaluation of social aspects	• Time and resource intensive (especially if highly participatory)	High (75.0%)
Mapping (GIS)	• Good communication tools	• No all CC components equally suitable (e.g., social)	Medium (80.0%)
Expert judgement	• Help identify needs in a more comprehensive assessment • Help validate and/or contextualize data • Good in data-poor contexts	• Challenging to reduce bias • Potential for low availability of experts • Success will depend on trust of expertise	High (80.0%)
Qualitative surveys /interviews	• Rich and local contextual data sets to integrate complexity of social aspects	• May be time and money intensive • Unclear how to integrate with other CC estimates • Difficult to generalize	Medium (86.7%)
Quantitative social research	• Can provide long-term data on socio-economic conditions	• Require large data sets • Lack of existing quantitative methods to estimate social CC • Count-based metrics may be inappropriate for social CC	Based on comments in Round 2

Still, advances in methods to combine social, economic, and ecological CC were considered imperative for more holistic CC (93.8% agreement). Experts agreed that mapping tools are moderately relevant for CC since they are effective at exploring spatial and temporal aspects of aquaculture across vast data types and sources (Falconer et al., 2020). Experts also noted that they could be good communication tools (Gangnery et al., 2020) that are simple to apply and easily understood by users and decision-makers, which could help improve the uptake of carrying capacity approaches in decision-making contexts. However, mapping tools might only be relevant for physical and ecological aspects of a holistic approach and are currently limited by data requirements (Falconer et al., 2020). Methods to map social conflicts and values have improved (Brown et al., 2020), especially related to broader marine spatial planning (e.g., Noble et al., 2019), yet are rarely applied to aquaculture contexts (Falconer et al., 2020). Furthermore, other approaches such as life cycle assessment (LCA) and ecosystem service valuation have potential to integrate multiple SES aspects within CC assessments, although consensus was not reached as some experts identified that these approaches are not ready for operationalization.

Experts expressed that different tools would have their respective challenges and limitations (see **Table 3.4**). Often, selecting the appropriate tool will be highly context-dependent and experts expressed that CC assessments should rather select form a range of tools to fit the specific assessment needs. Experts identified four considerations as highly important to guide the selection of tools (**Table 3.5**), including the *goals of the given assessment*, *the indicator(s) of interest*, the *availability of resources* (cost, data, time, and expertise), and the *communicability* of the tools. These considerations suggest that CC frameworks could benefit from case-specific guidance on the resource needs, outputs, and goals of different tools to help CC evaluators select the most relevant tools for their given context. This diversity also reflects the complexity of evaluating multiple indicators across a range of spatial scales for a holistic, interdisciplinary CC assessment. As experts noted, many of these methods would be used concurrently to address different aspects of aquaculture operations. As a result, experts agreed that **a holistic assessment of carrying capacity will require the utilization of a combination of quantitative and qualitative tools** to collect and assess various ecological, hydrographic, and socio-economic data sets. As one expert expressed, "I can't think of one human activity where you don't need multiple tools to solve the problem from the kitchen to the garage to managing the environment.".

Table 3.5 List of criteria ranked most important for guiding the selection of appropriate tool(s) to use in holistic carrying capacity assessments.

Tool-selection criteria	Description	% of experts rating "highly important"
Assessment goals	The objectives and priorities outlined in the CC assessment	92.3
Indicator(s) chosen	The indicator(s) that are chosen to be analyzed in the assessment	84.6
Communicability	Ability of tool to communicate outputs to assessment stakeholders and intended audiences	84.6
Resource availability	Resources, including time, money or personnel/expertise needed to apply the tool	84.6

3.4.3 Building a process for holistic carrying capacity assessments

To facilitate the implementation of the principles and best practices, experts provided feedback across Delphi rounds to develop a final three stage, eight-step process for holistic CC assessment (**Figure 3.3**). The development of this process was designed to be broad, presenting an overarching structure applicable to different contexts and assessment goals. The initial planning stage involves steps associated with setting the overall goals of the assessment, identifying the stakeholders, and determining specific priorities and definitions. In this process, stakeholders are defined and engaged early in the process to foster the appropriate inclusion of all necessary individuals and expertise. In this way, assessments can ensure that stakeholders are engaged throughout the carrying capacity process. The analysis stage includes identification and definition of indicators and thresholds, and the subsequent evaluation of aquaculture against the determined indicators and thresholds. The final sharing and learning stage includes communicating of assessment outputs with relevant stakeholders, and a review step. The process was proposed as iterative in nature, with the last review step connecting to early steps to evaluate findings against assessment goals based on feedback from stakeholders. As one expert noted, "going through the CC assessment process may identify that the original purpose of assessment is not achievable or beyond scope of available data/information.". As a result, this process resembles the basic structure of many adaptive management cycles (Schreiber et al., 2004) showing that the process is dynamic, continuously revisiting chosen indicators and thresholds and responding to changing contexts. This also follows adaptive protocols proposed in other ecosystem-based marine planning approaches such as Integrated Coastal Zone Management (ICZM) (e.g., Forst, 2009) and marine spatial planning (MSP) (e.g., Douvere & Ehler, 2011).

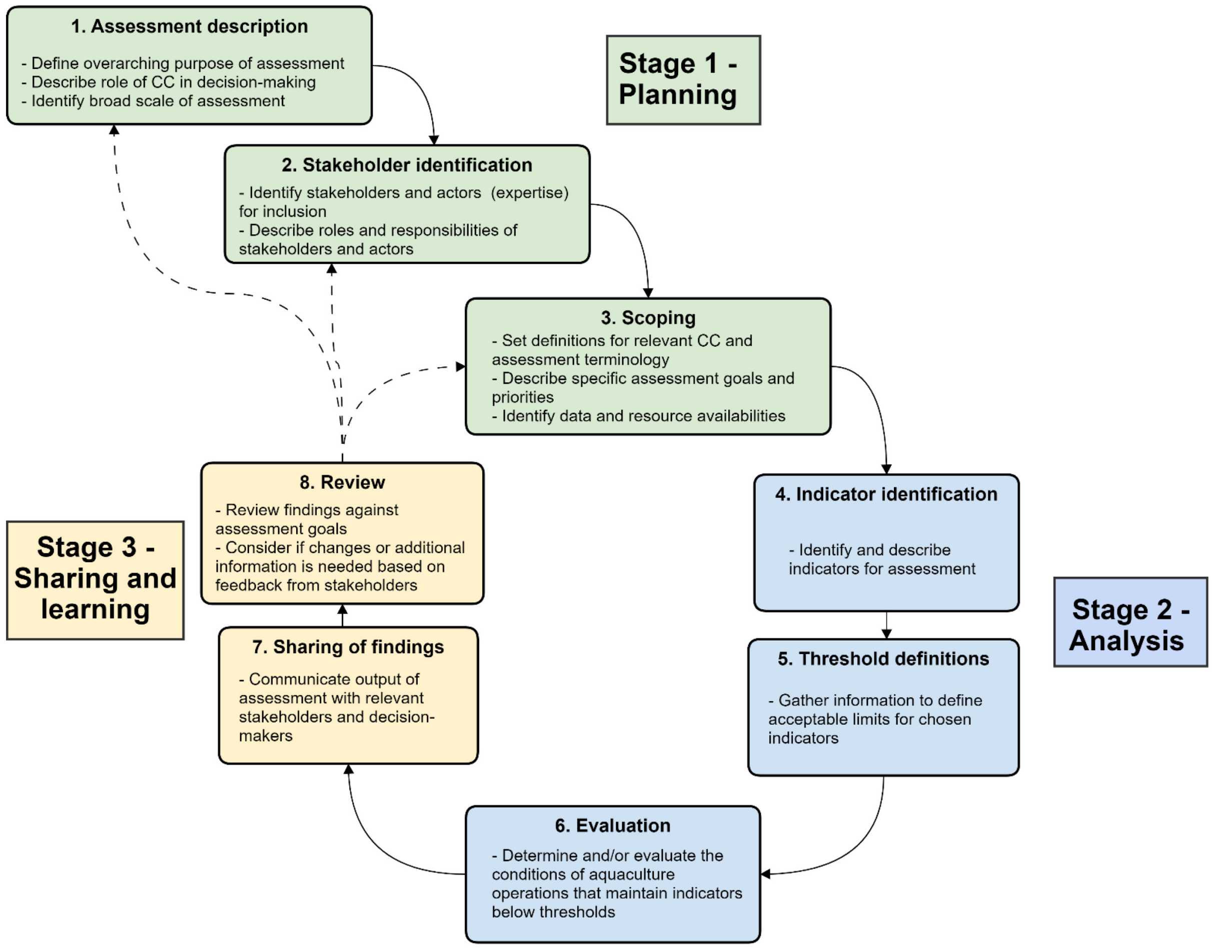

Figure 3.3 Step-wise process to guide the assessment of holistic carrying capacity for aquaculture.

Experts were asked to comment on the steps they felt were important to emphasize. Three steps were more frequently mentioned in open-ended comments: scoping, threshold definitions, and evaluation. One expert expressed that proper and inclusive scoping was essential because it sets the parameters and extent of the CC assessment. A clear understanding of the overall objectives can improve the legitimacy of the process and is crucial for properly identifying relevant indicators in subsequent steps. As another expert emphasized, "what are you trying to measure, conserve, preserve, protect? Because without that understanding of what your goal is, how do you know which is the right metric or the threshold?". Six experts indicated the importance of defining and measuring thresholds, with one expert mentioning that "at the end of the day, all arguments will be based on disagreements about what the acceptable limits will be.". In addition, this step should be emphasized because this will be both the most challenging due to data limitations and the need for broad engagement/consensus-building to set limits. Likewise, the evaluation step was emphasized due to challenges with lack of knowledge on what levels of aquaculture correspond to maintaining indicators below acceptable limits. In addition, evaluation is critical to provide feedback and embrace adaptive management (Douvere & Ehler, 2011). However, while many models and indicators are being developed to assess different aspects of CC, many are not yet ready for regular use and implementation (Cranford et al., 2012), making application and consensus in the analysis stage difficult. As a result, knowledge uncertainties and potential conflicts during these critical stages may compromise the effectiveness of the CC process.

3.4.4 Implementing a holistic CC approach for aquaculture

Most participants viewed a holistic approach as the preferred and ideal management system for aquaculture. One expert described the Ecosystem Approach to Aquaculture (EAA) as a "common sense" approach, which has only recently been formalized in a way to start thinking operationally about it (Brugère et al., 2018; Rodriguez, 2017). Likewise, experts expressed that carrying capacity fits well within the aquaculture policy process and may be most appropriate for early planning such as initial site selection and scoping (93.8% agreement) and obtaining leases and licensing for new development (93.8% agreement). Experts also endorsed that assessments of CC can help visualize risks and opportunities of aquaculture towards management that takes a more systems-perspective approach, such marine spatial planning (e.g., Gimpel et al., 2018). Yet, applying the theoretical aspects of the EAA to management and carrying capacity is complex (Arkema et al., 2006; Brugère et al., 2018). Experts attributed the difficulties to both internal barriers (theoretical and practical challenges with the CC process) and external barriers (wider political, governance and social/cultural factors), as well as logistical barriers (lack of accessibility of tools and data) that can influence the uptake, implementation and success of holistic CC assessments in decision-making (**Table 3.6)**

Table 3.6 Barriers and challenges to implementing more holistic vision of carrying capacity into aquaculture decision-making.

INTERNAL BARRIERS	EXTERNAL BARRIERS
Logistical barriers: • Comprehensive approaches data-intensive and time-consuming to apply • Limited funds (capacity) for carrying capacity assessment	
Conceptual barriers: • Vague and inconsistent definitions and understanding • Complexity and ambiguity of scales • Focus on farm-centered approach	**Institutional barriers:** • Needed data may not be collected • Aquaculture not always properly allocated in governance • Holistic approach not legislated • Scale of processes often larger than mandated to manage
Procedural barriers: • Lack of tools and guidelines • Lack mechanism to determine appropriate scale and stakes for processes	**Attitudinal barriers:** • Other political priorities might outweigh holistic approaches • Challenges achieving multi-stakeholder consensus • Bias in social assessments
	Knowledge barriers: • Poor research on many aspects of social-ecological system

3.4.4.1 Internal barriers

The difficulty experts faced agreeing on a common definition for many of the concepts and terms of carrying capacity illustrates the conceptual barriers that prevent its consistent application and implementation in decision-making. Indeed, many of the CC concepts and terms have had variable use in different contexts (for a review, see Weitzman & Filgueira, 2020), leading to confusion around what is being measured and why. During interviews, several experts expressed that many approaches incorporate CC but do not exclusively label them in such terms. The best practices in this study suggest that greater guidance on providing definitions that are context-based, user-generated and specific may reduce confusion and improve the ease of applying holistic CC assessments. In addition, defining the scale-domain early in the CC process can clarify the role of the assessment and guide the indicator selection. Emphasis on scoping during carrying capacity assessments is integral to creating a common language among stakeholders and can reduce confusion about the goals of the assessment.

Experts also identified procedural barriers that stem from a lack of adequate processes to apply a holistic framework for carrying capacity. While aquaculture decision-making is embracing more holistic management approaches, this has been largely done in a very piecemeal way, often lacking integration and/or coordination. To help address procedural barriers, this framework presented a practical step-wise process for conducing CC assessments in a more holistic way. In addition, the considerations for engaging stakeholders, choosing relevant indicators, and selecting appropriate tools may create some consistency in the procedures for holistic aquaculture CC.

3.4.4.2 External barriers

While carrying capacity has long been employed in aquaculture decision-making (Weitzman & Filgueira, 2020), experts voiced that poor knowledge and lack of data creates *knowledge barriers* to implementing a more holistic approach to CC. During Round 2, experts highly endorsed the need for more research on the societal benefits and risks of aquaculture (93.3% agreement), and social perceptions (87.5% agreement). Several experts advocated approaches that focus on the social aspects of aquaculture, seeing this aspect as critical roadblock in questions about sustainability. As one expert explained, "Science is great at performing an autopsy. It's not so great at keeping the patient alive.". Yet, practical definitions of social carrying capacity are still in their infancy (Kluger & Filgueira, 2020; Smaal & Van Duren, 2019) and there is not yet a consensus on available indicators or thresholds. In addition, experts identified that moving forward with a more holistic approach to carrying capacity in line with an ecosystem approach to aquaculture would require research to prioritize understanding both aquaculture's impacts on the environment beyond the farm-scale (81.3% agreement) and assess the cumulative effects of aquaculture of multiple farms in an area (100% agreement). Yet, the added complexity of incorporating multiple scales and considering a larger array of indicators requires a greater understanding of the system, which is not often well-known.

In addition, experts identified that institutional barriers exist due to underlying governance structures are often not suited to holistic management. The EAA is a holistic, wide concept which rarely fits in within rigid and siloed legislative frameworks. This makes it extremely challenging to create practical steps when there is no overlying structure of how to manage cooperatively or assess impacts cumulatively. Another challenge emerges as governments or industry often only collect or monitor information limited to legislative requirements, missing much appropriate information to answer holistic questions. In addition, many areas do not have permanent or regular monitoring program for many key indicators or elements. For example, Canada's Aquaculture Monitoring Standard only requires operators to consistently monitor benthic indicators on salmon farms (DFO, 2018). Finally, implementing a holistic approach based on the EAA stimulates conversations about social and environmental well-being beyond the realm of aquaculture, but deal with wider global food systems and a cumulative view of managing for the environment. Only in some jurisdictions are ideas around Integrated coastal zone management (ICZM) and Marine Spatial Planning (MSP) starting to become operational (e.g., Collie et al., 2012; European Commission, 1999; Nowlan, 2015; Tiller et al., 2012). In conclusion, re-structuring of governance mechanisms may be necessary to fully implement a holistic CC approach in line with the EAA. As a result, a practical approach to holistic CC may have to work with existing management structures which may be inherently unsuited to implement a broader view of governance.

Effective multi-stakeholder carrying capacity assessments may also face attitudinal barriers stemming from different values and priorities, and conflicting agendas and biases. For example, buy-in from involved stakeholders and governments will be critical for the successful implementation of the CC process but has been a persistent challenge to more holistic approaches to management (e.g., Gelcich et al., 2018). In some cases, implementing a holistic approach or changing the status-quo may not be a political priority. Other challenges stem from the inherent potential for bias and personal agendas in approaches to assess social aspects. For example, in some cases, social research may capture the views of a small number of powerful and vocal individuals or groups, potentially misrepresenting the majority views (e.g., Mustafaraj et al., 2011). Personal agendas and political interests make multi-stakeholder processes complex and difficult to achieve consensus or set a common vision on priorities, indicators and selecting thresholds. As a result, highly participatory and interdisciplinary CC assessments will be inherently more complex and challenging to implement.

3.4.4.3 Logistical barriers

Implementing an interdisciplinary, adaptive, and participatory systems-approach to CC capacity will undoubtedly be time, resource, and expertise-intensive. To minimize this internal barrier, this study has presented several tools that may be suitable when data and/or resources are limited. Yet, governments often lack the capacity (adequate funding or resources) to effectively understand, manage, or monitor for all the components of a holistic approach. During this study, experts often highlighted the need to balance cost and data availability when selecting appropriate indicators and tools. Still, governments may need to invest additional funding and resources into making more comprehensive CC assessments a reality. In this way, logistical challenges will continue to pose an external barrier to comprehensive assessments of carrying capacity. Logistical barriers such as these are indeed common to implementing any new approach and have been a persistent challenge to implementing the EAA (Brugère et al., 2018).

3.5 CONCLUSIONS

While several recent studies have contributed to the debate on carrying capacity for aquaculture (Kluger & Filgueira, 2020; Smaal & Van Duren, 2019; Weitzman & Filgueira, 2020), this is the first to generate consensus on best evaluative practices for holistic assessment of aquaculture CC. This study developed a series of guiding principles, recommendations, and considerations among a panel of diverse and experienced researchers and practitioners. The proposed step-wise process is best utilized in combination with recommendations and considerations for a shared framework for CC assessments. This study was limited to a primarily Western expertise, focusing on marine fish cage-culture systems, recognizing that these assessments and issues are highly variable with different types of aquaculture. Yet, the guidance provided in this paper was synthesized to reflect very broad-scale considerations for further development of a common framework for holistic CC of aquaculture. Since the process would depend highly on the context and local conditions, a strict protocol is not appropriate. How outputs contribute to practical decisions in the policy process (such as informing licensing or planning decisions) would need to be adjusted to reflect local conditions, environments, and cultured species. It should be emphasized that local contexts, conditions, and governance factors are critical, and that these best practices should guide framework development adapted to specific national, or regional contexts to be more useful in decision-making.

With growing policy recognition for more systems-perspectives decision-making for aquaculture, a holistic framework for CC could offer governments and decision-makers a strong tool to support more sustainable aquaculture management and planning. The general framework shares commonalities with existing holistic planning frameworks (e.g., ICZM, MSP), and consequently could be applied to assess CC in relation to other management problems. Yet, the implementation of holistic CC within decision-making may continue to be challenged by external factors including lack of knowledge, the influence of attitudes and political buy-in, and ill-equipped governance structures. Thus, more critical discussions on how aquaculture is allocated with governance systems and how decisions are made regarding management of food systems will continue to be an important step towards more holistic and sustainable aquaculture.

CHAPTER 4: KEY FACTORS DRIVING PUBLIC OPINION OF SALMON AQUACULTURE

The overall goal of this chapter is to understand differences in perceptions among the general public across Nova Scotia and to identify the most influential factors influencing positive or negative opinions of aquaculture. This chapter investigates the role of multiple variables on attitudes, utilizing ordinal regression models to identify the most relevant variables.

This research was approved by Dalhousie Research Ethics Board (REB file # 2020-5070) and followed all ethical protocols, including participant anonymity and confidentiality. Appendix C also provides recruitment documents, including recruitment materials (C.1-C.2), consent page (
C.3) and research documents including survey (C.4), and survey results (C.5-C.8). A map showing the distribution of survey results across Nova Scotia is provided in Appendix C.9

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Please note that this chapter appears exactly as it did in the published journal article.

4.1 ABSTRACT

Salmon farming has become a controversial topic, with public opposition and conflicts challenging the sustainability of the sector. As a result, a deeper understanding of public perceptions and factors influencing opinions becomes critical for developing sustainable and socially acceptable aquaculture. Based on previous social acceptance literature, this research aimed to investigate the influence of potential motivators on opinion towards salmon aquaculture. In a case study of rural and urban Nova Scotians, 495 people provided their perceptions of salmon aquaculture. Moreover, geographical factors, socio-demographics, and contextual factors were investigated. Geographic differences in factors and attitudes across urban and rural groups suggest an important mediating influence of residence type (urban and rural) on opinion. Ordinal regression analysis found that opinion was primarily influenced by individual characteristics and perceptual variables, i.e., age, environmental value orientation, salmon consumption patterns, perception of risks, and trust in government. Of minor importance were exposure and knowledge of salmon farming. The model indicates respondents who are older, have strong relational values with the ocean, high perception of risks and are distrustful of government are more likely to express negative attitudes towards aquaculture. This study emphasizes the need to recognize that opinion is nuanced, and deeply socially situated, based not only on individual trade-offs between economic benefits and environmental risks, but also on environmental values and relationships and trust regarding how aquaculture is managed. Further, this study highlights the importance of building public trust with decision-makers, along with continued mitigation of risks, in fostering more socially acceptable salmon aquaculture.

4.2 INTRODUCTION

Over the last 20 years, aquaculture has been the fastest growing food production sector. Since 2013, farmed salmon has become the largest single fish commodity by value (FAO, 2020a). However, the rapid expansion of salmon aquaculture has raised several concerns for the public, and in many places has become controversial (Young et al., 2019; Osmundsen & Olsen, 2017). The sustainability of the sector thus relies on integrated approaches to governance and management that consider interacting environmental, economic, and social aspects (Costa-Pierce, 2010; Soto et al., 2008). Understanding the social risks and benefits of aquaculture operations is relatively understudied but is increasingly considered necessary to make more informed decisions about development in ocean spaces (Krause et al., 2020; Ruiz-Chico et al., 2020a). Yet, a crucial part of achieving social sustainability requires that stakeholders, communities, and the public perceive aquaculture to be socially acceptable.

Previous studies have started to investigate social acceptance towards aquaculture through public perception research aimed to understand differences in negative and positive opinions. Many of these studies report an overall low awareness, and primarily positive perception of salmon aquaculture by the general public (Feucht & Zander, 2017; Froehlich et al., 2017), although opposition and conflicts have been reported across local communities, environmental NGO and stakeholders in salmon farming areas (e.g., Fløysand et al., 2016; Salgado et al., 2015). Previous perception research has begun to recognize geographic variability in attitudes at national and regional levels (e.g., Flaherty et al., 2019; Froehlich et al., 2017). Still, much existent survey research aims to provide representative overviews of public attitudes at regional and/or national spatial resolutions (e.g., Hynes et al., 2018; Ruiz-Chico et al., 2020a), and are often based around large urban centres removed from salmon farming operations. However, much of the policy debate and conflict around aquaculture occur at the local level, often in rural coastal communities. As a result, previous research may not fully capture the views and perspectives of those most vocal against salmon farming, or those living in rural areas where salmon farming is taking place. As different regions capture different socio-demographic and contextual settings, it becomes important to include diverse settings in understanding opposition and social acceptability of aquaculture.

Through the concept of social acceptance, this study takes an exploratory approach to understanding determinants of public opinions towards salmon aquaculture. While there is growing insight on public attitudes towards aquaculture, few empirical studies have explored the basis for and the factors influencing opinion, especially among opponents. This study aims to address this gap by assessing public perceptions of salmon farming across urban and rural areas and explore the main factors influencing opinion using Nova Scotia, Canada as a case study. Nova Scotia was chosen since it has several salmon farms across coastal rural areas.

Nova Scotia is also one of Canada's most rural provinces, with 43% of Nova Scotians in 2016 residing in rural communities with populations less than 1,000 (Statistics Canada, 2017). Government commitment to the development of the industry is quite strong and recently there has been interest in expansion. However, strong opposition has been present (Young & Matthews, 2010), and disputes over regulation, management, and sustainability have been prominent since the early 2000s (Kraly et al., 2022). Thus, salmon farming in Nova Scotia presents a valuable case study for exploring opposition and investigating social acceptance and its drivers. By identifying key variables influencing opinion, this study can offer insight into developing a conceptual framework for understanding social acceptance in aquaculture.

4.2.1 Social acceptance and potential influencing factors

In a policy setting, social acceptance is often defined to reflect public support towards projects, but is used as an umbrella term to reflect overall positive opinions of groups of individuals, and to differentiate between supporters and opponents. Social acceptance has been widely studied across a range of environmental sectors, including energy (e.g., Ribeiro et al., 2018; Wüstenhagen et al., 2007), mining (e.g., Mercer-Mapstone et al., 2017; Moffat & Zhang, 2014), water recycling (Ross et al., 2014), waste treatment (Milutinovic et al., 2016), and recently aquaculture (Bailey & Eggereide, 2020; Dalton & Jin, 2018; Hynes et al., 2018; Ruiz-Chico et al., 2020a). Previous authors have offered multiple conceptual frameworks for social acceptance (for a review, see Cohen et al., 2014), although none currently exist for aquaculture. For example, Devine-Wright (2008) recognizes three categories of factors influencing acceptance, including personal (demographics), social-psychological (perception and experiences) and contextual (siting, development). The present study draws from existing conceptual frameworks across other resource sectors, combined with insight from perception research in aquaculture to explore potential factors on the acceptance, or opinion, towards aquaculture.

A review of literature suggests that a combination of external conditions, individual characteristics, and attitudinal factors could influence opinion towards aquaculture (Dalton & Jin, 2018), although few studies have empirically investigated these associations. First, the geographic location of individuals may influence their opinion on aquaculture (Berenguer et al., 2005; Dalton & Jin, 2018). For example, previous research found that urban population have higher levels of environmental concern than rural residents (e.g., Stigka et al., 2014; Yu, 2014). In many cases, rural residents are often more directly affected by projects like aquaculture and have previously been found to have more resistance to projects in their area, a condition colloquially known as the NIMBY (Not In My Backyard) effect (Ertör & Ortega-Cerdà, 2015; Froehlich et al., 2017).

Second, individual traits, including socio-demographics such as gender and age have a long empirical tradition for explaining environmental attitudes and concern in multiple sectors (Dietz et al., 1998; Zelezny et al., 2000). Some studies have found that age, education, and employment have had some influence on opinion towards aquaculture (e.g., Hynes et al., 2018; Krøvel et al., 2019; Thomas et al., 2018). Likewise, differences in opinion about aquaculture have been observed across gender and income levels in Spain (Ruiz-Chico et al., 2020b).

Third, according to the "Value-Belief-Norm" (Stern, 2000) model of environmental behaviours, attitudinal factors include individual values, referring to a guiding principle and/or measure, associated with a given worldview or cultural context that denotes a preference for a particular state of the world (Pascual et al., 2017). Over the years, values have been linked to environmental behaviours (Dietz et al., 2005), and remain a focus of studies in resource and management sectors (e.g., Gatersleben et al., 2014; Kreller, 2021). For example, the New Ecological Paradigm (NEP) is a commonly applied scale used to measure environmental concern through a series of value statements (Dunlap, 2008). Yet, different types of values can be identified. *Instrumental* values are values attributed to the environment to achieve a particular end of use (Pascual et al., 2017). Comparatively, *intrinsic* values relate to the inherent value that the environment has independent of any human evaluation. These values have recently been distinguished from *relational* values, which arise a result of a relationship with the environment (witnessing, enjoying, using etc.) encompassing sense of place, feelings of well-being, and cultural or personal identities (Chan et al. 2016; Pascual et al. 2017).

Fourth, previous experiences and engagement with aquaculture can influence acceptance. In technology applications for wind and hydrogen power, studies have found positive relationships between knowledge and acceptance (Huijts et al., 2012). Experiences might make individuals more familiar with technologies, as some studies found that those living close to existing developments are more likely to be supportive (e.g., Van der Horst, 2007). Likewise, Hynes et al. (2018) suggest that more positive perceptions, and greater knowledge of aquaculture in Norway compared to Ireland may be due to higher familiarity and exposure with the industry. In contrast, Sinner et al. (2020) found that individuals who had more engagement with finfish aquaculture in New Zealand had lower acceptability.

Fifth, the relationship between trust, risk, and acceptance has been well explored in risk communication literature related to new technologies and water management (Huijts et al., 2012; Ross et al. 2014). Trust has been found to increase overall acceptance in technology applications (Huijts et al., 2012) and resource sectors such as mining (Mercer-Maptone et al., 2018; Moffat & Zhang, 2014). Lack of trust towards government and industry has been considered the basis for many conflicts in aquaculture, especially at the local level (e.g., Bailey & Eggereide, 2020; Mazur & Curtis, 2006).

Finally, public perceptions towards risks and benefits have long been a well-established factor influencing opinions and acceptance in environmental issues (Huijts et al., 2012; Ross et al., 2014). Likewise, public attitudes and stakeholder support for aquaculture expansion have been linked to perceptions towards environmental and economic risks (e.g., Chu et al., 2010; Bailey & Eggereide, 2020; Freeman et al., 2012; Whitmarsh & Palmieri, 2009). Furthermore, concerns over a multitude of environmental, social, economic, and political risks about salmon aquaculture have been consistently reported in the media, ranging from concerns over disease and parasites, interactions with wild salmon populations, adequate public consultation, to regulation and policy oversight, among others (Kraly et al., 2022; Olsen & Osmundsen, 2017; Rickard et al., 2018).

4.2.2 Research objectives

This exploratory research seeks to further the understanding of aquaculture opposition and its drivers by investigating how public perceptions vary across potential explanatory variables.

The overall objective of this study is to identify potential factors of public opinion of salmon farming. This work is guided by three overall research questions:

1. What are the prominent public perceptions of salmon farming and potential variables influencing opinion?
2. Are there differences in perception variables between urban and rural areas?
3. In what ways do perception variables influence negative opinions of salmon farming?

4.3 METHODS

4.3.1 Data collection

Perceptions about aquaculture were collected via a public survey conducted across Nova Scotia over a four-month period from May 1 to August 31, 2020 (Dalhousie Research Ethics Board file # 2020-5070). The research design purposefully sought to reflect the opinion of an interested sample of the public and capture negative views of aquaculture. This study was exploratory in nature, and thus the target population included individuals with an interest in, and opinion of, salmon farming in Nova Scotia. Therefore, the results of this survey were meant to capture views of a population with formed opinions to aquaculture in Nova Scotia, and not to be representative of all Nova Scotians. The survey was hosted online with the software Opinio (survey software hosted by Dalhousie University). Internet-based surveys are common in social science research and have been used previously to investigate perceptions towards aquaculture (e.g., Alexander et al., 2018; Chu et al., 2010).

A multi-modal recruitment strategy combining advertisements across social media, flyers, newspapers, and social-network mailing lists was employed to attain representativeness of an interested and informed target population. This survey recruited participants opportunistically through semi-regular announcements (about every two weeks) on multiple social media platforms (Facebook, Instagram, Twitter). In recent years, social media has become a common platform for public discussions around controversial issues (Marres & Moats, 2015), including aquaculture, and thus a suitable platform to recruit an interested target population. Social media recruitment also enabled social sharing/snowballing to reach a broader audience of interested population. In addition, multiple local, professional and society groups (for example, local environmental non-profit organizations) were invited to advertise the survey in their mailing lists to access a larger volume of relevant potential respondents. Finally, advertisement flyers in high-traffic areas (city of Halifax, and Dartmouth, Nova Scotia) and local news outlets supplemented recruitment to reach a broader geographic and demographic audience. While online surveys have sampling and data integrity limitations (Page Hocevar & Flanagin, 2017), internet-based surveys are beneficial for exploratory research since they can capture special interest groups (Lehdonvirta et al., 2021), making this approach desirable for capturing and analyzing negative views.

The survey consisted of 21 questions, featuring Likert-scale questions (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree), polar questions featuring a neutral option (yes, no, don't know), and categorical questions (Appendix C.5). A total of 495 respondents (over the age of 18, living mostly full-time (94.9% of participants) in Nova Scotia) completed the survey voluntarily and anonymously. The sample was stratified into two populations based on place of residence (urban or rural). A sample of 267 for urban and 228 for rural allowed a 95% confidence of +/- 6.0% and +/- 6.5% accuracy in survey results respectively. All questions were answered by more than 97% of participants, except four questions related to socio-demographics (Appendix C.6).

4.3.2 Variables explored

Public opinion of salmon farming was used as a corollary to explore social acceptance, and was measured across three items. First, participants rated their general opinion on salmon farming from very negative to very positive. Then, participants were asked to state their level of agreement regarding their support for salmon farming development in Nova Scotia, and finally, their perception of the trade-offs between benefits and impacts.

The explanatory variables were selected to reflect the effect of potential motivators of acceptance in the literature, as described in section 4.2.1 (For full list, see Appendix C.5). The effect of location was measured with geographic variables including coastal living habits (distance of home to the ocean and ocean visibility) and place of residence (urban or rural). The effect of individual characteristics on opinion were explored through several demographic variables (age, gender, education, and household income) and employment in a marine sector. The effect of personal value system was explored by eliciting the level of agreement of participants towards a series of 13 statements representing two intrinsic, two instrumental, and 7 relational values, in addition to two well-tested statements from the New Ecological Paradigm scale (Dunlap, 2000). To test the effect of familiarity and exposure on opinion, participants self-rated their interest in, and knowledge about aquaculture. Exposure included both local fish farm exposure (visited farm or have a salmon farm where they live) and fish consumption patterns (degree of fish consumption and choice of salmon). The effect of trust was tested by investigating the confidence of respondents towards three key actors involved in aquaculture management: regulators (government), salmon farming companies, and the scientific community. Finally, to explore the effect of perceived risks from aquaculture, participants were asked to rate whether they think aquaculture creates negative or positive impacts on 16 socio-economic and ecological issues.

4.3.3 Data analysis

Results were analyzed using SPSS (version 27). Descriptive statistics provided summaries of participant responses to variables tested. Principal Components Analysis (PCA) was employed to understand the distinctiveness of environmental value orientation among participants. Visualization of a scree plot and calculation of eigenvalues over 1 were used to select the components that explain how the data are clustered (Cattell, 1966; Tabachnick & Fidell, 2007). To ensure the data was likely factorizable, the overall Kaiser-Meyer-Olkin (KMO) measure and Bartlett test of sphericity were calculated. A Varimax orthogonal rotation was employed to aid interpretability, forcing variables into the relevant components (Thurstone, 1947). Geographic differences among perception variables were tested with non-parametric chi-square tests of homogeneity and Mann-Whitney U tests (Appendix C.7), with post-hoc analysis using z-tests of proportions with Bonferroni correction. The level of significance was set at 0.05 for all statistical tests.

The potential influence of explanatory variables was explored by calculating association coefficients for Somers' D (for ordinal measures), Cramer's V (for categorical measures), and Kendall's Tau-b (for continuous measures). In addition, Mann-Whitney U and Kruskall-Wallis tests were calculated to identify group differences among variables. Then, ordinal regression models were fit to predict negative opinions towards salmon aquaculture based on several explanatory variables and identify the most influential explanatory variables on opinion. All variables with significant associations and group differences were selected as potential model variables. Variables were sequentially eliminated based on significant p-values (< 0.05) and lowest Akaike Information Criterion (AIC) to find the most parsimonious model that best predicts negative opinions to salmon aquaculture. For the conciseness of the paper, only the model with the best-fit is explained below.

4.4 RESULTS

4.4.1 Descriptive analysis – comparing perceptions

4.4.1.1 Location characteristics

The geographic distribution of respondents revealed a tendency towards coastal living habits (**Table 4.1**). Coastal living was especially prominent among rural respondents ($p < 0.05$), with a statistically higher proportion of rural respondents with an ocean view (57.5%; $p < 0.05$) and those who lived at, or within 500 metres of the ocean (59.6%; $p < 0.017$).

Table 4.1 Summary of participant characteristics (N = 495). Asterisks indicate statistically significant differences in proportions between urban and rural responses with p values < 0.05.

	Variables	Category	% Urban (n = 267)	% Rural (n = 228)
Location characteristics				
*	Ocean visible from home	Yes	39.1	57.5
		No	60.9	42.5
*	Distance of home to ocean	Within 500 metres	31.9	59.6
		500 m to 1 km	26.2	7.9
		More than 1 km	41.2	32.4
Individual characteristics				
	Gender	Female	58.9	56.2
		Male	41.1	43.8
*	Age	18 - 34	37.3	10.5
		35 - 54	24.2	20.0
		55 and older	38.5	69.5
	Education	High school or less	8.2	7.9
		Secondary degree	55.1	58.8
		Post secondary or professional degree	38.2	29.4
	Annual household income (CAD)	$39,000 or less	19.1	16.2
		$40,000 to $79,000	30.3	30.3
		Above $80,000	38.2	29.4
	Employment in a marine sector	Yes	39.0	34.6
		No	61.0	65.4

4.4.1.2 Individual characteristics

Demographics of the two samples were similar (**Table 4.1**), except for a significant difference in age distribution ($p < 0.05$), with statistically significant higher proportion of rural respondents over 55, and higher proportion of urban individuals between 18 and 24 ($p < 0.017$). Most respondents had some form of post-secondary education, many holding advanced degrees (30.8% of participants). More than one third (35.6%) of respondents reported an annual household income (in CAD$) above $80,000. Over a third (37%) of participants indicated that they or an immediate family member were employed in a marine sector, including primarily fishing (38%) and marine research (28%), but also marine conservation, aquaculture, and coastal tourism, among several others (Appendix C.6).

4.4.1.3 Values orientation

To explore the effect of personal value system on opinion, respondents rated their level of agreement surrounding 13 value statements about the ocean (**Figure 4.1**), with only a few statements with statistical differences between urban and rural groups (Appendix C.7). There was general consensus on the importance of personal relationships with the ocean, with 84% or more of participants agreeing with all relational value statements. In addition, respondents generally favoured the intrinsic right of nature to exist over the intrinsic right of humans to modify the ocean. Yet, many respondents also believed in the instrumental value of the ocean related to supporting economic development.

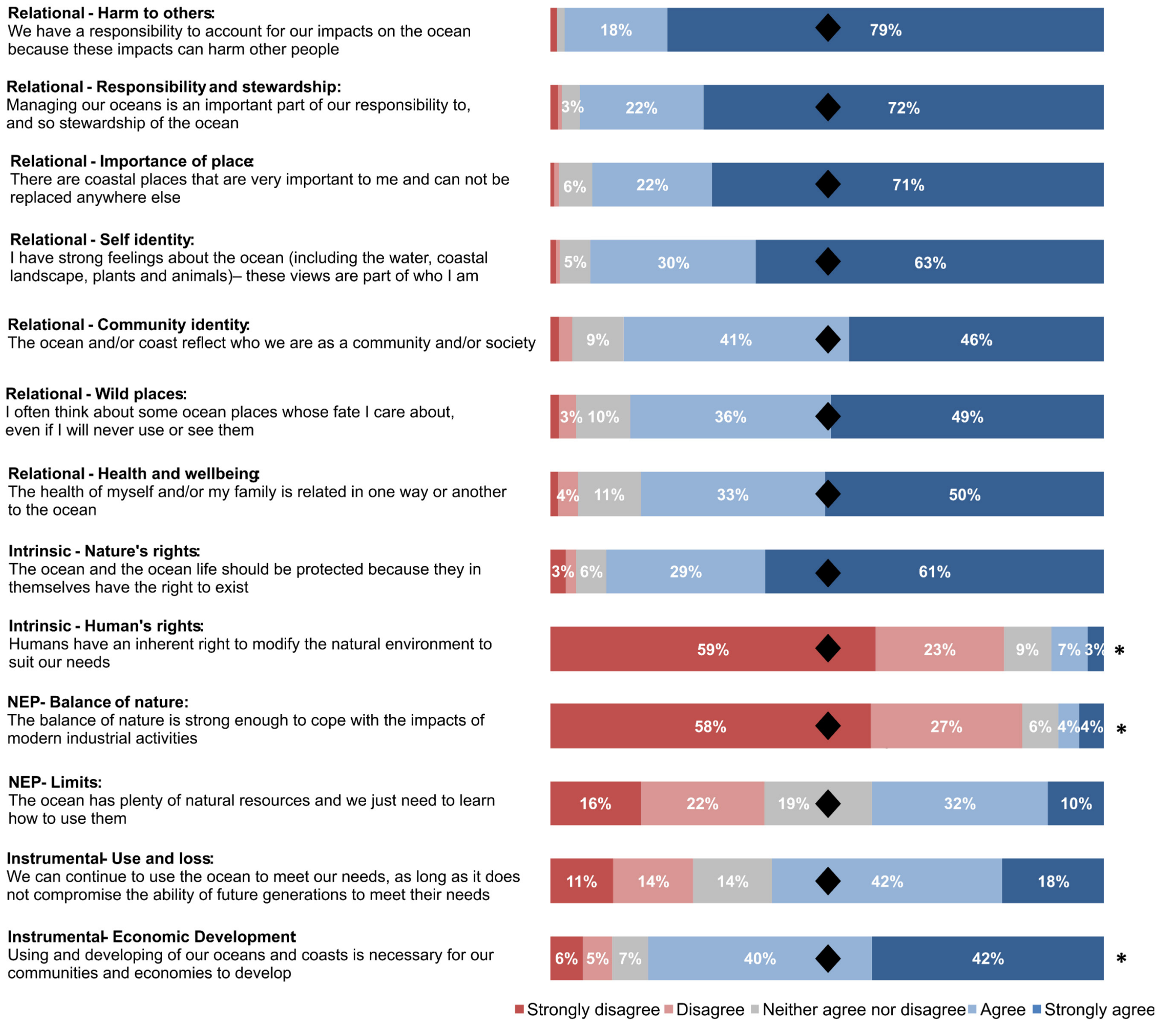


Figure 4.1 Respondent ratings towards various value statements about the ocean. Diamonds indicate median responses. Asterisks indicate significant differences between urban and rural groups ($p < 0.05$). Note: mentions of 2% or less are shown as coloured bars.

A Principal components analysis (PCA) was run on value statement responses (see **Figure 4.1**) to explore and identify patterns in how people value the ocean. PCA results were validated through inspection of the correlation matrix (all items had at least one correlation coefficient greater than 0.3), a KMO measure of 0.841 and statistically significant Bartlett test of sphericity ($p < 0.001$). The PCA revealed two distinct components relating to how participants sorted their values about the ocean, accounting for 52.8% of the total variance (**Table 4.2**). The interpretation of the data was consistent with different value types people hold towards the ocean, with relational values emphasizing the relationship with the ocean strongly loading on

Component 1 ("Relationship"), and instrumental and NEP values, emphasizing the human use of the ocean, strongly loading on Component 2 ("Use").

Table 4.2 Results of a rotated Principal Components Analysis (PCA) on 12-items, showing loading coefficients for each item on two extracted components (from N=475 participants). Blanks represent non-significant component loadings (< 0.3).

Items (Values)*	**Components**	
	Relationship	Use
Relational - Self identity	.811	
Relational - Harm to other people	.784	
Relational - Responsibility and stewardship	.733	
Relational - Importance of place	.726	
Relational - Wild places	.726	
Relational - Health and well-being	.690	
Intrinsic - Nature's rights	.606	
Instrumental - Economic development		.817
NEP - Limits of nature		.696
Instrumental - Use and loss		.673
NEP - Balance of nature		.667
Intrinsic - Human's rights		.573
Eigenvalues	4.06	2.28
% of variance	33.8%	19.0%
Cumulative %		52.8%

*The value statement about the relational value on community identity was removed since it had a communality measure < 0.3, indicating it is poorly related to other items (Tabachnick & Fidell, 2007).

4.4.1.4. Familiarity and exposure to aquaculture

Participants expressed moderate levels of knowledge about salmon farming, yet relatively high levels of interest in learning more about it (**Figure 4.2**). In general, respondents from rural areas believed they were more knowledgeable than urban respondents ($p < 0.05$). Both urban and rural participants want to learn more about aquaculture, with no statistical difference between groups (Mann U = 27915.5, $p = 0.241$). Respondents obtain information about salmon farming from multiple sources (Appendix C.6), with environmental NGOs and scientists being the most frequently reported sources. Still, news, government, and industry were also referenced by over 50% of respondents.

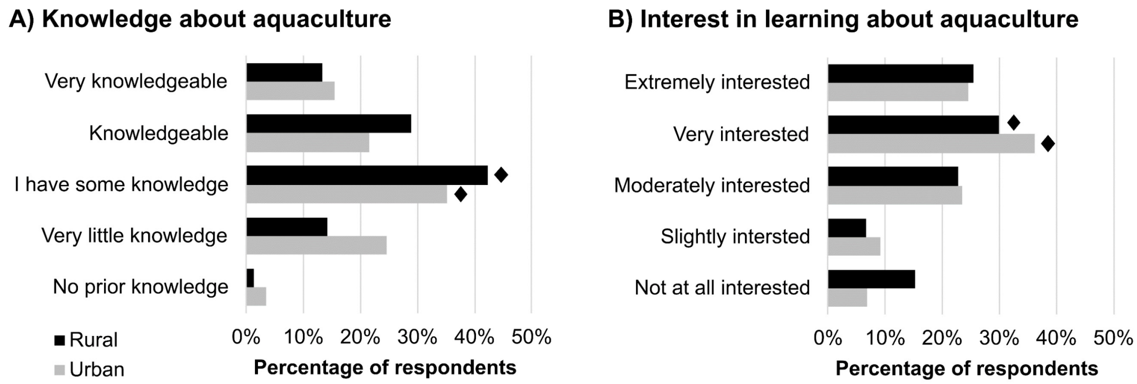


Figure 4.2 Urban and rural respondents reported A) degree of existing knowledge about salmon farming (n = 491) and B) degree of interest (n = 490) in learning more. Diamonds represent median values.

Both urban and rural respondents consume fish on a regular basis, with over half (55.2%) eating fish once a week or more (**Figure 4.3A**). There was no difference in the proportions of fish consumption patterns among urban and rural participants ($p = 0.494$). More than half (55.4%) of participants consume wild-caught salmon, but only one-quarter consume farmed salmon (25.3%) (**Figure 4.3B**). Generally, more urban participants (32.7%) consumed farmed fish compared to rural participants (16.7%), a significant difference in proportions ($p < 0.05$). Over one quarter (26.0%) of respondents do not eat salmon.

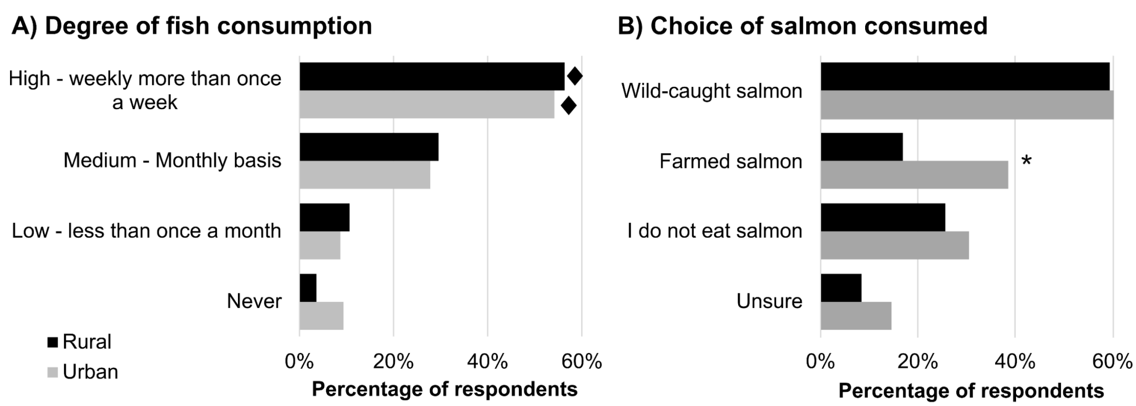


Figure 4.3 Consumption patterns of urban and rural respondents based on A) how often respondents eat fish (n = 494) and B) whether respondents eat different types of salmon (n = 495). Diamonds indicate median response. Asterisks represent significant differences in proportions ($p < 0.05$) between urban and rural respondents.

Almost half of the respondents live in salmon-farming communities (42.9%) (Appendix C.7). A larger proportion of rural respondents (60%) live with salmon farms in their area, compared to only 28.0% of urban respondents ($p < 0.05$). Still, many urban respondents were unaware of whether their area had a farm (28.4%). Further, approximately 57% of participants had never visited a salmon farm, independent of location ($p = 0.984$).

4.4.1.5. Trust

To examine the relative level of trust of respondents towards actors, respondents were asked to rate how they felt towards statements concerning the status of scientific understanding, government management, and industry accountability (**Figure 4.4**). Overall, most respondents did not think there is sufficient scientific understanding of the industry's impacts, with no statistically significant difference between urban and rural respondents (Mann U = 31813.0, $p = 0.055$). Most respondents were distrustful of both government and industry, which was more pronounced among rural respondents compared to urban respondents ($p < 0.05$).

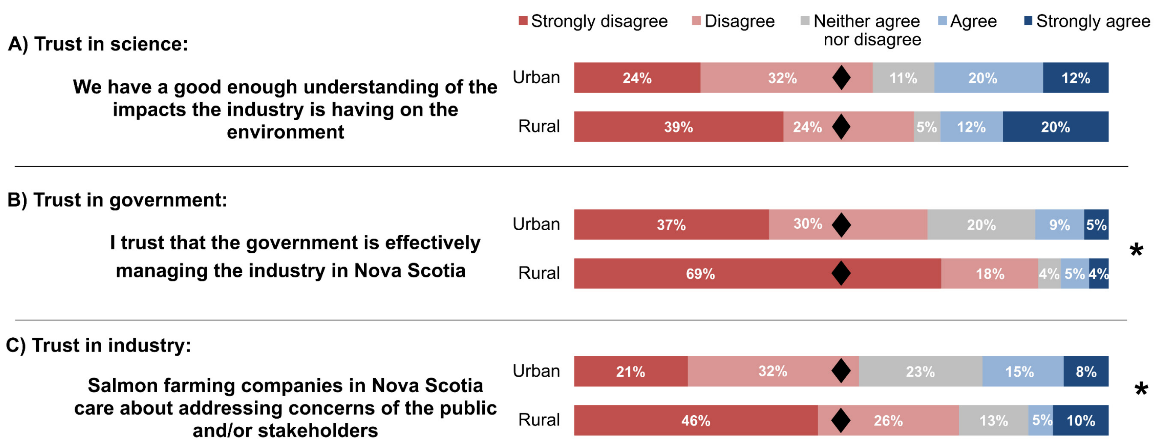


Figure 4.4 Response of rural and urban respondents to statements related their trust in A) Science, B) government, and C) industry related to salmon farming (n=484). Diamonds indicate median response, while asterisks indicate statistically significant differences between respondents ($p < 0.05$). The original phrasing for A and C were reversed for clarity.

4.4.1.6. Perceived risks

Participants were asked to rate whether they believed aquaculture had a positive or negative effect on various aspects of the social, economic, and ecological environment (For full ratings, see Appendix C.7). Across most ecological and socio-economic aspects, respondents perceived primarily negative impacts due to aquaculture (**Figure 4.5**). Positive impacts were predominant only regarding how aquaculture provides towards employment and income (44.0% positive), and for its contribution to Nova Scotian and/or Canadian economy (40.1% positive). For all aspects, significantly more rural participants perceived negative impacts from aquaculture than urban (**Figure 4.5**; $p < 0.05$). Given the similarity in responses across impacts, a new variable was generated representing the average response across all perceived impacts. This new scale had adequate internal consistency, measured by a Chronbach's alpha of 0.962, where alpha values above 0.7 indicate that the set of items measure the same concept or dimension (DeVellis, 2003).

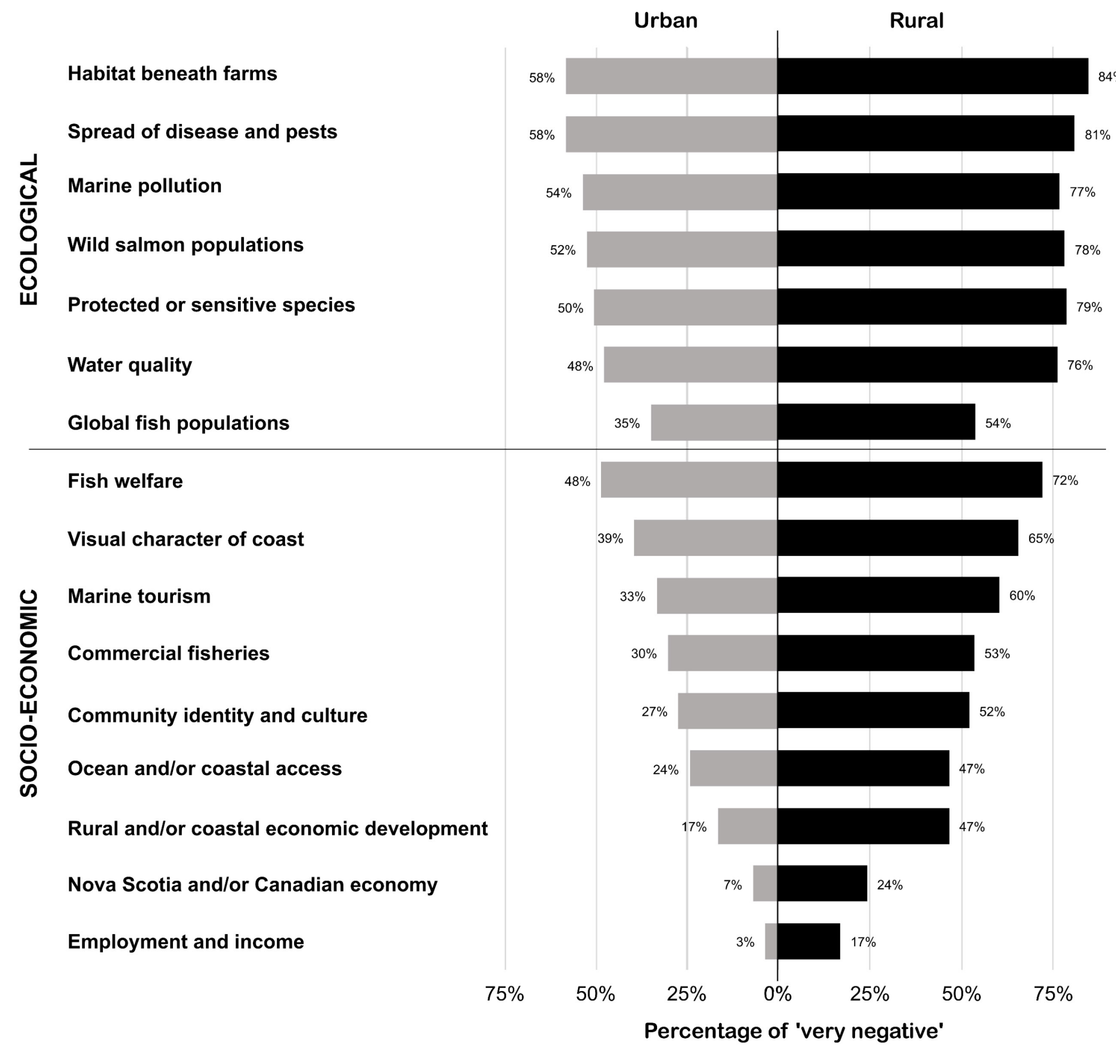


Figure 4.5 Percentage of urban and rural respondents perceiving "very negative" impacts of salmon aquaculture on various socio-economic and environmental aspects.

4.4.2. Opinions of salmon farming and their drivers

4.4.2.1 Acceptability of aquaculture

Respondents had predominantly negative views of salmon farming across all opinion variables (**Figure 4.6**). Differences in how urban and rural respondents view aquaculture were significant across all opinion measures, with more negative views in rural participants ($p < 0.05$). A high Chronbach's alpha (0.940) indicates that general opinion, development of the industry, and trade-offs all adequately measure the same phenomenon (i.e., social acceptance).

Given the similarity in participant responses, responses to general opinion of salmon farming (**Figure 4.6A**) were used for exploratory analysis.

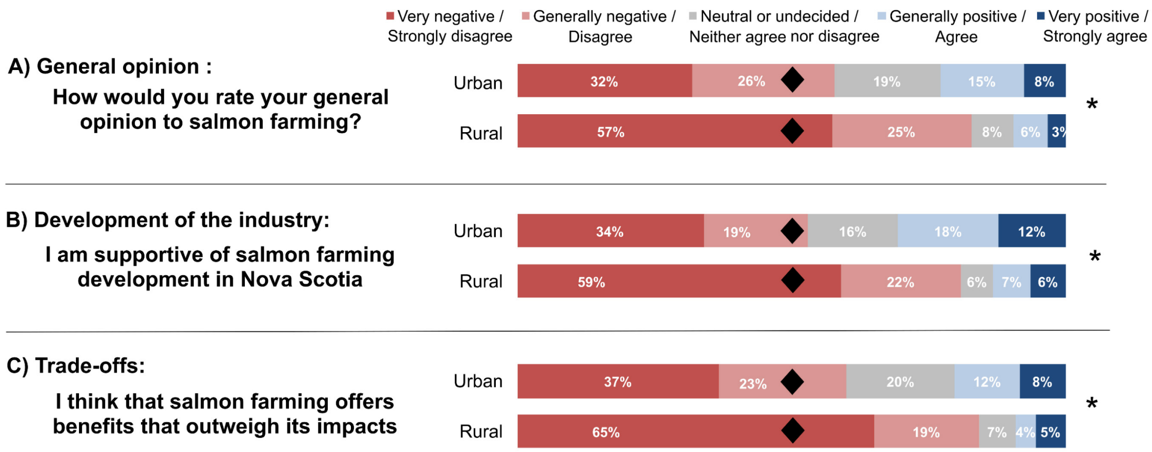
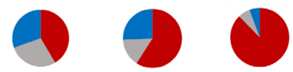
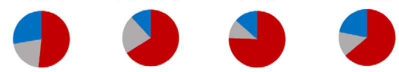
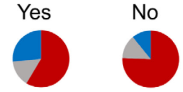
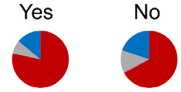
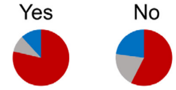
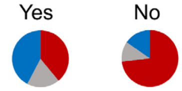
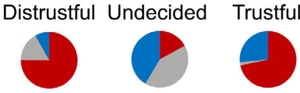
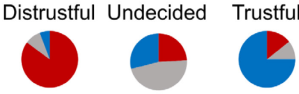
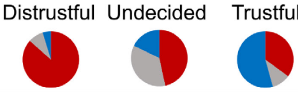


Figure 4.6 Urban and rural respondents' ratings towards variables measuring opinion to salmon farming (n = 485). Diamonds indicate median responses, while asterisks denote a statistically significant difference between groups ($p < 0.05$) Note: two levels of legends based on wording of questions.

4.4.2.2 Identifying factors influencing opinion

To explore the influence of explanatory variables on public opinion, measures of group differences association were calculated (**Table 4.3**; Appendix C.8). Opinion varied significantly across many explanatory variables, but not always between all groups within the variable. For example, public opinion was similar across both moderately and highly knowledgeable respondents, with post-hoc analysis revealing significant differences in opinion scores only between poor knowledge and moderate/high knowledge levels ($p < 0.001$). In addition, public opinion was similar for respondents who were distrustful and trustful of science, but significantly different compared to undecided individuals ($p < 0.001$). Along with identifying group differences, measures of association provide a preliminary indication of the level of influence of explanatory variables on opinion. Six variables had weak levels of association (> 0.2), indicating that variables may have a small influence on opinion. Ten variables had moderate associations with opinion and are considered those most relevant for understanding opinion.

Table 4.3 Opinion response across various explanatory variable, with coefficients of association (n = 485). Only variables with significant associations and group differences are displayed ($p < 0.05$). Bolded values highlight associations above 0.2 (below which are considered negligible as per Prion & Haerling, 2014). Asterisks indicate continuous variables, so levels are not displayed.

Variable	Association (d, τ_b, or V)	% Opinion by levels (Negative / Neutral / Positive)
Effect of location		
Residence type	**0.268**	Urban, Rural 
Effect of individual characteristics		
Age	**-0.342**	18-34, 34-54, Over 55 
Gender	0.185	Male, Female 
Income	0.128	< 20k, 20-39k, 40-79k, >80k 
Employment	**0.211**	Yes, No 
Effect of personal value system*		
'Relationship' value scores	**-0.255**	
'Use' value scores	**0.405**	
Effect of familiarity and exposure		
Aquaculture knowledge	-0.124	Low, Medium, High 
Interest in learning*	0.169	
Living in salmon farm community	0.126	Yes, No 
Wild salmon consumption	**-0.227**	Yes, No 
Farmed salmon consumption	**0.428**	Yes, No 
Effect of trust		
Trust in science	0.126	Distrustful, Undecided, Trustful 
Trust in government	**0.666**	Distrustful, Undecided, Trustful 
Trust in industry	**0.454**	Distrustful, Undecided, Trustful 
Effect of perceived risk*		
Perceived risks	**-0.593**	

A cumulative odds ordinal logistic regression with proportional odds was run to identify the most prominent drivers of opinion on aquaculture (measured from positive to negative). All 16 explanatory variables from **Table 4.3** were originally modelled, and subsequently removed to find the most parsimonious model that identified the most important acceptance factors (**Table 4.4**). The final best-fit model to the observed data ($\chi2(877) = 355.749$, $p = 0.406$) significantly predicted the dependent variable over and above the intercept-only model ($\chi2(9) = 377.360$, $p < 0.001$). The assumption of proportional odds was met (i.e., that each independent variable has an identical effect at each cumulative split of the dependent variable), as assessed by a full likelihood ratio test ($\chi2(9) = 13.492$, $p = 0.142$). Tests to see if the data met the assumption of collinearity indicated that multicollinearity was not a concern (for all variables, Tolerance > 0.1, VIF < 10). While many cells were sparse with zero frequencies (66.7%), the model adequately explained negative opinions of aquaculture, accounting for 70.7% of the variance (Nagelkerke R^2).

Table 4.4 Cumulative odds ordinal regression statistics for the prediction of negative opinions to aquaculture based on seven explanatory variables (N = 447).

Explanatory variable	Levels	Odds Ratio	95% Confidence Interval	
			Lower	Upper
Age				
	18 to 34	0.375*	0.183	0.770
	35 to 54	0.362*	0.162	0.808
	Over 55	1		
"Relationship" value scores		1.438*	1.042	1.985
"Use" value scores		0.585*	0.395	0.866
Wild salmon consumption				
	Yes	2.244*	1.173	4.291
	No	1		
Farmed salmon consumption				
	Yes	0.289***	0.149	0.559
	No	1		
Trust in Government				
	Distrustful	3.166*	1.128	8.887
	Undecided	1.527	0.535	4.357
	Trustful	1		
Perceived risks		6.621***	3.985	11.000

*p < 0.05, ** p < 0.01, *** p < 0.001

Seven explanatory variables had statistically significant effects on the prediction towards public opinions of salmon farming, including: age, "relational" value scores, "human use" value score, wild salmon consumption pattern, farmed salmon consumption pattern, trust in government, and perceived risks (**Table 4.4**). Age was inversely associated with opinion, with young (18-34) and middle-aged (35-54) individuals 62.5% and 63.8%, respectively, less likely to have negative opinions of aquaculture than participants over 55. An increase in resonance for "relationship" values was associated with an increase in the odds of considering salmon farming to be more negative. In contrast, an increase in resonance towards "use" values was associated with more positive opinions (**Table 4.3**), and a significant decrease in the odds of feeling more negative towards salmon farming. Farmed salmon consumption was inversely associated with opinion (**Table 4.3**), with farmed salmon consumers being 71.1% less likely to have more negative opinions than those who do not eat farmed salmon. Comparatively, wild salmon consumers were 2.244 times as likely to hold more negative opinions towards aquaculture than those that do not eat wild salmon. Trust in government was a significant variable influencing opinion, with those distrustful of the government being 3.166 times as likely to hold more negative opinions of aquaculture compared to those who are trustful of government. The odds of those who were undecided about their trust in the government feeling more negative towards aquaculture was similar to that of those are trustful of government (odds ratio =1.527 (95% CI, 0.535 to 4.357, p = 0.429). Higher average perception of aquaculture risks was associated an increase in the odds of considering salmon farming to be more negative.

4.5 DISCUSSION

This study assessed public perceptions of aquaculture to investigate opinions on salmon farming and identify the most relevant factors predicting public opposition. This research presents one of few survey methodologies to gauge general public opinion and is one of few to empirically explore a range of potential perception variables for aquaculture (e.g., Freeman et al., 2012; Krøvel et al., 2019). This stands apart from earlier public perception research that has focused on analysing public opinion by consumers (e.g., Ruiz-Chico et al., 2020a,b; Whitmarsh &Palmieri, 2011) or through media portrayals (e.g., Froehlich et al., 2017;

Osmundsen & Olsen, 2017; Thomas et al., 2018). Using a case study of Nova Scotia, Canada, these results reflect a sample of the population that was largely in opposition, both towards salmon aquaculture as an industry and towards local development in the province. This is consistent with negative public perceptions of salmon farming reported across Canada (e.g., Flaherty et al., 2019; Kraly et al., 2022), despite positive opinions being common across other salmon-producing countries (Froehlich et al., 2017). Findings from this research embody the perspectives of a specific portion of the population and should not be interpreted to represent all Nova Scotians. Although respondent demographics were consistent with age and gender distributions across urban and rural Nova Scotia, respondents exhibited higher education and income levels than the demographic distribution of Nova Scotia. Findings also represent a primarily coastal demographic, with nearly half of respondents having ocean views. Furthermore, while salmon farms are only present in a few areas across Nova Scotia, nearly half of respondents lived in communities with exposure to salmon farms and responses were characterised by those who were knowledgeable about aquaculture. Since this research aimed to investigate potential motivators and reasons for opposition, the study was purposefully designed to capture the views of an interested population. As a result, the non-probabilistic online survey approach taken was a suitable method for exploratory research of this nature, acknowledging and incorporating self-selection and other sampling biases of the method (Lehdonvirta et al., 2021).

This research is one of the first to investigate how public perceptions of salmon farming vary spatially between urban and rural areas. Findings show that people living in urban areas were more supportive of salmon aquaculture than people from rural areas. While greater opposition in rural population is consistent with what is often considered a NIMBY (not in my backyard) perspective, these findings show that urban and rural differences are difficult to interpret on their own, but rather reflect an amalgamation of a more nuanced, diverse set of features across values, trust, demographics, and perceptions. Therefore, opponents in rural areas should not necessarily be labelled as "NIMBYs", as it is an overly simplistic, and sometimes pejoratively applied concept to capture the diverse views represented (Devine-Wright, 2009). Urban respondents were generally younger, supportive of instrumental values, more likely to consume farmed salmon, and had greater recognition of economic benefits from aquaculture. Rural respondents were generally older, had significantly more negative perception of risks, and lower levels of trust towards government and industry than urban respondents. Familiarity was also directly related to geographic area as rural respondents had higher exposure to salmon farms in their area, and perceived greater levels of knowledge about aquaculture than urban respondents. These findings reflect other social acceptance literature that demonstrates significant differences between urban and rural communities (e.g., Stigka et al., 2014). These findings suggest that attitudes to aquaculture vary spatially, although residence type was not a significant predictor in the regression analysis. Therefore, this suggests that place of residence is not an ultimate driver of opinion, but rather reflect an amalgamation of other acceptance factors and reflect different social and demographic contexts of populations. Likewise, other authors argue that geographic location is indirectly associated with opinion by reflecting the external physical, economic, and social features of an individual's surrounding (Berenguer et al., 2005; Dalton a& Jin, 2018). Therefore, residence type may not be a suitable explanatory variable for opinion but can still act as an indicator to reflect the different characteristics of the individuals living there. This underscores the importance of including both urban and rural perspectives in understanding public social acceptability and navigating aquaculture conflicts.

Age was a significant predictor of opinion, with younger age groups (18-34 and 34-54) having more positive opinions towards salmon farming than older (above 55) individuals, 87.7% of whom had negative opinions. While previous studies have found that age influenced opinion of aquaculture (Krøvel et al., 2019; Thomas et al., 2018), these studies found that older people had more positive opinions. These findings may partly reflect other social, demographic, and geographic variabilities in responses, as age distribution varied significantly across urban and rural groups. Another potential explanation for more negative opinions among older individuals draws on the concept of "Shifting Baseline Syndrome", whereby each generation perceives the state of the ecosystem in their childhood as normal (Pauly, 1995). This has been argued to explain generational differences in attitudes towards environmental changes across a range of issues, such as fisheries science, climate change, and conservation (Soga & Gaston, 2018). Since salmon farming in Nova Scotia was minimal until the 1990s and 2000s, older individuals would have grown up in the absence of salmon farms as part of their baseline norm. Given that younger people were more likely to support aquaculture, opinions of aquaculture may slowly improve in the future. However, preferences and perceptions are not static, meaning continual research and monitoring is required if acceptability is to be implemented into aquaculture governance.

While social values are increasingly being studied to investigate opinions towards environmental policy issues such as energy technologies (e.g., Johansson & Laike, 2007) and climate change (e.g., Nilsson & Biel, 2008), this study was the first to explore the connection between personal value systems and acceptability in aquaculture. Participants exhibited a strong resonance for a relational connection with the ocean and coast, reinforcing studies from other sectors that maintain that perceptions are often mediated by relational values associated with the relationships of people with each other and their environment (Chan et al., 2016; Klain et al., 2017). Concurrently, an anthropocentric perspective, whereby nature is valued because of benefits it can provide humans, was apparent by participants who agreed on the instrumental values of the ocean, especially to support economic development. The ordinal regression model revealed that the likelihood of opposing salmon aquaculture increased with higher perceptions of the "relationships" values provided by the ocean but decreased with higher perception of the "use" values of the ocean. The strong influence of both value types on opinion maintains ongoing arguments considering multiple social values as an essential part of environmental management and decision-making (Arias-Arévalo et al., 2017; Ives & Kendal, 2014; Pascual et al., 2017). At the same time, it also highlights the need to further investigate how other personal motivations such as sense of identity (e.g., Gatersleben et al., 2014), goals, and personal or social norms (Huijts et al., 2012) may influence opinions of aquaculture.

While opinion varies in response to individual characteristics, social acceptance is often discussed in terms of contextual variables reflecting individual attitudes regarding their experiences and perceptions of salmon farming. Experience with salmon as a food product was an important driver of acceptance, with salmon consumption patterns significantly predicting opinion among respondents. While consumer studies have long identified a market segmentation between consumption of wild and farmed salmon, this study further points to the relationship between social acceptance and purchasing behaviours. In recent years, consumer purchasing behaviours have been linked to perceived environmental performance, which has been argued as more important than aspects such as quality (Bronnmann & Asche, 2017; Whitmarsh & Palmieri, 2011). This could identify a potential role for market-based governance mechanisms such as eco-certification to help improve public perception of farmed products (e.g., shellfish; Gray et al., 2021). However, certifications may not fully capture concerns about aquaculture, especially among local stakeholders (Weitzman & Bailey, 2018). For example, salmon consumption choice and patterns have also been linked to moral and ethical concerns over fish production methods, including issues of trust and concerns about nature (Schlag & Ystgaard, 2013). Regardless, these findings suggest that understanding social acceptance is not only relevant for policy and development but also has implications for consumer behaviours and market acceptance.

This study found only a marginal effect of other experience variables like aquaculture exposure and knowledge on opinion. Negative opinions were somewhat more prominent among respondents living in communities with exposure to salmon farms, consistent with findings from other salmon-farming areas (e.g., Katranidis et al., 2003). However, this variable was not included in the final regression model, indicating that other factors are more important in influencing attitudes towards aquaculture, which follows mixed results on the influence of geographic proximity on acceptance (e.g., Johansson & Laike, 2007; Warren et al., 2005). It also highlights the potential oversimplification of NIMBY perspectives in explaining opposition to aquaculture. In fact, some scholars have proposed evaluating spatial patterns of acceptance to emotional and psychological attachment to a specific location rather than exposure per se (Devine-Wright, 2009).

Regarding knowledge, it has been assumed that knowledge leads to more positive opinions, with communication and education about aquaculture often being promoted to improve social acceptability (Kaiser & Stead, 2002; Thomas et al., 2018). Yet, this study found high levels of perceived knowledge associated with both positive and negative opinions of aquaculture. Furthermore, visiting a salmon farm had no influence on opinion, despite many respondents (42.6%) reported having had visited a farm. As a result, strategies for improving public trust and opinion focusing solely on increasing exposure and knowledge for aquaculture may not be sufficient. Nevertheless, education efforts may still be valuable at helping individuals decide about aquaculture, as the percentage of respondents feeling neutral of aquaculture decreased with increasing knowledge. These findings support a potential indirect, moderating effect of knowledge and experience on public opinion (e.g., Huijts et al. 2012), although the relationship between familiarity and other factors requires further investigation.

Overall, trust played a role on opinion to aquaculture, with distrust in government being a significant predictor of negative opinions. Likewise, other studies have emphasized poor trust in government as an important conflict in aquaculture, highlighting changes to regulatory and management processes as a priority (Carr, 2019; Mazur & Curtis, 2006; Salgado et al., 2015). Findings from this study suggest that public conflict, and therefore social acceptance, is deeply intertwined with environmental justice concerns related to aquaculture decision-making processes (Ertör & Ortega-Cerdà, 2015). The significance of trust in governance and procedural justice in social acceptance are also consistent across other areas such as renewable energy technology (Segreto et al., 2020) and mining (Moffat & Zhang, 2014). As a result, efforts to both understand the factors that influence trust and improve government trust may be necessary for improved acceptance of aquaculture. In addition, this might require a shift beyond a current emphasis on government-led approaches to aquaculture governance. For example, stakeholders have criticized the dual role of the government as both regulator and promoter in Canada (Maxwell & Filgueira, 2020; Rigby et al., 2017). Poor confidence in state-led governance of aquaculture has led to a rise in private governance mechanisms such as third-party certification (Bush et al., 2013), as well as an interest in greater community empowerment. Institutional settings that can accommodate interests and influence of beyond-government actors may therefore open avenues for managing conflicts and improving trust (Vince & Haward, 2017).

Finally, respondents had an overall high negative perception of ecological and social risks, which was a strong predictor of opinions to salmon farming. Most respondents felt salmon farming created multiple ecological risks, but most prominently to the habitat beneath farms, spread of disease and pests, for sensitive species and wild salmon populations, which is consistent with reported issues portrayed in the Canadian media (e.g., Kraly et al., 2022; Weitzman & Bailey, 2019). Findings were also consistent with other studies that have found that diverse aspects of environmental risk and justice considerations contribute to opposition (e.g., Ertör & Ortega-Cerdà, 2015). Yet, respondents also identified several socio-economic risks such as negative impacts to the visual character of the coast, coastal access, and risks to coastal tourism and capture fisheries. Likewise, socio-economic concerns over area-use conflicts and distribution of socio-economic benefits have been identified by stakeholders in other parts of the world (e.g., Bailey & Eggereide, 2020; Krøvel et al., 2019). Despite overall negative perceptions, results indicate a recognition of positive economic benefits, highlighting the continued priority for minimizing environmental risks but also maintaining economic benefits (Whitmarsh & Palmieri, 2011; Whitmarsh & Wattage, 2006). These findings continue to illustrate that attitudes to aquaculture are largely influenced by a nuanced perception of trade-offs in the weight people attach to economic benefits against perceived environmental degradation (e.g., Chu et al., 2010; Krøvel et al., 2019). Continued research, improved management and practices, and heightened communication of multiple risks and benefits will likely be important for sustainable and socially acceptable aquaculture.

4.6 CONCLUSIONS

This study investigated social acceptability of salmon farming by exploring a range of variables to test what shapes negative public opinion of aquaculture, using Nova Scotia as a case study. To our knowledge, this is the first study to explore how public opposition unfolds geographically across such small spatial resolutions rather than focusing on local case studies or media portrayals. Findings suggest that public opinion of aquaculture is mediated by a variety of geographic conditions, individual characteristics, and context-dependent variables. The formation of attitudes is therefore nuanced, with influencing factors being diversified and dependent on local contexts (Fournis & Fortin, 2017). The ordinal regression model identified the variables having the largest influence towards more negative opinions of salmon farming, indicating that opinion can largely be predicted through a combination of socio-demographic characteristics, values, salmon consumption patterns and perception of risks and how they are managed. Importantly, this study is the first to document the influence of ecosystem values on aquaculture perceptions, supporting findings in the energy sector suggesting that worldviews and values are one of the most important predictors of attitudes (e.g. Sposato & Hampl, 2018). Opposition to aquaculture is therefore dependent not only on perception of risks but also reflects individual constructs like value systems, and perceptions of how aquaculture is implemented (i.e., trust in actors). This study highlights the importance of recognizing that social acceptability of aquaculture is multi-faceted, and deeply socially situated. Further examination into how geographic, individual, perceptual, and socio-demographic factors interact to shape opinion is needed to better understand the nature of social acceptance of aquaculture. Still, given the emerging field of social acceptance of aquaculture, these findings offer new insights into key variables that could support future development of a conceptual framework for social acceptance in aquaculture. Since this study comprises a biased subset of the population, inferences about raw perception data should not be generalized. Similar research designs could, however, be valuable for understanding public opinion and social acceptance across other types of aquaculture or other marine resource-based sectors. In conclusion, policy and decision-makers aiming to foster more sustainable salmon aquaculture that is socially acceptable may consider the trade-offs between environmental, social and economic effects, addressing issues of trust, and catering solutions to reflect local and potentially divergent societal values.

CHAPTER 5: THE ROLE OF CONTEXTUAL FACTORS ON LOCAL PERCEPTIONS OF SALMON AQUACULTURE

The overall goal of this chapter is to understand perceptions among local stakeholders in three salmon-farming communities in Nova Scotia, and the influence of those perceptions on their attitude towards salmon farming. This chapter aims to investigate differences between local case study areas and explore the role of context in shaping perceptions. This cross-case analysis was subsequently used to identify factors that influence those perceptions and attitudes.

This research was approved by Dalhousie Research Ethics Board (REB file # 2020-5071) and followed all ethical protocols, including participant anonymity and confidentiality. A methodological flowchart outlining this study can be found in Appendix D.1. Appendix D also provides recruitment documents, including recruitment e-mail (D.2) and the research summary and consent document (D.3), and research documents including questionnaire (D.4), interview schedule (D.5), and detailed coding results (D.6-D.8). Appendix D.9 presents additional information from secondary data sources which were used in building case studies to contextualize interviews but were not included in publication due to publication length constraints. Appendix D.10 provides a summary of key findings from questionnaire data used to contextualize interview responses.

Citation:

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Please note that this chapter appears exactly as it was submitted for the journal article currently under review.

5.1 ABSTRACT

While aquaculture continues to grow worldwide, environmental and social challenges have made its sustainability an important public issue. Thus, understanding social aspects of aquaculture, including community perceptions and attitudes can help inform more sustainable decision-making. While existing literature identifies spatial differences in opinions across areas, the role of context in shaping and influencing perceptions and attitudes has not been empirically explored. This research aims to fill this gap through a case study comparison of perceptions and preferences towards marine salmon farming in three rural salmon-farming communities in Nova Scotia, Canada where the industry has both been present, and publicly controversial. Qualitative interviews illustrate a complex discourse around salmon farming, with arguments, conflicts, and perceptions manifesting differently across each case study area. Differences across areas support ongoing arguments on the importance of considering local contexts in understanding social acceptance. Comparative analysis of perceptions across case study areas suggests that participants evaluate aquaculture based on different histories and experiences, values and beliefs, and relationships with place unique to their area. These findings have broader implications for understanding how attitudes towards aquaculture form and can help guide decision-makers in planning for societally endorsed and equitable aquaculture.

5.2 INTRODUCTION

Aquaculture is one of the fastest-growing global food industries, with production expected to at least double by 2050 (Pernet & Browman, 2021). Yet the rapid growth of the industry has spurred environmental and social challenges and thus the sustainability of the sector has become an important public issue. Social aspects of aquaculture have become important considerations in the management of aquaculture, especially in line with the United Nations (UN) Sustainable Development Goals (UN, 2015), "Blue Growth" (FAO, 2015), and ecosystem-based management approaches (Krause et al., 2020). Still, social aspects of aquaculture have only recently been investigated in the literature, largely focusing on consumer preferences (e.g., Whitmarsh & Palmieri, 2011), media portrayals (e.g., Froehlich et al., 2017;

Kraly et al., 2022), and perceptions of stakeholder groups (e.g., Hynes et al., 2018; Thomas et al., 2018). At the general level, public opinion surveys suggest public support in many countries (e.g., Froehlich et al., 2017). At the local level, however, conflicts and opposition have been reported in many salmon farming areas (e.g., Maxwell & Filgueira, 2020; Salgado et al., 2015), creating controversy that may challenge the development of the sector (Young et al., 2019). This mismatch in opinion emphasizes the distinction between the public and local residents and stakeholders, who are most directly affected by local developments. Therefore, a focus on community perceptions is particularly relevant for understanding potential social impacts of aquaculture.

As social research in aquaculture is relatively new, existing research has focused more on describing the perceptions of aquaculture rather than providing substantive explanations of what motivates and influences perceptions. Previous empirical research suggests the importance of individual factors such as perceived risks and benefits, knowledge, and trust on perceptions towards aquaculture (Hynes et al., 2018; Mazur & Curtis, 2008; Sinner et al., 2020). Other studies have alluded to the relevance of other factors including community values, economic conditions, and the performance of other industries (Banta & Gibbs, 2009; Kaiser & Stead, 2002). These studies highlight the complexity of factors motivating the formation of attitudes, often recognized to be diversified, dynamic, and dependent on both individual and local contextual factors (Wüstenhagen et al., 2007).

While empirical research studying the role of contextual factors on perceptions has been common in other sectors (e.g., energy; Wiersma & Devine-Wright, 2014), few studies have explored the ways that these factors shape, motivate, and influence perceptions and opinions towards aquaculture. This research uses case studies from salmon farming in Nova Scotia, Canada to examine the attitudes towards salmon farming across three rural areas including communities around Digby, Shelburne, and Liverpool to investigate factors associated with those attitudes. Social responses to aquaculture are explored in the context of different histories of the industry, demographic and economic characteristics, and personal or shared values. This research sought to answer two primary questions:

1. How do participants in three rural areas in Nova Scotia perceive salmon farming in their areas?

2. How do contextual factors contribute to perceptions of salmon farming?

Comparing priorities, preferences, and perceptions of three different salmon farming areas can help identify key patterns in social acceptance that occur in different contexts and build a stronger understanding of how public response to aquaculture unfolds in local communities where the industry is present.

5.3 METHODS

Conducted from an interpretivist perspective (Schwartz-Shea & Yanow, 2013), this research was designed as a multiple case study comparison (Yin, 2009) involving data collected from participants across three salmon farming areas in the western region of Nova Scotia, Canada (**Figure 5.1**). The multiple case study approach was chosen as it is valuable for building theory and providing rich contextual data (Stake, 2006). To enhance the validity and credibility of results, multiple measures were used to triangulate relevant themes and observations (Yin, 2009), including questionnaires and interviews (primary data), as well as secondary data sources (documents and media) (Appendix D.1). The community-studies were chosen because many aquaculture conflicts occur and are mobilized at a community level, and although public attitudes are certainly important and have been studied, exploring contextual drivers of perceptions fits better with a local approach. The case study sites described below were selected since they are all coastal rural communities where salmon farming has operated for at least 20 years and where conflicts around salmon aquaculture have been debated in public forums and media, as well as mobilized by organized advocacy groups. Yet, sites were chosen due to a pre-supposition that they have different experiences with, and ultimately attitudes towards salmon aquaculture.

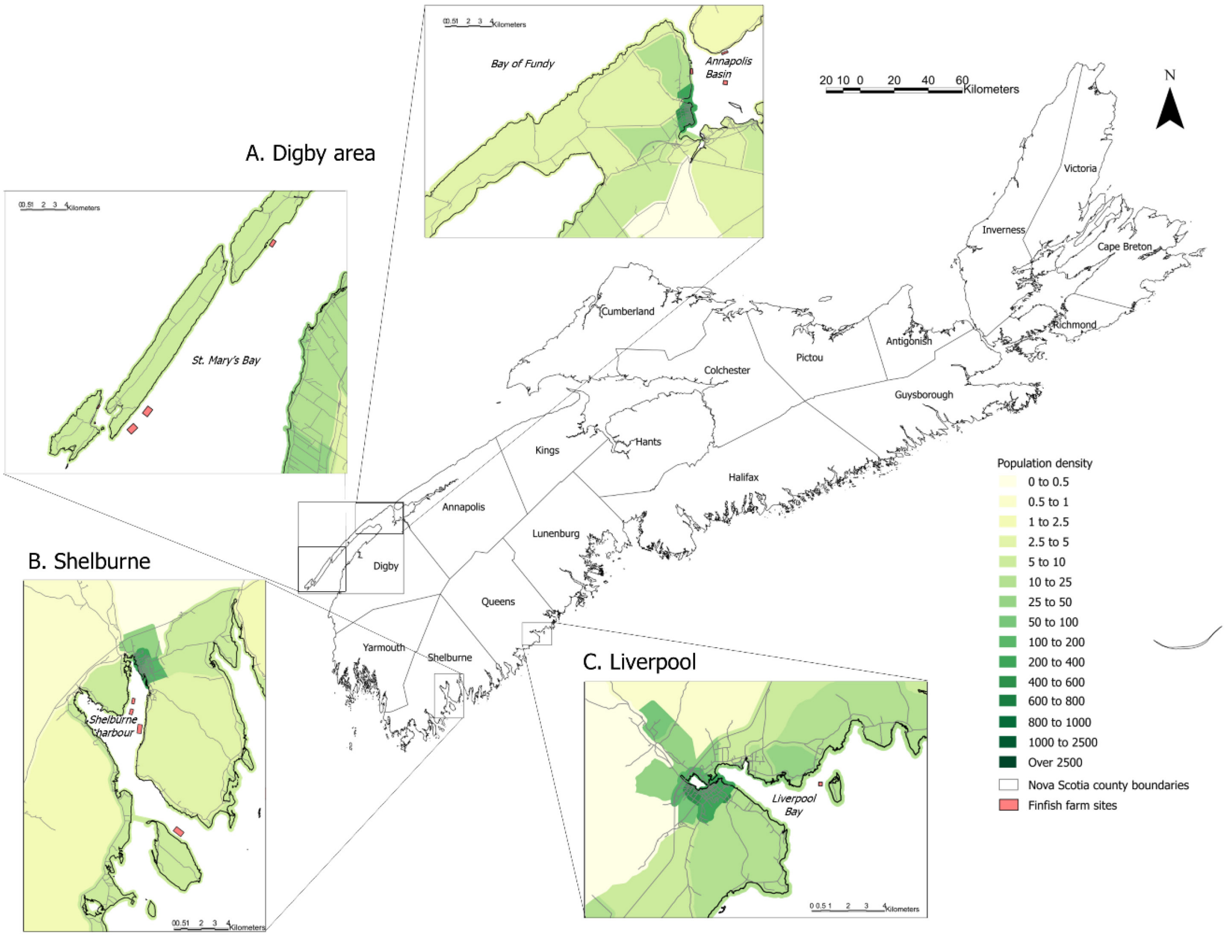

Figure 5.1 Map of case study regions (inserts), showing population densities (per square kilometre) and location of salmon farms within the case study areas: A) Digby area, B) Shelburne, and C) Liverpool. Population density obtained from boundary open data and final counts from Canadian 2016 Census.

This study was conducted between May to October 2020 with ethics approval from Dalhousie University (REB#2020-5071), applying a qualitative approach drawing from semi-structured interviews and questionnaires with 24 participants in three salmon farming areas in Nova Scotia: Digby (9), Liverpool (7), and Shelburne (8). This study applied purposeful participant selection to identify individuals with distinct views and experiences of aquaculture, and diverse interests in aquaculture, including residents (8), local (municipal) government officials (6), members of community and environmental interest groups (4), commercial fishers (3), and tourism and business operators (3). The interviews were performed one-on-one via a phone or video-call and lasted about one and a half hours.

The interview questions drew on previous understanding of factors influencing perceptions in both the aquaculture literature (e.g., Mazur & Curtis, 2008; Whitmarsh & Palmieri, 2009) and other resource sectors (e.g., Moffat & Zhang, 2014), as well as social conflicts expressed in the media (e.g., Kraly et al., 2022). The participants were guided through four sections of questions (**Table 5.1**), beginning with a discussion around the participant's backgrounds, including their connections to the ocean and priorities for coastal development. Second, questions explored participants' experiences with, and understanding of, the current aquaculture industry, including feelings about engagement and their relationships with industry and government. Third, perceptions around various potential risks and benefits of salmon aquaculture captured the perceived challenges and opportunities of the industry. Finally, questions around participant preferences and priorities for aquaculture development in the area explored specific attitudes towards aquaculture.

Table 5.1 Relevant topics guiding questionnaire and interview discussions.

Section	**Topic**
Background and priorities	Introduction with participant
	Importance of coastal and ocean spaces
	Priorities for coastal development in area
Experiences and interactions	Degree of interaction with industry
	Stakeholder engagement and communications
	Trust of industry and government
	Knowledge of salmon aquaculture
Industry perceptions	Overall opinion towards aquaculture
	Perceptions of risks and benefits
Future of the industry	Development options for the industry
	Improvements and paths forward

A probing questionnaire was first distributed that consisted of closed survey questions to get participants to consider specific topics under each key area and offer additional detail to interview responses. The interviews then guided participants through a series of open-ended questions, allowing the participants to bring up new issues or topics. The interviews were audio-recorded with prior consent from the participants and manually transcribed, assigning numeric identification codes to transcripts for anonymity of the participants.

Once the interviews were transcribed, a combination of deductive and inductive coding was carried out using NVivo 12 PRO. First, initial coding segmented groups of text into deductive codes based on the questionnaire topics and open coding based on emergent themes and patterns, without trying to limit or narrow the list of codes (Van den Hoonard, 2012). Second, the previous coding was re-examined with a more descriptive lens to identify themes that linked topics across case study areas. Third, coding was re-refined by creating a descriptive matrix comparing themes across case study areas to reveal nuances in topics and themes across areas. Themes were further refined by drawing on case study data including secondary data and questionnaires (Appendix D.9).

5.3.1 Background and study site

5.3.1.1 Aquaculture in Nova Scotia

The aquaculture industry in Nova Scotia includes a variety of finfish and shellfish species and has grown in tonnage and value since the mid-1990s driven largely by increased markets for high-value species such as Atlantic salmon. In 2020, salmon production in Nova Scotia was valued at $68.7 million, contributing 76% of the total value of aquaculture products in the province (Province of Nova Scotia, n.d). While salmon farming gradually increased throughout the 2000s, a moratorium in 2013 prohibited the installation of new finfish and shellfish farms in Nova Scotia. Following subsequent regulatory changes, the moratorium was lifted for finfish farms in 2017, while no new sites have yet been approved. In 2020, there were 36 licensed ocean finfish aquaculture sites across Nova Scotia, employing a total of 288 full and part-time employees Province of Nova Scotia, n.d).

5.3.1.2 Case study descriptions

The case study locations represent areas where salmon farming has been operating for over 20 years but have different intensities of salmon farming and histories with the industry (**Table 5.2**).

Table 5.2 Socio-demographic and salmon farming characteristics present in each case study area. Statistics from 2021 Census.

	Digby		Shelburne		Liverpool	
	Town of Digby	Municipality of the District of Digby	Town of Shelburne	Municipality of the District of Shelburne	Liverpool	Region of Queens Municipality
Population size	2001	7242	1644	4336	2546	10422
Land area (square km)	3.16	1654.59	8.75	1816.71	3.59	2387.52
Population density (per square km)	634	4.4	187.9	2.4	708.5	4.4
Population % change (2016 to 2021)	-2.9	1.9	-5.7	1.1	-0.1	1.2
Median age	55.2	53.6	50.8	54.4	53.2	55.6
First salmon farm	1995		1991		2000	
Number of active leases	8		4		1	
Size of lease (hectares)	1.5 to 42.2		8 to 28		4	

The Digby area is in Western Nova Scotia, and includes the historic Town of Digby, and the rural communities within the Municipality of the District of Digby. Strong tidal currents (tidal range of about 22 feet) bring in abundant plankton communities, making the area prime for large aggregations of birds and large marine mammals such as whales. Historically, the Digby area has relied on traditional industries including fishing and forestry, and is situated within Canada's most lucrative lobster fishing zones. Digby is also a popular international tourist destination, famous for its scallops, whale watching, and drawing people into its natural beauty and historic villages that have remained largely unchanged. The geographical area of Digby is the most active for salmon farming in the province, which have been operating since the mid-1990s.

Shelburne Harbour is a deep harbor nestled in Nova Scotia's South Shore region. Nearby population centers include the Town of Shelburne and numerous small rural communities within the Municipality of the District of Shelburne. The coastline along the bay consists of wetlands, beaches, and salt marshes that provide ideal habitat for migratory birds, including the endangered Piping Plover. Shelburne Harbour hosts moderate tides (7.9 foot tidal range), and is considered one of the world's best natural harbors, providing safe ice-free passage for a number of vessels. Employment in the Shelburne area is primarily fishing, as Shelburne

Harbour provides port access to Nova Scotia's second-largest lobster fishing zone. The Town of Shelburne is a historic area, with many buildings dating back to when Loyalist settlers arrived in 1783. Salmon farming first began in Shelburne Harbour in the 1990s, with three small sites operating near the Town of Shelburne by 2000.

Liverpool Bay is located on Nova Scotia's South Shore, including the Liverpool community and surrounding rural communities in the Region of Queens Municipality in Queens County, Nova Scotia. Liverpool Bay is home to several fish species that support commercial and sport fishing, as well as several important bird species. On the eastern side of the bay lies Beach Meadows Park, a popular recreational beach area and an important wetland habitat for the endangered Piping Plover. Liverpool Bay is an outflow of the Mersey River, one of Nova Scotia's remaining wild salmon rivers. Liverpool Bay is an important fishing area for species including herring, lobster, scallop, and mackerel. Tourism has become increasingly important in Liverpool, drawing in tourists to enjoy its numerous beaches, coastal parks, and lighthouses. Salmon farming in Liverpool Bay consists of one small salmon farm that has been in operation since 2000 and is currently undergoing an application for expansion.

5.4 PERCEPTIONS ACROSS CASE STUDY AREAS

Perceptions within each case study area reflected a complex discourse around aquaculture manifesting a range of positive to negative attitudes towards aquaculture. Thematic coding identified three main categories of contextual factors that motivate and underly the perceptions and attitudes towards aquaculture across case study areas, including: 1) history and experiences; 2) values and beliefs; and 3) relationships with place (see Appendix D for the detailed list of themes). How the main perceptions and attitudes towards aquaculture differed across contextual factors are described in the following section (**Table 5.3**).

Table 5.3 Summary of the main features of contextual factors in each case study area.

	Digby	Shelburne	Liverpool
History and experiences	• Entrenched in early opinions • Industry has had time to evolve	• Indirect interactions (processes not people) • Promises and expectations	• Environmental consequences of other industries • Recent changes as a platform
Values and beliefs	• Community empowerment • Long-term future • Supporting livelihoods	• Conservation and tradition • Long-term environmental health	• Community empowerment • Self-sufficiency • Sustainability and balance
Relationship with place	• Place of living and working • Priority for economic growth and diversity • Protection of diverse habitats and resources	• "Lifeline" of community • Natural and unspoiled • Priority to preserve image and traditions	• Ocean as an aesthetic "asset" • Priority to revitalize community • Use based on visual character and environmental health

5.4.1 Perceptions in the Digby area

5.4.1.1 Current perceptions shaped by historic comparisons

When describing perceptions of salmon farming in Digby, the participants frequently reflected on past experiences and events. Some participants noted that strong opposition among some community members has been present since the beginning of the industry. Some participants recognized that when aquaculture first came, limited scientific knowledge about the area or about salmon farming impacts led to poor siting and operational decisions; mistakes that were used to justify negative perceptions.

Contrarily, some participants felt that the government and industry have "learned" from past mistakes, acknowledging that the industry is improving its communication with the public and becoming a better corporate and community partner. One participant linked this change to having time to reflect and adapt, and that improvements were part of "the evolution of the industry and evolution of a company.". The participants' responses suggest that industry changes have been noticed in the community and are partly responsible for positive opinions about aquaculture.

Early mistakes had a lasting impression on several participants. One participant noted that despite improvements in the industry, their trust had still not recovered due to previous experiences, which could be a response in part built on the culture of the area: "The amount of detail that people remember around here it boggles the mind. So, you screw us over, we are going to remember it.". Some participants recognized growing hostility over aquaculture, in part leading to a form of "entrenchment of opinions" within the community. Some participants noted that salmon aquaculture has thus become quite emotional for many, creating tension between friends and neighbors and creating community splits that "physically, emotionally, spiritually, [it] takes a toll.".

When asked about the confidence in governments to manage aquaculture, the participants often drew on historical experiences across multiple sectors. Several participants noted feeling "forgotten" and "pushed aside" by both federal and provincial government agencies. For example, some participants referred back to the government's history of management conflicts in wild fisheries (e.g., Davis & Bailey, 1996), reflecting a growing mistrust in government.

5.4.1.2 Perceived impacts on local livelihoods

In Digby, the ocean is intrinsically linked to livelihoods and community prosperity: "[The ocean] is my livelihood. The economic driver for the whole southwest end of Nova Scotia is the fishery itself. It's the economic lifeblood of the Maritimes really.". The participants in Digby often built their arguments around how aquaculture negatively or positively impacts local livelihoods. Many participants highlighted the benefits of employment and economic spinoffs from aquaculture to the area. The participants noted that the industry seemed to be good employers and that employees enjoyed their jobs. These benefits were often linked to opportunities to support rural livelihoods by helping diversify income beyond wild fisheries and support the need for economic development. However, the potential economic benefits of aquaculture were criticized due to low pay and benefits. Others highlighted that the local economic benefits and jobs created could be greater and were never as many as the industry claimed.

Arguments related to the wild fishery were intertwined with concerns over the long-term prosperity of the region: "If the fisheries go down, we stop.". Conflicts with aquaculture emerged regarding concerns with traditional fishing, particularly the encroachment of fishing grounds. Even among supporters, ensuring access to fishing grounds was seen as important for aquaculture governance. Further, environmental impacts were often connected to risks to commercially important species such as lobster. Finally, visual impacts and access to the waters and beaches were also emphasized in relation to the effect on marine tourism, another relevant local livelihood.

5.4.1.3 Valuing community and long-term prosperity

In Digby, values of long-term prosperity emerged when considering the potential impacts of salmon farming. The participants emphasized their values towards safeguarding the ocean and coastal areas to support traditional livelihoods long-term:

> There's huge concerns, whether it's from the fishermen, or whether it's from people in our area that are concerned because if everything is used, there is nothing left for the future, nothing left for the grandchildren or anyone…

For supporters, aquaculture was seen as a part of a long-term future for the economy and food security. However, others believed salmon farming poses unacceptable risks to maintaining a future for existing livelihoods like wild fisheries. For these participants, the values held by government were not believed to adequately consider the long-term future of communities, nor sufficiently protect existing livelihoods from aquaculture risks.

Several participants highlighted that the provincial government is biased to benefit the industry not citizens, which was seen by some as a consequence of its dual role as both promoter and enforcer. The participants also linked their mistrust of government to the government's active support for the industry, including creating grants and supporting research programs, poorly enforcing regulations, and providing subsidies for fish mortalities.

The participants in Digby noted that the government's engagement is a "manipulative", "ministerial act with no meaning", which would need to be substantially improved to better represent, respect, and empower communities, and ultimately fulfill existing regulations. Some participants expressed sentiments that the government is deceitful and dishonest, reflecting a perception of communications from the government to be anything but forthcoming or transparent. Consultation processes were perceived to exclude relevant stakeholders, but should include wild fisheries representatives among a broader panel of community members, emphasizing that decision-making processes should empower the people affected by aquaculture. Some participants emphasized an erosion of trust in government beyond aquaculture, stemming from the government's economic growth mindset over community well-being. In this way, perceptions of salmon farming were also intertwined with confidence in the government respecting community values.

5.4.2 Perceptions in Shelburne

5.4.2.1 Preservation of place and community

In Shelburne, the participants expressed how community identity and livelihoods were intrinsically linked to the conservation of the ocean, stating that "life depends on the water" and that the ocean is "our lifeline". In particular, they described how lobster and groundfish fisheries have been the essential building blocks of the economy in the area. As one participant described, "when the fishermen are doing well, everyone does well.". Others drew on aspects related to the natural beauty of the area, describing the ocean as a "natural", "unspoiled" environment that was considered an important driver for tourism, recreation, and migration to the area.

The heritage of Shelburne, including the fishing history, was the foundation for narratives about the importance of preservation of local livelihoods and the environment. Some participants describe a sense of "holding on to the past" in Shelburne that could influence how some people will react to potential opportunities from aquaculture or other industries, as these initiatives would "destroy(s) the feel of the place.":

> I think some of the locals are quite vocal, but then they're quite the same people who are quite vocal about everything. You know, they, they don't want oil, they don't want fish farms, they don't want anything really. They just kind like to be back into the 17th century until it comes to needing groceries, electricity...

The participants perceived that salmon farming could threaten existing fisheries and tourism industries; for example, through aesthetics, further impacting these traditional livelihoods.

Some participants described the importance of the relationships within the community, describing it as a "sleepy town", with lots of small businesses and a close-knit community that helps each other. Over the years, the participants recognized social tensions driven by a divide in opinion on salmon farming, creating conflicts between neighbors and friends. As a result, the clear divide in the community opinions on aquaculture has for many impacted the relationships and sense of community people have, further influencing any vision of moving forward with aquaculture.

5.4.2.2 A history of unmet expectations

In Shelburne, the participants described disappointment and conflicts with the industry over a history of unmet promises and expectations. After the collapse of Atlantic groundfish in the 1990s, aquaculture became the "new hope", with many youth taking aquaculture courses with the aspirations for careers. In 2012, Cooke Aquaculture announced plans to build a processing plant in the area, promoting the benefits of jobs and income to the area. These plans, supported by government funds, were abandoned in 2016 amidst delays and political constraints. The participants expressed their frustration as the hope was never realized, feeling that communities and governments have been consistently misled by industry. For some, disappointment and frustration deteriorated their confidence in government, feeling that government does not prioritize the community since the money given to the industry was never put back into the community, resulting in a "black mark on the whole aquaculture industry.".

For some participants, direct interactions with the industry were not a primary motivator to perceptions, as the perceptions were based more on how the industry fits in with the community. One participant noted direct interactions with the industry have been good, referring to helpful conversations with employees. Yet, some participants perceived an unwillingness of the industry to care about the local environment (e.g., by not taking accountability for debris) or community (e.g., by not having open communication). Some participants also recognized the opportunity of salmon farming for local employment, but also had concerns over whether the industry is contributing to the well-being of the community, e.g., poor employment benefits and limited financial benefit into the community.

5.4.2.3 Community, political, and industry motivations

The participants emphasized that salmon farming gets wrapped up in wider political mindsets about economic development, which are not perceived to prioritize safeguarding the marine environment. In addition, current management approaches were perceived to be based on a flawed notion of the ability to control nature. These perceptions reflected environmental values that emphasized the importance of conserving the environment, which was believed to be the centre of all benefits people receive from the ocean.

In Shelburne, the participants felt they were not receiving answers to their questions, which was linked to an industry culture that values secrecy under the premise that information is proprietary. Furthermore, the participants expressed perceptions that industry attitudes were contemptuous and uncaring during community engagement. Open and transparent communication were emphasized as necessary improvements for the industry and essential for building trust. Some participants recognized that showing respect for the community would require that a company does not try to "muscle their way into somewhere", reflecting perceptions over the philosophy and ethics of aquaculture companies.

The perceptions in Shelburne often related to broader beliefs of salmon farming as a "big business", which "come[s] in and kind of ravish[es] the area, tak[ing] what they want and leav[ing].". The participants illustrated how people are a bit resentful of foreign companies, passed on past experiences in other industries such as wild fisheries. These perceptions also reflect broader negative perceptions of all extractive industries: "And it's not uncommon. It happens everywhere in the world where the industry wants to take advantage of the natural resources of the place.".

Political processes were often perceived to provide no incentive to meaningfully consider community perspectives. The participants linked these perceptions to wider political system flaws, including political motivations (e.g., getting votes) and the expertise of those in power (i.e., past industry professionals) that manifested a feeling that aquaculture policy is "driven by stakeholders rather than people that matter.". For some participants, engagement processes are merely a "manipulation of the process", as participants are "rarely engaged in any way, shape or form, other than to be told in a patronizing way that we [government] have things under control.". The participants in Shelburne emphasized how processes inadequately consider local knowledge, e.g., of local fishers, which was deemed to be essential for building trust with communities. Similarly, the participants expressed frustration over the government's perceived unwillingness or lack of commitment to provide true and accurate information to the public. Several participants noted that education and communication processes were key for building public trust, recognizing uncertainty, and acknowledging the lack of knowledge about aquaculture in the area. Many had little direct experience with aquaculture in Shelburne, as their understanding of the industry was based on its history in other places, stemming from what they were told by friends, family, and media.

5.4.3 Perceptions in Liverpool

5.4.3.1 Recent changes as a platform for conflicts

Some participants perceived that the public conflicts around salmon farming only recently emerged, despite the industry being in the area for 20 years. However, plans for expansion in Liverpool may be acting as a platform to bring up wider environmental issues about salmon farming:

> It has been there for a lot of years, and nobody said anything about it, but the fact that it's the opportunity for it to be expanded has now put it into focus... It's just raised the issue for everything around salmon farming.

For some participants, the industry has substantially overcome its "growing pains" during the early years of the industry and is actively working to continuously improve its practices. Some participants also noted good experiences with industry personnel, perceiving the industry to be accountable for past mistakes and forthcoming with information. Others noted that these conflicts were emerging amidst recent social and economic changes in the area, driven in part by changing attitudes toward a more self-sufficient environmentally focused community identity.

Along with social changes, the area has experienced economic changes in many traditional industries in the area. Participants described the area as once being "hopping" with economic activity, but it was hit hard by the groundfish collapse in the mid-1990s, and the closing of Bowater Paper Mill in 2012. These examples were used to highlight participants' deteriorated trust in both the provincial and federal government's ability to protect existing industries. Since then, the area has shifted away from traditional industries toward an increasingly important tourism and eco-tourism industry.

5.4.3.2 Industry as "neighbors"

The participants in Liverpool described their relationships with the ocean as linked to their own and their community identity and well-being. The coastal areas in Liverpool were described as one of the province's "most beautiful assets", "gorgeous", and "rugged". As a result, the participants felt that salmon farming interferes with both their vision and experience of the area since salmon farming is "right in the middle of everything that we love.". Recently, the Municipality underwent a branding to the "Queen's coast", reflecting how important the community feels about the ocean.

In addition, perceptions around salmon farming were intertwined with broader community priorities towards revitalizing Liverpool. For example, some participants felt aquaculture might conflict with opportunities to grow the local population provided by the active coastal housing sector, potentially impacting community well-being. Critics highlighted the noise, debris, and slime on the rocks caused by the farm as potential detractors to attract new residents. Yet, others did not believe these visual impacts have dissuaded people from moving or visiting the area. While the participants recognized that direct local employment benefits were low, some felt that aquaculture can increase supply-chain business opportunities and income generation to help revitalize Liverpool as an economic center. In addition, some participants felt that lobster fishermen could benefit from a potentially higher abundance of lobster near salmon pens.

Other responses in Liverpool perceived the industry as a "poor neighbor", feeling that the industry does not contribute to local community well-being. In this way, perceptions of salmon farming were linked to broader questions about the need for making decisions for community needs rather than solely economic growth: "Why introduce [salmon farming] more to a small little province when it doesn't fit our image?... Like it's so disrespectful of, of what we are wanting for our community and our province.". Several participants criticized that the money from aquaculture leaves the community or province, as the salmon farming company in the area was from another province. Employment that the industry provides was also perceived to not stay in the community, as participants felt the employees do not live in the area.

Distribution concerns were also mobilized to argue against potential food benefits as one participant claimed that salmon is mostly exported.

5.4.3.3 Perceptions based on interpretations of values

Perceived impacts of aquaculture built on shared values about transparency and open communication. Several participants expressed frustration about their voices not being heard, with others feeling public engagement processes were "restrictive" regarding who participates. One participant described the public consultation process as a "publicity event", expressing how the industry skirted around questions with no real desire to answer questions. In this way, industry and government cultures and priorities were perceived to inadequately consider local needs and desires for transparency and communication.

Some participants believed the information they wanted was "hidden away" and not easily accessible, which was linked to a sense of disempowerment: "Well, I think, I think public input and consultation is so very important because we're the ones that can be impacted by whatever decision…". For some, increased transparency and communication were suggested to help people make informed decisions based on more than potential misinformation they hear in the media. The participants thus emphasized the need for open, proactive communication to the public by government and industry, especially about how decisions are made and the siting process.

However, for others, increased transparency was perceived as insufficient since they did not trust that the government or industry will do what they say. Some participants felt governments ignored advice or scientific evidence, drawing on reasons such as evidence not fitting "the model the government wanted", or because the goal was simply to maximize profits. Likewise, industry was felt to not be genuine about demonstrating that it cares about the environment, only driven by values of profit or when negative impacts affect their operations or productivity, such as during mortality events.

Perceptions about salmon farming were frequently juxtaposed with broader values about sustainability expressed by many Liverpool participants. Many participants highlighted that "sustainability was king", recognizing a perceived global shift in social values towards sustainability.

Some participants described sustainability as a balance between environmental, economic, and societal goals and impacts, recognizing a place for aquaculture within broader sustainable development goals and local rural development. For these participants, the need for governments to rigorously monitor and enforce salmon aquaculture to ensure "win-win" scenarios between different goals was emphasized. These participants felt that the companies are genuinely working towards sustainability by applying best practices with the goal of not harming the environment.

A second understanding of sustainability emerged as dependent on the environment at the center. Some participants perceived that salmon farming impacts marine habitats, in particular wild populations of sensitive species (like wild salmon) and commercial species (especially, lobster). Likewise, this understanding of sustainability was evident across participants who desired more information about the environmental risks of salmon farming. Yet, other participants saw salmon farming as sustainable, claiming that evidence does not support negative environmental impacts. Some participants even highlighted potential environmental benefits of aquaculture, drawing on examples of wild salmon re-stocking efforts currently underway locally and within Atlantic Canada (Smith, 2019).

5.5 THE ROLE OF CONTEXT ON PERCEPTIONS OF AQUACULTURE

While the interviews revealed some common arguments and conflicts across the case study areas, the different ways in which those arguments manifested across the areas emphasize the important role that local context plays in shaping perceptions, and ultimately, attitudes about salmon farming. An appreciation of context should thus be incorporated in decision-making as more than just the overall setting of an area, recognizing that contextual factors directly influence how individuals perceive and understand aquaculture, including its risks and benefits.

Perceptions across the case study areas revealed that, to varying degrees, all three categories of contextual drivers influenced how respondents perceived salmon aquaculture in their areas, including history and experiences, values and beliefs, and relationships with place (**Figure 5.2**). While each contextual factor is described below as separate, it needs to be recognized that "context" is inherently dynamic and that factors can overlap and interact with one another. Indeed, values are often considered to emerge from the relations between nature and society (e.g., Acott & Urquart, 2018) and values can vary situationally (Stern, 2000). Further, historical factors influence the connections individuals have with their environment and community, with the accumulation of experiences over time building and changing an individual's "sense of place" (Hay, 1998; Stedman, 2003).

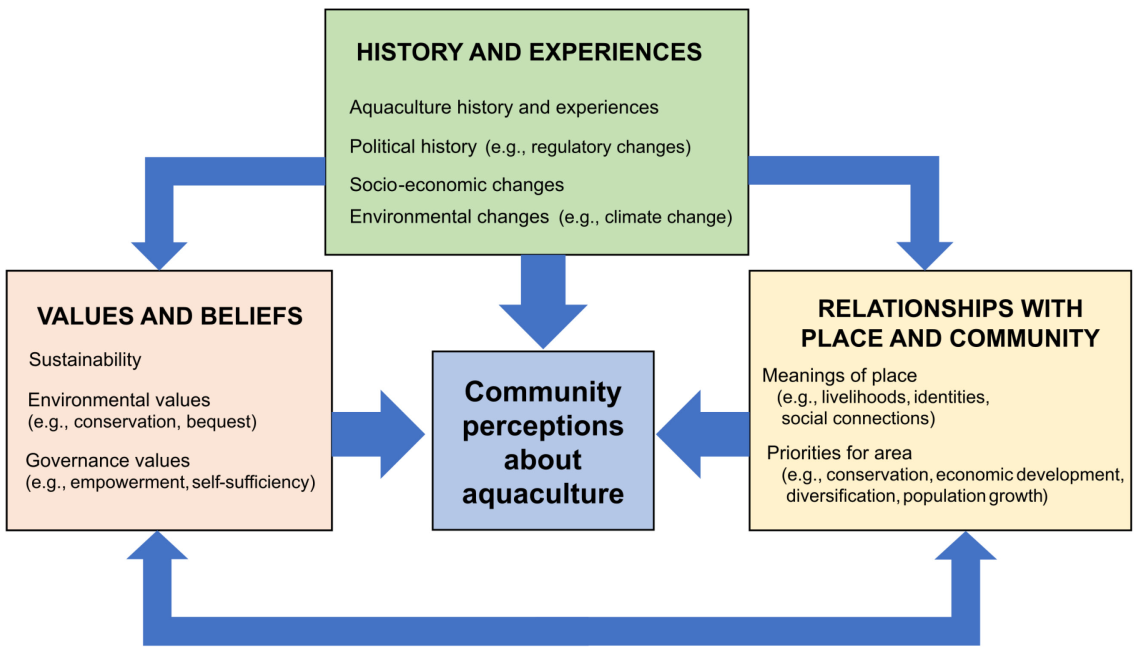

Figure 5.2 Framework of conceptual drivers of aquaculture perceptions.

5.5.1 History and experiences

This research revealed a diversity of ways historical contexts influence perceptions about salmon aquaculture and identified relevant factors, including the industry's history and participant's experiences with the industry, political history and past conflicts, local socio-economic changes, and wider environmental changes. Industry experiences and history were strongly linked to a participant's perceptions about aquaculture, especially in areas with long interactions with aquaculture. However, this study reinforces conflicting findings in the literature, where greater exposure and familiarity with aquaculture can be linked to both positive (e.g., Hynes et al., 2018) and negative perceptions (e.g., Sinner et al., 2020) of the industry. In this study, frequent exposure to local industries over time was linked to positive opinions about aquaculture, especially where experiences were based on personal connections and changes were perceived to improve aspects that are valued by individuals. Contrarily, this study found greater exposure to local industries can lead to negative opinions and deterioration of trust if the participants feel they are consistently treated unfairly or if promises are not met over time. Historical influences on perceptions illustrate that public response to aquaculture is a process (e.g., Wolsink, 2018) that evolves with new events, historical and social conditions, and experiences.

The influence of previous experiences on perception agrees with earlier work suggesting that past practices can tarnish the industry's reputation (e.g., Alexander, 2022), making it challenging to re-build trust. Further, findings from this study indicate that practices impacting the industry's reputation can come from industry practices in other areas, not only from local farms. For example, the participants in Shelburne reported low aquaculture knowledge, yet reportedly drew on mediated experiences and impressions based on the history of operations elsewhere communicated by media to form their perceptions about the risks and benefits of aquaculture.

Across the case study areas, histories of different natural resource conflicts were also highlighted. In some areas, these conflicts resulted in major economic and social repercussions that changed the social fabric and economic profile of communities. In many cases, participants mobilized these conflicts to reflect on their eroded trust in government. The presence of long-standing natural resource conflicts suggests a sort of "legacy issue" of environmental conflicts that form a setting under which any industry, including aquaculture, is perceived within communities (Alexander, 2022; Salgado et al., 2015). As a result, pre-existing levels of trust shaped by historical factors can influence the confidence in the actions of government or industry.

Perceptions about aquaculture were also partly shaped by the environmental and socio-economic changes in an individual's life. Historical changes in the size and distribution of natural populations of commercially important species such as lobster, and formerly wild Atlantic salmon (Dadswell et al., 2022), were linked to the participants' desire to protect existing industries from salmon farming. For some participants, changing environments, including increased storms and climate change are felt to be heightening issues of salmon farming escapes, disease, and mortalities. As a result, perceptions of environmental changes were used in arguments that salmon farming presents an added threat to the resilience of vulnerable ecosystems.

5.5.2 Values and beliefs

In the context of this study, values can be described as a principle associated with a given worldview, a preference regarding how the world should work, or the importance of something that people uphold for itself or others (Pascual et al., 2017). This study has shown that social response to aquaculture was influenced by an interacting set of values about environment use, social and economic development, and governance decisions, reflecting broader dialogues around natural resource management influenced by beliefs and values about how humans use the natural environment (Mazur & Curtis, 2008) and how decisions are made for the well-being of societies. These findings support ongoing discussions within social acceptability literature that places values as a central motivating factor in people's response to environmental management (Stankey & Shindler, 2006).

Values are not specifically place-bound and are assumed to be relatively stable and enduring. Yet, values are "contextual" in that they can be spatially distinct and can be highly individual but may also be shared between networks of groups and/or communities (Kenter et al., 2015). In Digby, environmental values were linked primarily to resource availability, alongside social values of employment and livelihoods. Comparatively, in Shelburne, environmental values about conservation are related to broader questions of human well-being. Values in Liverpool centered around an appreciation of the environment as part of the community's image and governance systems that empower the voice and decisions of communities. These differences demonstrate the contextual nature of values that emerge in specific locations, and influence perceptions about salmon farming in different ways, which has been observed in other sectors (Williams & Schirmer, 2012).

The participants expressed multiple values in their discourses around salmon farming, with sustainability being the most prominent, despite slightly different interpretations of the concept, including sustainability as a) the long-term productivity of resources, b) a systemic view of balancing social, economic, and ecological goals, and c) the resilience of socio-ecological systems where the environment is at the center (White, 2013). The findings suggest that whether aquaculture was considered "sustainable" was a strong predictor of opinion but varied based on different interpretations of the term. Likewise, multiple understandings of sustainability were linked to conflicting, often contradictory perceptions of aquaculture risks in Norway (Lindland et al., 2019), suggesting that how sustainability is measured may influence the perceived legitimacy of aquaculture. Similar to sustainability, the manifestation of other values was not necessarily linked to the participants' decisions to support or oppose aquaculture. For example, in Liverpool, critics reflected beliefs that a vital community depended on community empowerment in decision-making while supporters believed vital communities depended on attracting marine economic development, including aquaculture. This example illustrates how the participants make judgements about aquaculture based on different meanings of community vitality, influenced by the values they consider important.

The participants perceived differences between industry, government, and community values, leading to an emergent sense of "us versus them" linked to fundamental values rather than specific impacts, experiences, or interactions. The participants often described government and industry motivations and values as contrary to their own, or those that form community identities. For example, in both Liverpool and Shelburne, the government's growth mindsets and economic priorities were not seen to coincide with self-sufficiency and preservation values held by locals. Similar to findings elsewhere (e.g., Ford et al., 2022; Lindland et al., 2019) a sense of distrust emerged as the participants felt government and industry did not respect the community's interests or values, suggesting a legitimacy-gap based on a disjointed understanding of what is valued (Boltanski & Thévenot, 2006).

5.5.3 Relationships with place and community

Perceptions toward salmon farming were often linked to contextual factors related to the ways participants expressed their place-specific connections with their area, including their image and vision for their environment and community. Likewise, recent research suggests that the extent to which one considers their connections with nature as part of their image of "self" can influence the types of environmental concerns and situations that motivate behaviors (Aguilar-Luzón et al., 2020). The findings in this study also support ongoing narratives on the influence of place attachment and place identity as motivators of societal perceptions and attitudes to aquaculture (Alexander, 2022; Ford et al., 2022).

Across all case study areas, emotional connections between participants and their local environments were expressed, encompassing notions of place attachment. Some described their intimate connections with the ocean and emotional attachment to coastal areas. For others, the ocean is felt to be intrinsically intertwined with the "fiber of the people who live here", and the industries it supports (such as fisheries) were perceived to be inseparable from people's prosperity and survival. Therefore, a strong sense of place attachment was linked to place meanings described by the links between marine spaces and use, livelihoods, and mental well-being. In this way, the places and their ascribed meanings become influential so that place and identity become intertwined (Devine-Wright, 2009). As a result, place attachments and connections with community and personal identities make the contextual history of "place" important for understanding conflicts and social risks of aquaculture (Ford et al., 2022).

Different meanings of place and priorities for an area manifested different perceptions towards aquaculture. For example, concerns over the productivity of marine resources and concomitant effects on local livelihoods dominated perceptions in Digby. The participants in Liverpool engaged in discussion around the distribution of economic benefits and how the industry can contribute to revitalizing the local community. The participants in Shelburne expressed how salmon farming does not fit with a wider sense of preservation of history and tradition within the community. In this way, some participants felt salmon farming detracts from what makes the ocean and coastal spaces "special" to communities. As a result, a common theme that emerged across opponents was that aquaculture does not fit with the vision and image people have about their environment and community. In contrast, participants with positive perceptions often noted that salmon farming has been in the area for over 20 years and suggested that its existence is already intertwined with the image of the place. Similarly, the fit between industry activities and community aspirations has also been found in other aquaculture areas (e.g., Alexander, 2022) and in other sectors such as mining (Prno, 2013). Therefore, the findings from this work suggest that perceptions of the industry, and interpretation of risks and benefits are intertwined with perceived disruptions to place identity (Devine-Wright, 2009).

5.6 CONCLUSIONS

The case studies demonstrate the complexity of experiences and perceptions of the salmon farming industry in Nova Scotia, illustrating that contextual factors are important drivers of the understanding and perceptions of aquaculture. In summary, the perceptions reflect a multifaceted discourse over salmon farming impacts and management influenced by local relationships, wider values, and history across multiple scales. While specific perceptions and conflicts cannot be generalized to reflect all Nova Scotians or all communities, the goal of this multiple case approach was inherently to generalize to a set of theoretical assumptions about what influences perceptions, and are thus useful in this regard. The framework of contextual factors influencing community perceptions that emerged from the qualitative analysis of perceptions across case study areas form potentially generalizable knowledge about how perceptions, and attitudes towards aquaculture form. Ultimately, understanding what drives judgments of societally responsible aquaculture should thus recognize that perceptions, public trust, and attitudes are inherently contextual.

CHAPTER 6: LOCAL RESPONSES TO SALMON AQUACULTURE: DIMENSIONS OF CONFLICT AND CONTROVERSY

The overall goal of this chapter is to understand differences in perceptions among residents and key stakeholders in salmon farming communities in Nova Scotians and the influence of those perceptions on their attitude about aquaculture. This chapter explores differences among groups with different responses to aquaculture, from opposition to support, to identify the factors that influence those decisions. Ethics and research documents are located in Appendix D. A full list of themes and topics used to inform the analysis is described in Appendix D.11. A summary of key perceptions along major themes across groups with different responses can be found in Appendix D.12.

Citation:

Weitzman, J., Filgueira, R., & Grant, J. (in review). Dimensions of legitimacy and trust in shaping social acceptance of marine aquaculture: an in-depth case study in Nova Scotia, Canada. *Journal of Environmental Science and Policy*.

Please note that this chapter appears exactly as it was submitted for the journal article currently under review.

6.1 ABSTRACT

A major challenge facing sustainable aquaculture governance are disputes raised by social conflicts, highlighting the need to better understand and incorporate social dimensions into more holistic planning and policy. This study applied an in-depth qualitative approach to investigate key drivers that influence social acceptance of salmon aquaculture, drawing from interviews in coastal communities in Nova Scotia, Canada. From interviews, four main perspectives towards the planning, management, and development of salmon farming emerged, revealing a complex discourse of conflicts and controversy. This study argues that social responses to aquaculture are driven by perceived legitimacy and trust of the sector. Conflicts over the perceived legitimacy of policies and processes emerged, including arguments around what motivates and informs decision-making and how participants are involved in decision-making processes. In addition, conflicting paradigms of knowledge and perceived fairness in engagement processes highlighted the need for transparency, communication, and relationship-building. Controversy over a diversity of perceived environmental and social impacts reflected nuanced perceptions of how aquaculture contributes to individual and community well-being. This study also found perceptions of legitimacy to be deeply intertwined with evaluations of trust in government, industry, and science, which is a key predictor of social responses. Understanding these perceptual factors, separately and with their interdependencies, can provide decision-makers with insights to guide their regulatory, operational, and engagement processes. Ultimately, this work can serve to facilitate a better understanding of the motivators behind public responses to salmon aquaculture which can help bring social considerations into more holistic aquaculture governance.

6.2 INTRODUCTION

While aquaculture is often considered crucial for meeting rising food demands, it is increasingly considered a “wicked” problem for governance, which needs to manage a contention over diverse issues including ecological and socio-economic impacts and user conflicts (Osmundsen et al., 2017). With increasing recognition of the desire to move towards more holistic management approaches like the Ecosystem Approach to Aquaculture (Brugère et al., 2018), there is an increasing necessity to consider social dimensions in aquaculture planning and policy (Krause et al., 2015). This recognition has in part given rise to a discourse about concepts such as social acceptance of aquaculture (Mather & Fanning, 2019).

Social acceptance (SA) reflects social attitudes on the operation, management, and impacts of specific projects. Beyond aquaculture, the study of SA is a well-established field of study of environmental policy and practice, with international research on the acceptability of contexts including mining (e.g., Moffat & Zhang, 2014), energy production (Gaede & Rowlands, 2018), wind farms (Wüstenhagen et al., 2007), land use (Busse & Siebert, 2018), forestry (Ford & Williams, 2016), and wildlife conservation (Stankey & Schindler, 2006). In a policy setting, social acceptance refers to the broad acceptance of an activity by a range of groups, a combination of interrelated aspects of market acceptance, socio-political acceptance, and community acceptance (Wüstenhagen et al., 2007). Social acceptance also has a more psychological definition that reflects a judgmental process by which individuals form opinions about current operations and judge whether they are favourable considering other alternatives (Brunson, 1996). These definitions reflect more recent discussions in the literature, where social acceptance has been argued to be not an outcome, but a complex and dynamic process (Wolsink, 2018). Furthermore, these definitions highlight a behavioural component of SA and underscores a suite of factors that influence judgements.

Social acceptance research broadly seeks to understand the perceptions, opinions, and attitudes of people, and how they influence their behaviours. The distinction between social acceptance and its associated terms can be unclear in the SA literature (Busse & Siebert, 2018) and warrants definition. In this study, *perceptions* reflect the general way an individual understands aquaculture or an aspect of aquaculture (for example, perception of risks and benefits). Related to perceptions, *opinions* reflect the beliefs individuals have formed on a particular aquaculture topic. *Attitudes* describe an individual's negative or positive evaluations of an issue or topic concerned with aquaculture. Attitudes influence *behaviours* about aquaculture, which in this study are described as the actions individuals take regarding aquaculture, or the outward expression of attitudes. In this way, this paper separates attitudes from social response, the latter referring to the behaviour to support or oppose aquaculture.

An important part of understanding social acceptance relates to analyzing factors influencing positive and negative attitudes toward aquaculture, and how those factors contribute to individuals' behaviour to support or oppose aquaculture. Behaviours are complex, and likely a result of various intricate interactions between multiple factors. For example, acceptance may depend on the ability of aquaculture to meet social and economic demands (e.g., employment, recreation) and environmental concerns (Kluger et al., 2019). Further, trust, relationships, and interactions with local companies and governments have been strongly linked to social acceptance (Segreto et al., 2020), and are often mapped as a necessary component of achieving SA (Moffat & Zhang, 2014; Thomson & Boutilier, 2011). In addition, studies across resource and technology sections often recognize the importance of contextual factors like experiences and values, which are highly place-specific, on social acceptance (Kim et al., 2014, Wiersma & Devine-Wright, 2014). Therefore, an important aspect of SA unfolds at the community level, reflecting a localized process mobilized by local stakeholders (Wüstenhagen et al., 2007).

Community acceptance is relevant in discussions about ocean-based salmon aquaculture, where strong local opposition has emerged in many places around the world. In Canada, salmon farming has long been a controversial issue, with competing arguments and claims made by governments, stakeholders, and residents (Young & Matthews, 2010). In Atlantic Canada, governments have supported aquaculture development since the 1980s, seeing opportunities for rural economic development, especially in the face of declining employment from fisheries and forestry (Young & Matthews, 2010). However, rapid expansion of the industry was met with local concerns among residents, fishers, and environmental groups (e.g., Walters, 2007). As a result, salmon farming has been a primary sector in Atlantic Canada for exploring societal perceptions and attitudes (e.g., Flaherty et al., 2019; Maxwell & Filgueira, 2020; Trueman et al., 2022).

While social acceptance research is already a well-established field in many resource sectors, there is comparatively little empirical work regarding SA of aquaculture. Yet, research investigating how groups of individuals make social acceptability choices and what drives those behaviours is becoming increasingly critical to wider discussions about sustainable aquaculture (e.g., Krause et al., 2015; Mazur & Curtis, 2008). Conflicts around salmon farming in Nova

Scotia, Canada, thus provide an opportunity to better understand community acceptance of aquaculture. This study explored perceptions and attitudes of salmon farming in three rural communities in Nova Scotia to investigate the key drivers and motivators that influence social responses to aquaculture. This research adds to existing research by exploring a range of perceptual factors on the attitudes towards aquaculture and can lead to a better understanding of the conflicts and arguments responsible for attitudes. In addition, this work can build a stronger foundation for developing frameworks to explain how public response to aquaculture unfolds in communities where the industry is present.

6.3 METHODOLOGY

6.3.1 Context: Salmon aquaculture in Nova Scotia

Salmon aquaculture in Nova Scotia has grown in both production and value since the 1990s. Favourable natural environments around the province, as well as easy access to international markets, have made Atlantic provinces like Nova Scotia prime areas to support an increased industry (ACOA, 2004) and an untapped opportunity for coastal and rural economic development (e.g., Ivany et al., 2014). Despite a five-year moratorium on new aquaculture farms in Nova Scotia between 2013 and 2017, regulatory and operational changes prompted a restored interest in the expansion of the industry. Since the moratorium was lifted, the province has received several applications for site expansions, installation of new sites, and exploring options for new companies in the area.

Yet, conflicts and criticisms among community, environmental, and interest groups have accompanied the growth of the salmon aquaculture industry. For example, organized advocacy groups have mobilized campaigns, organized events, and petitions against open-net pen salmon farming. Concerns over the environmental sustainability of aquaculture, including concerns related to marine benthic habitat, fish health, and welfare, and risks to wild fish from disease and salmon escapes have contributed to public appeals for major overhauls of Nova Scotia's regulatory system (Doelle & Lahey, 2014). These conflicts have captured substantial media attention, reflecting a growing controversy around multiple issues (Weitzman & Bailey, 2019). As a result, potential salmon farming expansion in the province has set a platform for a renewed interest in social impacts and conflicts between government, industry, and social goals.

Aquaculture governance in Nova Scotia can be challenging, representing a patchwork of regulations and systems across departments and scales (Doelle & Saunders, 2016). At the federal level, the *Fisheries Act* provides the overarching framework for environmental assessment for aquaculture under the Department of Fisheries and Oceans (DFO). Through a memorandum of understanding, the provincial Minister of Fisheries and Aquaculture is given jurisdiction over the regulation and management of aquaculture operations within Nova Scotia, including administering aquaculture licences and leases. In the case of new, or amendments to, marine licences or leases, applications undergo an adjudicative process by a three-person independent Aquaculture Review Board. This process also includes provisions for public engagement, including the requirement of a public meeting during scoping and a public hearing no more than 30 days before the final decision. Regarding aquaculture, communities are only involved through formal engagement processes throughout the adjudicative process since municipalities do not have jurisdictional authority in the ocean, and consequently over marine aquaculture.

6.3.2 Research design and data collection

This study applied a grounded theory approach to understand what motivates and shapes social responses to aquaculture. This study was carried out with ethics approval from Dalhousie University (REB#2020-5071). Applying a qualitative approach drawing from thematic coding of interviews, the objective was not to provide empirical measures of what influences attitudes, but rather to analyze the perceptions expressed through in-depth interviews to better understand the underlying reasoning.

Semi-structured interviews were carried out between May and October 2020, with 24 participants in three salmon farming areas in Nova Scotia: Digby, Liverpool, and Shelburne. These areas all comprise rural coastal communities in western Nova Scotia, where vocal conflicts against open-net pen salmon farming have captured media attention and manifested in the formation of active anti-salmon farming groups. This study applied a purposeful sampling of participant selection to identify individuals with distinct experiences, views, and interests in aquaculture, including residents (8), local (municipal) government officials (6), members of community and environmental interest groups (4), commercial fishers (3), and tourism and business operators (3). All interviews were performed one-on-one over a phone or video-call and lasted about one and a half hours each.

Semi-structured interviews asked the participants a standard set of questions to center the discussions but were also broad and open allowing for follow-up questions and allowing both consistency and flexibility during data collection (Creswell, 2013). The analysis of attitudes drew from questions focused on four key areas including: experiences with and understanding of salmon aquaculture, trust in the actors in the industry, perceptions of the various risks and benefits, and preferences and priorities for aquaculture development in the area.

6.3.3 Data analysis

Once interviews were transcribed, a combined process of deductive and inductive coding was carried out using NVivo 12 PRO. First, open coding of transcripts divided sections of texts into codes representative of the full breadth of potential topics around aquaculture. Codes were conceptually categorized to identify topics and themes across the transcripts. Axial coding was used to find relationships between categories and identify additional sub-categories. An iterative review of the transcripts across multiple rounds of coding refined the themes and topics in the final codebook (Appendix D.11). Consistent with a grounded theory approach, the final codebook was used as an interpretive framework for data analysis (Creswell, 2013). The topics and themes were used to identify commonalities in perceptions and attitudes across participants to describe the main perspectives towards salmon farming. Comparison of the codes across interview groupings (categorizing social responses as either support or opposition) was used to identify insights and common factors influencing different social responses. The transcripts were re-examined across response groupings to investigate how the most prevalent themes manifested within each grouping of attitudes, which can help advance theory on what motivates attitudes and identify key perceptual factors. Unique attributes, while interesting, inhibits generalizability (Kennedy, 1979) so this study focused on the most common attributes shared among perspectives to help build theoretical premises which can be positioned to give rise to assertions about situations akin to the one studied.

6.4 ATTITUDES TOWARD SALMON FARMING

Based on the in-depth interviews, four different perspectives emerged reflecting different perceptions and attitudes about salmon farming (**Table 6.1**). While this study details the four perspectives as distinct, they should be understood as a continuous spectrum of responses from opposition to support. This section describes the experiences, arguments, and perceptions unique to each perspective, drawing on relevant participant quotations.

Table 6.1 Summary of main perspectives about salmon farming.

Perspective (number of participants)	**Main viewpoint towards aquaculture**	**Response category**	**Preferences**
"Not good anywhere" (7)	Problematic nature of the industry, intertwined with criticisms beyond aquaculture that included government and corporate motivations	Oppose	Land-based
"Not good here" (5)	Not a good fit for the area, reflecting a clash of local desires and values against government and industry motivations and processes	Oppose	Land-based or improvements
"Tolerable" (5)	Benefits need to be weighed against impacts, with improvements to resolve uncertainty about the industry	None (i.e., unaligned)	Improvements needed
"Moving forward" (7)	Opportunities support industry growth, if done sustainably and not at the expense of the environment and community	Support	Conditional increase

6.4.1 The "Not good anywhere" perspective

Several participants expressed negative attitudes about salmon aquaculture within broader arguments about natural resource management, sustainability, corporate motivations, and approaches to governance, and defined the "nature of the industry" as inherently problematic.

The participants claimed salmon farming to be unsustainable because of a cumulation of incidents around the world and scientific evidence of its adverse effects.

Perceptions of aquaculture risks were intertwined with wider concerns over the use and care for the environment. Some participants used concerns over the impacts of domesticated or genetically modified salmon escapes on wild populations to show how “man is always thinking they are smarter than nature.”. Disease and animal welfare concerns were deemed part and parcel of poor domestication processes and intensive farming seen among other animal-rearing industries (like poultry and dairy). Others considered salmon farming as a manipulation of the natural processes: “I don't see these as salmon… The same way growing meat in a Petri dish, this is not natural.”. The participants described how this reflects a broader belief of issues within current political and economic systems that do not thinking holistically about the environment.

Criticisms of the motivations and mindsets of large corporations also characterized this perspective. Some participants felt the industry held a demeanor of contempt towards community concerns, driven by a lack of incentive to be forthcoming and truthful. Likewise, participants perceived the industry to harbour disdain towards regulations and environmental protection, leading to loss of perceived accountability of the industry. Some felt that the industry will act in a deceitful or secretive way to achieve its goals, driven by a principle of “maximizing profits at all costs”.

These participants expressed strong criticisms of the influence of industry on governance, including opinions that government policies and procedures were biased to industry interests. Concerns over the dual mandate of the government to regulate and promote the industry were reflected in what one participant refers to as “hand in glove” action. The creation of bias was thought to be related to individuals in decision-making roles having industry backgrounds, a feature also shared with other industries like forestry.

This perspective emphasized governance issues beyond aquaculture and criticized broader ways that governments use and manage natural resources. Some participants linked their attitudes of aquaculture to examples from other industries where government management has failed to predict and respond to nature in managing resources. In this way, concerns around salmon farming were seen as a product of a flawed policy system based on a growth mindset, which manifested in low confidence in government priorities for social or community well-being: “This government has to start planning without expansion in mind. That isn't the goal - the goal is happiness, quality of life and standard of living.”.

Many participants were pessimistic in their assessment of whether decision-makers could implement effective solutions to build a sustainable salmon farming industry. This perspective questioned the necessity of salmon as a food product, arguing that salmon farming was not part of the solution for either global or local food security, noting how salmon is an elite, expensive and luxury product not accessible to many Nova Scotians. Rather, all participants believed salmon farming operations needed to be completely removed from the coastline, with land-based aquaculture the only way forward for the industry.

6.4.2 The “Not good here” perspective

Several participants emphasized concerns over the local impacts, believing that salmon farming was not a good “fit” for the area. These participants expressed concerns over where farms were placed and believed current sites to be shallow and not receive adequate flushing, leading to concerns over animal welfare, marine habitat degradation, and consequences to wild populations. Several participants also expressed conflicts with other marine users, especially wild capture fisheries and tourism. These expressions suggested a perceived need to protect community livelihoods and well-being, much of which depends on maintaining the aesthetic and supportive values of the marine environment.

These concerns also included expressions that salmon farming does not fit into the broader culture of the place and does not represent what the community wants for the future. In this way, high levels of place attachment served to motivate opposition to aquaculture, as aquaculture was often seen to pose a threat to the community and place: “[For] everyone that I know… income depends almost entirely on the fishery. So, it [impacts on fisheries from salmon farming] would entirely wipe out income completely. It's so close to home that it does get emotional.". Concerns over foreign ownership emerged, juxtaposed with a community culture of supporting small local businesses, and more natural, self-sufficient lifestyles. In some ways, participants perceived local salmon companies as "outsiders", with little willingness to meaningfully consider or contribute to the well-being of local communities. There also emerged a desire to attract job opportunities and diversify employment locally, but salmon farming was not considered "part of that mix", especially given the belief that the industry only provided few poor-quality jobs.

Another central theme surrounded low confidence in how the provincial government makes decisions, engages the community, and enforces and monitors the industry. Many perceived government decisions to be motivated by economic growth rather than science and evidence. The participants reflected on experiences where they felt pushed aside when presenting the government with evidence against salmon farms.

In addition, the participants perceived the government to have poor decision-making processes, leading to poor siting decisions and overall management. The participants had little confidence in the government's ability to enforce regulations, believing the government to not adequately punish the industry for regulatory violations. Insufficient communication and engagement processes were highlighted, with many participants perceiving the government to not be doing enough to meaningfully consider the community in decision-making. These participants advocated for community empowerment: "I think that the community… we have a voice, you know, it's, the government does have, shouldn't be allowed to make decisions for a community that clearly does not want open pen fish farms.".

This perspective was also characterized by reference to experiences with local industry operations. These participants perceived the industry as not accountable, forthcoming, or a good community partner. The participants felt that the industry does not take accountability for the marine pollution and debris that wash up along the shoreline. Some participants referenced incidents where the industry has operated beyond lease boundaries, reflecting a perception of the industry going about its business with a brazen attitude.

Consequently, many participants were pessimistic about the future of the sector, but recommended a shift to land-based, seeing it as an opportunity to create win-win scenarios for the local environment and community. As one participant described, “Get it away from the coast cause it's just ruining our coasts.”. However, others suggested improvements, including open and transparent communication and rigorous environmental assessments.

6.4.3 The “Tolerable” perspective

A third perspective emerged among respondents who manifested a complex discourse about weighing benefits and risks, presenting a neutral position on aquaculture. Benefits recognized by participants revolved mainly around future local and global needs. Globally, participants advocated food security benefits, especially given a growing population. Locally, participants acknowledged the potential of aquaculture for employment and economic benefits to communities.

Yet, this group also expressed negative perceptions of the socio-economic benefits aquaculture affords to communities. They highlighted concerns about the overexploitation of the local area that can sometimes happen with foreign industries: “So it isn't, I don't even know if I have a negative attitude towards fish farming. I think I just have a negative attitude toward the 'Grab and go' thing that sometimes happens.”.

The participants reflected on experiences of broken promises and unmet expectations as reducing confidence in the industry and the government’s commitment to the communities. For some, this manifested as low trust in government as an institution, based on experiences with other industries, such as fisheries. In relation to aquaculture, some perceived a lack of company accountability, exemplified by beliefs that companies do not do enough to remove litter that washes ashore from farms. As a result, the participants emphasized the need for industry to become better community partners and work with communities to create win-win scenarios.

Central to this perspective was a sense of uncertainty around the industry and its governance. Many participants identified a range of potential environmental impacts of salmon farming, but many admitted they knew little about it, drawing from examples in other areas and the media, but recognized they had little direct interactions with the industry. Some participants recognized that few direct experiences with the industry can lead to uncertainties and fear around the impacts of the industry. Thus, the participants believed improvements in education and communication were necessary for the industry:

> I think that if they maybe explain their objectives and what they are doing with this fish and their plans are for the future. Maybe if they explained things a little bit better to everybody, people might settle in with a little bit more.

In particular, several participants wanted more information about environmental risks, how governments make siting and policy decisions, and about economic benefits to communities.

6.4.4 The "Moving forward" perspective

Supporters of salmon farming embodied a perspective focused on both local socio-economic benefits and global food security opportunities from salmon farming. The participants expressed excitement over the potential benefits of expansion, and the possibility to create jobs and support economic spinoffs in the area, where there is a need for economic development. Globally, salmon aquaculture was seen to support protein needs now and in the future. The perceptions reflected a sense that aquaculture was needed if people want to continue eating fish.

These participants recognized that industry changes over the years have led to significant positive improvements. The participants recognized the industry's "growing pains" at the infancy of the industry in Nova Scotia. For these participants, the industry has worked hard to improve communication, conduct research, and change practices and technologies in response to issues and community concerns. In addition, some participants recognized that governments have made substantial regulatory improvements, although they highlighted the need to continue improving regulations, especially by simplifying and standardizing them. In addition, participants also identified that it was critical that industries work with fisheries interests and that siting decisions do not interfere with traditional fishing grounds.

The participants often linked positive attitudes to good personal interactions with the industry. The industry was portrayed as genuine and forthcoming with information, with participants describing the industry as open to questions, and wanting to be part of the community:

> I think they do listen, at least in my experiences... [the industry] is a great advocate for caring for his workers, for caring what the community think and want. And they want to be part of the community.

This perspective considered aquaculture a sustainable industry and argued that there is little evidence to support major environmental risks for aquaculture locally. For these participants, current sites were considered adequately located to support salmon growth without environmental harm. In addition, the participants felt the industry was operating farms well, reflected in their confidence in current regulations: "There are small issues but no real negative impacts. Because if you do everything right in terms of husbandry, stocking density, etc. you don't have negative impacts.".

These participants addressed criticisms of fisheries impacts, drawing from statistics on the continued profitability and population status of wild stocks. Drawing from experiences, these participants argued that not all fishers are affected by, or oppose aquaculture, and others in fact benefit from increased lobster catches near cages. Rather, they believed much of the criticism towards aquaculture is based on misinformation and other factors such as attitudes towards any change in people's community or environment. Still, the participants highlighted the sector should continue increasing oversight, reducing risks, and conducting scientific research.

6.5 IDENTIFYING FACTORS DRIVING SOCIAL RESPONSE

6.5.1 Perceptual factors around legitimacy

Three main dimensions of legitimacy emerged from thematic coding describing participant attitudes towards aquaculture, including input legitimacy, throughput legitimacy, and output legitimacy (**Table 6.2**). In recent years, research has begun to consider legitimacy concepts for analyzing complex social conflicts and exploring social acceptance of the industry and its governance (e.g., Bjørkan & Eilertsen, 2020; Sønvisen & Vik, 2021). Likewise, this study demonstrates conflicting perceptions of legitimacy across perspectives (Appendix D.12), reinforcing the utility of legitimacy as a frame to operationalize social acceptance as embedded within particular social contexts (Washington & Zajac 2005; Zimmerman & Zeitz, 2002).

Table 6.2 Main themes emerged from interview coding, categorized within three main dimensions of governance legitimacy.

Dimensions of legitimacy	Themes	Examples
Input legitimacy: *based on perceptions related to the procedures, processes, and policies that feed into decision-making processes*	Evidence behind decisions	"I've been up there with the suits, they think they are the experts, but WE are experts, we're the ones living next to it for 20 years."
	Priorities and motivations	"They go ahead and do whatever they want…It's a private company… They will do what they wanted to fit their business model…"
	Industry oversight	"But if they follow the rules and do what they're supposed to do, I can't see where its impacting anything."
	Who makes decisions	"…it's a flawed system. It's not supervised… and it seems to be driven by the stakeholders rather than the people that matter."
Throughput legitimacy: *the ways that people are involved in the policy process, involving knowledge and engagement*	Transparency and availability of information	"So they hide the renewal down a deep rabbit hole on the website of NSDFA. Like it's not, it's not bright and top and center…"
	Reliability of information	"They [the government] let the media outline it. And media… they usually don't agree. They slant it…"
	Community and stakeholder engagement	"Um, so it's, as far as I'm concerned, the industry seems to take a 'pound sand' attitude about community engagement."

Output legitimacy: *relates to the outcomes of policies and procedures (e.g., the social and environmental impacts of aquaculture)*	Environmental impacts	"It's not a matter of if it's just when the bottom will become polluted…it's a real mess."
	Material well-being (economic and health impacts)	"It would certainly be wonderful to get one of these companies in and build a 2-3 billion dollar for GDP."
	Subjective well-being (experience, aspirations, spiritual)	"…when it started to smell, the kids couldn't go on the beach anymore…"
	Relational well-being (concerning personal and social relations)	"The most negative impact…was the way that [the industry] went about dividing the community."
	Distribution of risks and benefits	"They [industry] are great at wanting to employ people but not throw their money around the community."

6.5.1.1 Input legitimacy – Policies and procedures

Participants commonly focused their arguments about aquaculture on several themes regarding the legitimacy of policies and procedures and manifested questions around how decisions are made (**Table 6.2**). Increasingly, aspects of governance have become more prominent in public conflicts of aquaculture (Condie et al., 2022; Ertör & Ortega-Cerdà, 2015; Salgado et al., 2015). In addition, these findings are consistent with emerging discourses of mistrust towards regulative agencies and the need to reform many policy processes (Billi et al., 2022).

One topic of contention revolved around how governments use evidence in their decisions. While the participants agreed that scientific research and evidence-based decision-making were paramount, differing views emerged on how effectively science was being applied, reflecting polarized views among participants (e.g., Condie et al., 2022). In this study, opponents perceived governments to be ignorant of scientific findings that may denounce the industry, reflecting concerns of a broader regulatory environment in Canada that has not responded effectively to results of scientific analysis (Soomai, 2017). A perceived tendency of governments to ignore science in decision-making was often linked to eroded trust in government and industry science, leading to arguments that decisions should be based on rigorous, independent scientific evidence. In comparison, positive attitudes manifested as confidence in the scientific evidence used in decision-making, with supporters believing that decisions undergo multiple rounds of consultation so that evidence is "under the radar" multiple times. In addition, this study found competing values over including experiential knowledge of local experts in decision-making. These arguments reflect differing epistemologies of science for aquaculture planning, which has been linked to conflicts in perceptions in aquaculture in New Zealand (McGinnis & Collins, 2013).

One major theme put forward by opponents reflected the priorities and motivations behind policy decisions, which were perceived to ignore broader environmental impacts and social well-being. This study reinforces findings in other salmon farming areas (e.g., Ford et al., 2022; Lindland et al., 2019), where communities have criticized economic motivations and growth priorities of government and industry. In addition, these criticisms were linked to a sense of distrust, as participants felt government and industry did not respect the community interests or values, suggesting a legitimacy-gap based on perceived disagreements regarding what is valued (Boltanski & Thévenot, 2006).

Perceptions of industry oversight emerged in relation to how governments oversee the aquaculture industry to protect the environment and public interest. In the present work, disagreements emerged over the ability of governments to meet regulatory expectations through monitoring and enforcement, which the participants considered critical for ensuring sustainability. These findings further support ongoing public criticisms, which are demanding stronger and more stringent regulatory oversight (see Mather & Fanning, 2019). In addition, conflicts over the content of regulations emerged, with opponents perceiving regulations as not the claimed “gold standard”, criticizing perceived deficits in the government’s process for Environmental Impact Assessments (EIA), as well as a lack of transparency and inadequate communications. These findings are consistent with research from Norway, where poor content legitimacy of regulations and policies has related to low acceptance of aquaculture (Bjørkan & Eilertsen, 2020; Sønvisen & Vik, 2021). Conversely, supporters recognized regulatory changes in the province (e.g., Withers, October 2015), leading to the perception of substantive improvements and positive attitudes towards aquaculture regulation.

Social responses were also driven by arguments around who makes decisions, reflecting perceptions of procedural fairness and participatory governance. Perceptions of bias and misrepresentation manifested concerns over distribution of power into the hand of industry, with opponents feeling decisions are driven by industry desires more than desire of communities. These concerns were also linked to criticisms regarding the dual role of government acting as both regulator and promoter of the industry, a longstanding source of conflict across Atlantic Canada (e.g., Doelle & Lahey, 2014; Maxwell & Filgueira, 2020; Rigby et al., 2017). Others highlighted structural issues with having government positions held by previous industry members. These concerns manifested a sense of "bias" and poor legitimacy of policy processes, since neutrality of policy makers is as a key component of procedural legitimacy (Tyler, 2007). In addition, opponents linked their feelings of distrust, of being ignored, and unfairness of government and industry to a perceived exclusion of citizens and relevant stakeholder groups during aquaculture decision-making. Complaints about fair and participatory governance for aquaculture have likewise motivated opposition movements in Europe (Ertör & Ortega-Cerdà, 2015). Furthermore, opponent perspectives encapsulated issues beyond aquaculture but related to decentralized community planning, reflecting a desire for communities to have greater power in determining what types of industries are best for an area. These issues are consistent with growing resistance against top-down management for more integrated, holistic marine planning in coastal Nova Scotian communities (Wilson & Wiber, 2009). Yet, supporters refuted the shift towards more bottom-up management approaches, stating this approach is driven by people who have little understanding and awareness of aquaculture issues.

6.5.1.2 Throughput legitimacy—Engagement and information

The findings from this research suggest that social responses to aquaculture are driven both by how people access and trust information about aquaculture, and how individuals are engaged during decision-making (**Table 6.2**). Likewise, social acceptance research has identified links between attitudes developed through experiences and knowledge (e.g., Stankey & Schindler, 2006), reflecting ideas about the legitimacy of governance throughputs, or how people perceive the way they are engaged (Schmidt, 2013). These findings also corroborate discussions of the importance of transparency, inclusiveness, accountability, and openness in mediating the legitimacy of governance throughputs (Taylor, 2019).

This work reinforces the critical role that transparency of information plays in the social acceptance of aquaculture (Trueman et al., 2022), leading to more accountable and legitimate governance (Schmidt, 2013). Opponents highlighted the lack of access to reliable, independent information about aquaculture, reflecting resistance movements in other salmon farming areas (e.g., Baines & Edwards, 2018; Ertör & Ortega-Cerdà, 2015). Conversely, supporters perceived information to be available, though often provided through personal experiences and dialogue; these participants thus raised issues of making the public aware of information, emphasizing the importance of education and awareness-raising. In addition, the participants stressed that their perceptions around transparency were also influenced by the way governments and industry communicate information, highlighting the importance of improving clarity and minimizing confusion in the effectiveness of transparency (Fox, 2007).

These findings illustrate that social responses to aquaculture were intertwined with perceptions of the reliability of information about aquaculture. The relevance of this theme reinforces the link between legitimacy of information and knowledge and social acceptance (Cullen-Knox et al., 2017), where the "effectiveness" of evidence-based decision-making relies on perceptions of credibility, relevance, and legitimacy of scientific knowledge (Cash et al., 2003). For example, the opponents expressed little trust in the information made available by the government and industry, which was often perceived as "propaganda" for the industry. In addition, different perceptions on the legitimacy and trust towards information suggest that for some individuals, awareness-raising and transparency alone will not necessarily generate positive attitudes. Yet, all perspectives presented rational arguments based on "objective and factual knowledge", emphasizing how conflicting paradigms of knowledge can influence social responses (Aestre & Vik, 2013). Yet, scientific knowledge can become politicized, as interest groups can "cherry-pick" information and mobilize scientific findings to support conflicting positions on aquaculture (Sønvisen & Vik, 2021). This process of "cherry-picking" may contribute to misinformation, which was quoted by both supporters and opponents as a challenge for the industry. Several participants criticized the role of media, both news media and social media, which is reportedly spreading misinformation about the industry and its benefits and risks. Yet, many participants referred to media as sources of information, suggesting a complex role of media in social conflicts, which has been previously recognized in aquaculture debates in Atlantic Canada (Maxwell & Filgueira, 2020; Trueman et al., 2022).

Negative perceptions were not always embedded in deficits in public understanding or lack of knowledge, but in affective responses to how individuals are communicated with and engaged. Some participants expressed how communication alone is meaningless if the government and industry are not open and inclusive, giving locals the opportunity to speak and be heard. Likewise, social acceptance literature across other resource sectors considers procedural fairness, that is processes that allow citizens to express their views, intertwined with trust and acceptability of processes (e.g., Huijts et al., 2012; Mercer-Mapstone et al., 2018). In addition, how industry and government respond to public concerns was a common theme raised by opponents, who described feeling "handled" or "manipulated" by government and industry, and frustrations over concerns "laying on deaf ears", built from experiences of in-action following public criticism. Conflicts also involved fairness in the ability of different interest groups, including citizens and key stakeholders (like fishers) during engagement processes. Responses were also driven by conflicting views on the quality of interpersonal relationships between aquaculture (industry and government) and community during engagement. Many opponents perceived industry and government to be contemptuous and disingenuous, contrasting with positive interactions expressed by supporters, who perceived the industry and government to be genuine, open, and forthcoming. These findings echo conflicting views on engagement in aquaculture in other areas (e.g., Billing, 2018; Sinner et al., 2020), reinforcing the need for positive, respectful relationships between community and industry actors. Reflecting findings from other sectors (e.g., mining; Mercer-Mapstone et al., 2018; Moffat & Zhang, 2014), these results suggest that both the extent and quality of contact are key predictors of social responses, emphasizing the importance of the nature of relationships on building trust and driving social acceptance for aquaculture (Baines & Edwards, 2018).

6.5.1.3 Output legitimacy–Perception of impacts and outcomes

The perceptions reflected various themes related to output legitimacy as reflecting a complex process of weighing perception of risks and benefits, in addition to judgements on whether they are deemed appropriate based on what societies want and value (**Table 6.2**). These findings reinforce perception of risks and benefits as an important driver of social response, supporting other social acceptance studies in aquaculture (e.g., Bailey & Eggereide, 2020; Freeman et al., 2012; Mazur & Curtis, 2006; Whitmarsh & Palmieri, 2009).

Perceptions of environmental risks of salmon farming was a recurring theme shaping diverging attitudes to aquaculture among participants. The emphasis of potential environmental impacts such as impacts on wild marine species and habitats from disease, escapes, and fish waste reflect well-known conflicts around salmon aquaculture around the world (Cullen-Knox et al., 2019; Olsen & Osmundsen, 2017; Rickard et al., 2018; Krøvel et al., 2019). Likewise, this was reflected in the importance placed on environmental impact assessments to mitigate potential risks, underscoring the importance of planning for, and minimizing risks to the marine environment in improving the perceived legitimacy of aquaculture.

Moreover, social responses to aquaculture exhibited complex arguments over the consequences of environmental and social impacts on individual and community material, subjective, and relational well-being. These findings underscore the importance of ongoing work investigating how to incorporate well-being into aquaculture decision-making (Alexander, 2022; Krause et al., 2015), advocating a focus away from governance mechanisms that prioritize economic growth through the "Blue Economy" to more holistic priorities of well-being encapsulated by the "Blue Communities" approach (Campbell et al., 2021).

Perceptions of aquaculture's influence on material well-being encompassed conflicting arguments around economic benefits, including direct employment and potential economic spinoffs, emphasizing social responses as intertwined with whether aquaculture acts as a potential provider to communities and reinforcing the importance of socio-economic impacts in perceived legitimacy of aquaculture (Bjørkan & Eilertsen, 2020). In addition, conflicting ideals about aquaculture's potential impact on other livelihoods, including concerns over fisheries displacement, marine access, and visual impacts, reflected similar concerns over aquaculture expansion at the expense of other social and economic activities in other areas (e.g., Ertör & Ortega-Cerdà, 2015). An important part of material well-being also manifested as conflicts around the role of aquaculture as a food system, echoing broader contention over the health benefits of salmon (Amberg & Hall, 2008), and how aquaculture can address food security amidst increasing global demands for seafood (Belton et al., 2020).

In addition, the participants also expressed concerns regarding the impacts on subjective (that is spiritual, emotional, or mental) well-being. For example, aesthetic concerns were often linked to people's non-instrumental uses of the environment for recreation or enjoyment, encompassing aspects such as sense of place, spiritual, and cultural heritage (e.g., Cooper et al., 2016). For example, a prominent criticism of opponents revolved around their perception of the industry as not being a legitimate user of the environment, since the industry was perceived to interfere with how they experience and value the environment. These concerns support ongoing discussions within broader social acceptance literature placing values as a central motivating factor in people's attitudes towards environmental governance outcomes (Stankey & Shindler, 2006). In addition, perception of benefits was influenced by how participants felt they contributed to individual and community aspirations for the area, a feature previously found in other salmon farming areas (e.g., Alexander, 2022).

A recurring theme also emerged over aquaculture's impacts on relational well-being, as conflicts around aquaculture impact relationships between individuals. For example, several participants believed aquaculture to create community impacts by generating social tensions and creating a process of "othering", a form of cultural differentiation, that is, the increased differences between various groups in a community (Vanclay, 2002). As some participants described, these conflicts have impacted relationships within the community, thus community cohesion and overall sense of social well-being.

Another relevant feature related to perceived output legitimacy of salmon aquaculture emerged out of conflicts underlying the desire for fair distribution of risks and benefits. For example, while many participants recognized positive economic impacts of aquaculture, the fairness in the distribution of economic benefits was a more relevant driver for acceptance, and a major criticism raised by opponents. Distribution of benefits has likewise been recognized as an important facet of conflicts in other salmon farming areas (e.g., Ertör & Ortega-Cerdà, 2015; Sinner et al., 2020), which similarly recognizes that focusing on purely material benefits such as contribution to Gross Domestic Product (GDP) is unlikely to build public confidence in aquaculture. In addition, opponents criticized that through government subsidies and incentives, government and taxpayers are paying for the industry and their mistakes, while also receiving very little tax revenues from fish farms, leading to unjust distribution of benefits (e.g., Ertör & Ortega-Cerdà, 2015). These findings reinforce conclusions from wind energy developments (Gross, 2007) that found that unjust distribution of benefits can create a perception of financial "winners and losers" and damage the social well-being of communities. As a result, this study supports findings from other sectors emphasizing that factors related to distributional justice and distributive fairness are a key component of the social acceptance of aquaculture (Huijts et al., 2012; Wüstenhagen et al., 2007; Zhang et al., 2014).

6.5.2 Perceived trust

Perceptions of trust emerged as the primary driver and determinant of differences in attitudes, suggesting trust as a key perceptual factor of social response. Likewise, trust has been regarded as a primary motivator for social acceptance in aquaculture (Alexander, 2022; Freeman et al., 2012; Mazur &Curtis, 2008; Tiller et al., 2017) and other resource sectors (e.g., Ford & Williams, 2016; Huijts et al., 2012; Ross et al., 2014). This study considers trust as a cross-cutting issue, as it was influenced by other elements (like the assessment of risks, fairness, and awareness), and likewise also influenced them. Pre-existing, and sometimes prejudiced, opinions about individuals and institutions (Evans & Revelle, 2008) can also influence perceptions of trust. For example, a history of conflicts in other industries can erode institutional trust in government (Salgado et al., 2015), while beliefs about corporations can influence the trustworthiness of large aquaculture companies (Ford et al., 2022). Moreover, perceptions of throughput legitimacy based on how individuals are engaged influenced trust between individual persons, which emerged as an important motivator in people's response to aquaculture, supporting the important role of relationship building for effective decision-making (Parkins & Mitchell, 2005; Moffat & Zhang, 2014). Perceptions of trust can also shape and motivate other perceptual factors. For example, trust in scientific information and actors communicating scientific information may lead to more positive evaluations of risks and benefits (Huijts et al., 2012), creating dynamic interplays between output legitimacy and trust. Taken together, these findings emphasize the critical need for governments and industry to build and maintain trust for more legitimate aquaculture decision-making.

This study identified several themes relating to the trustworthiness of the procedures underlying aquaculture governance, suggesting that institutional trust was a key factor in driving social responses to aquaculture. This study thus supports arguments that institutional trust may be more important than interpersonal trust between individuals in legitimate planning and decision-making (Parkins & Mitchell, 2005). Opponents expressed strong distrust in government decisions. Their arguments remarked on both perceived failures to enforce the regulations that govern the industry and in themes related to challenges with governance structures, often extending to other resource sectors as well. Yet, supporters had high perceived confidence in government, citing regulatory changes as a major driver of built confidence. While industry trustworthiness was also a point of contention between opponents and supporters, perceived trust was similar for both industry and government, highlighting the interconnectedness of actors within the sector. The trustworthiness of other actors may also apply to understanding social acceptance (e.g., Alexander, 2022), as the participants in this study criticized the role of media and NGOs in shaping the information that people receive. In conclusion, perception of procedural legitimacy is a relevant determinant of trust, ultimately guiding people's responses to aquaculture.

6.6 UNDERSTANDING SOCIAL ACCEPTANCE IN AQUACULTURE

The in-depth interviews with residents and stakeholders in three salmon farming communities revealed a diversity of perceptions about the management and potential impacts of salmon aquaculture, manifesting as four diverging perspectives towards aquaculture. Likewise, recent research has identified a range of differing views and conflicts within communities amidst the expansion of salmon aquaculture (Froehlich et al., 2017; Lindland et al., 2019; Young et al., 2019), reinforcing ongoing debates on the controversial nature of salmon aquaculture (e.g., Condie et al., 2022; Young & Matthews, 2010). Conflicts, concerns, and priorities were not homogeneous, even among those with similar overall opinions, suggesting that decision-makers should acknowledge a continuous spectrum of perspectives towards aquaculture. These findings recognize that the controversy over aquaculture symbolizes more than just attitudes about salmon farms; rather, the controversy incorporates a suite of wider public issues, such as animal rights, food safety and security, corporate power, and community empowerment (Ladd, 2011). Further, social responses expressed nuanced considerations of how aquaculture supports individual and social well-being, reflecting not only the physical manifestations of impacts (in terms of relocation, employment etc.) but also the meanings, perceptions, and social significance of changes. Accordingly, policies that consider different understandings of value and well-being domains may contribute to more legitimate planning for aquaculture.

Comparison of salmon farming perspectives within Nova Scotia communities revealed perceptual factors around trust and legitimacy as the most relevant attributes explaining differing attitudes shared among perspectives (**Figure 6.1**). By identifying a diversity of perceptual factors that shape attitudes toward aquaculture, this work can inform further development of conceptual models for social acceptance and understand the key drivers of social responses. Framing of perceptions around legitimacy proved useful to organize emergent themes related to participant's perceptions of how decisions are made, how stakeholders are engaged and informed, and how benefits and costs from aquaculture are distributed. This conceptual model also recognizes feedback across components of legitimacy, contending that each component of legitimacy, on its own, is insufficient to evaluate social responses to aquaculture. Likewise, legitimacy is deeply intertwined with evaluations of trust in government, industry, and science, which is a key predictor of social responses. While this model only considers perceptual factors, other factors may affect social response to salmon farming, such as individual traits (e.g., socio-demographic variables) and contextual factors. Nevertheless, this conceptual model can help clarify the relative importance and interactions between perceptual drivers of social acceptance in aquaculture and help inform the design of more sustainable and legitimate aquaculture governance.

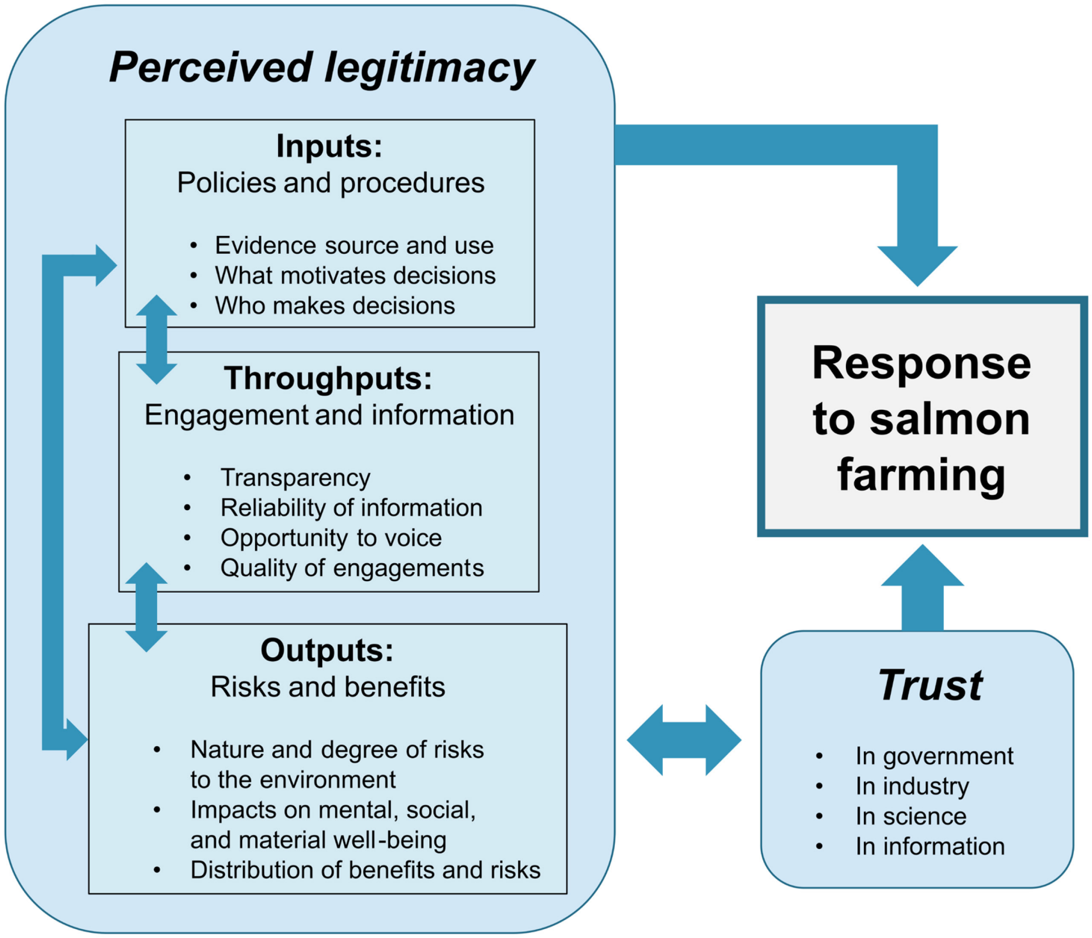

Figure 6.1 Conceptual model of perceptual factors and how they interact to influence social response to salmon farming.

CHAPTER 7: CONCLUSIONS

7.1 INTRODUCTION

Aquaculture continues to be an important sector to address growing global food demands and support economic growth and improved livelihoods. Aquaculture presents opportunities to meet the United Nations (UN) Sustainable Development Goals (SDGs) of reducing hunger, supporting well-being, and promoting sustainable economic growth. Thus, implementing sustainable aquaculture is central to achieving many SDGs (FAO, 2017), but may require a shift towards more systems-thinking governance and management (Stead, 2019). In response to the rapid growth of aquaculture and the need to manage the interactions of aquaculture with other resource users and ecosystems, the FAO developed the Ecosystem Approach to Aquaculture (EAA) as a systems-approach strategy for integrating aquaculture within wider ecosystems such that it promotes sustainable development, equity, and resilience of interlinked Social-Ecological Systems (SES) (Soto et al., 2008). Despite the inception of EAA over ten years ago, it has had a varied uptake in decision-making contexts and continues to face challenges in tackling complex governance issues, in part due to limited capacity to incorporate and implement the range of conceptual and technical knowledge demanded of such an approach (Brugère et al., 2018). Despite the challenges, implementing EAA could be operationalized through more holistic assessments of aquaculture that consider inter-linkages between social, economic, and environmental sustainability and well-being.

Developing an integrated view of carrying capacity (CC) may serve as a valuable way to implement a holistic approach to aquaculture assessment, offering a tool to assess whether aquaculture activities are within the acceptable physical, production, ecological, and social thresholds relevant to operationalizing the EAA (Ross et al., 2013). Yet, the full integration of different carrying capacity components does not yet exist, and it remains poorly understood whether such an approach can tackle complex governance issues of SES or align with EAA principles. In addition, little research has investigated social aspects of aquaculture, and how to define, measure, and incorporate social considerations into carrying capacity.

The overall objective of this thesis was to investigate carrying capacity for the holistic assessment of salmon aquaculture in the context of an Ecosystem Approach to Aquaculture. To achieve this objective, this research aimed at answering two overarching questions:

1. How can carrying capacity be mobilized to support the holistic management of salmon aquaculture?

2. What factors determine the socially acceptable limits of salmon aquaculture?

The results from this thesis highlight that carrying capacity for more holistic assessment of salmon aquaculture is a dynamic, interdisciplinary, and complex topic that will continue to require conceptual and technical knowledge to effectively implement into decision-making. This concluding chapter first discusses the strengths and weaknesses of existing carrying capacity applications to discuss the potential role of CC in more holistic aquaculture management. Then, this chapter situates the overarching results of this thesis within the context of closing the gap towards a better understanding of how to define, measure, and consider social carrying capacity. This chapter subsequently synthesizes the findings and considerations across the thesis chapters to discuss a path forward for integrating holistic carrying capacity (HCC) into aquaculture planning and decision-making, highlighting considerations of multiple limits embedded within a context of social values and relevant policy settings. This chapter concludes with a summary of the research limitations of this thesis and an agenda for future research opportunities and needs.

7.2 THE ROLE OF CARRYING CAPACITY

7.2.1 Opportunities and challenges

The last 40 years have witnessed a suite of definitions, tools, and methods for estimating CC in aquaculture, marking what can now be considered a mature field of study (Chapter 2). Carrying capacity's varied applications across diverse fields, as well as its conceptual simplicity and flexibility, and its recent attention in aquaculture settings offer opportunities to capture multiple objectives related to sustainable resource management (**Table 7.1**). Carrying capacity has been developed considerably within aquaculture to quantify the potential biomass of species for aquaculture, determine optimal sites for production, and understand the impacts of culture production on the surrounding environment (Chapter 2). Carrying capacity for aquaculture can recognize multiple management objectives (**Table 2.1**) and the field of study offers several well-developed methods to evaluate ecological, social, governance, and economic interactions (Chapter 2). In particular, the extensive research into defining indicators and tools for production and physical aspects of carrying capacity present useful and robust measures to assess the environmental suitability for sites and the economic viability of aquaculture projects. Likewise, ongoing research is working towards supporting many of the necessary research pillars identified as important in aligning carrying capacity for an EAA (Chapter 2). For example, ongoing CC research has expanded models to include a wider set of considerations, such as disease (Ferreira et al., 2021). In addition, multiple tools already exist that are highly suitable for measuring different aspects of carrying capacity (**Table 3.4**; Chapter 3), and that continued advances in models and Geographic Information Systems (GIS) applications (e.g., Taji et al., 2022; Tsiaras et al., 2022) are making significant contributions to improving the reliability and usefulness of carrying capacity estimates. While social carrying capacity (SCC) remains largely in a development stage (Anaïs et al., 2020), ongoing research is working to develop SCC tools and measures; for example, using media analysis to scope for social priorities (Kluger et al., 2019), and surveys to create an index of social acceptance to measure social carrying capacity (Ruiz-Chico et al., 2020c). These strengths highlight a promising future role for carrying capacity to guide planning, management, and monitoring processes for many parts of the social-ecological system in which aquaculture is embedded.

Table 7.1 Summary of opportunities and challenges for mobilizing carrying capacity for holistic assessments of aquaculture.

	Opportunities	Challenges
Conceptual	• Rich research area with extensive supporting literature • Conceptually simple, well-understood across many fields	• Vague and inconsistent definitions, and application of CC concepts
Policy-relevance	• Supports practical pathways into many decision-making processes • Fits well in early planning (e.g., site selection, license applications)	• Needed data often not collected • Many policy procedures not equipped for holistic CC considerations
Logistics	• Availability of tools to choose from given logistical constraints	• Many tools are expensive, time-consuming and data intensive
Procedures available	• Suite of well-developed indicators and tools (e.g., models) • Tools suitable for spatial analysis (e.g., GIS)	• Current estimates often prioritize few interactions and single CC components • Paucity of methods for measuring social CC for aquaculture • Seldom accounts for cumulative or long-term temporal changes
Knowledge base	• Substantial contribution to biophysical suitability • Availability of reference points for several ecological processes	• Understanding and measuring SCC is in its infancy • Poor representation of important ecosystem processes and indicators that reflect the complexity of SES

While this thesis presented some opportunities for future work in developing and implementing a holistic approach to carrying capacity, several critical challenges remain that will continue to hinder the ability of CC to support holistic assessment of aquaculture (**Table 7.1**). A prominent challenge emerged over the language about carrying capacity, which was found to be unclear or inconsistent, leading to different interpretations and applications of the concept (Chapter 2 and 3). Furthermore, consultations with aquaculture and carrying capacity experts revealed that defining relevant CC terms and concepts was essential for effective CC application in decision-making (Chapter 3). Still, there was no agreement among the responses of the experts on shared definitions of any of the individual CC components (i.e., physical, production, ecological, or social carrying capacity). Rather, the experts contended defining terms should occur on a case-by-case assessment basis. However, including assessment-specific definitions goes against mainstream thinking of providing strong and rigid definitions that can be extrapolated to multiple contexts (e.g., DFO, 2015). As a result, improving the clarity and consistency of language around carrying capacity is critical to operationalizing a useful and robust holistic carrying capacity approach.

In addition, the findings suggest considerable challenges remaining in measuring and determining relevant indicators that operate at the thresholds of systems (Chapter 2). The literature revealed several requirements of effective indicators, including that indicators are relevant, proven effective, quantifiable, feasible, and policy-relevant (Cranford et al., 2012), favouring those that are easy to use (Gibbs, 2007). Likewise, the experts highlighted that selecting a few key indicators was key, and would require trade-offs in cost, relevance, reliability, and complexity (Chapter 3). Yet, this task becomes exponentially more challenging when merging different CC components, data types, scales, and issues across all social, economic, and environmental attributes. Other critical questions remain as to what, and who, defines a "threshold". Traditionally, CC is understood through "absolute" thresholds which reflect a natural (or biological) tipping point in the system, although experts recognized all thresholds are based on what is "acceptable" and thus a product of societal values (Chapter 3). Therefore, greater understanding of how to define and measure social perceptions and values will be necessary to mobilizing this socially determined definition of thresholds (Chapter 3), especially given the paucity of research on social acceptability of aquaculture (Chapter 2). Likewise, the experts identified procedural barriers for many CC aspects, including a lack of adequate tools and mechanisms for measuring indicators required for a more holistic perspective (e.g, far-field interactions, social aspects) (Chapter 3). Furthermore, logistical barriers exacerbate these challenges since many of the tools and approaches needed to support more participatory, interdisciplinary, and comprehensive assessments are data intensive, time-consuming, and require diverse expertise to apply, generating challenges in mobilizing tools that are useful and desirable in practical decision-making contexts. The challenges identified in both Chapters 2 and 3 reinforce the diverse research needed before operationalizing a holistic approach to CC, which can partially be mobilized by the research agenda in Chapter 2.

Another key challenge that emerged from this thesis included external factors such as ill-equipped governance structures, as well as the influence of attitudes and political buy-in that can shape how holistic tools and approaches are mobilized and applied in decision-making (Chapter 3). In Chapter 3, findings suggest that a practical approach to holistic CC may have to work with existing management structures, which may be unsuited to implement a broader view of governance. For example, governance processes and programs may only collect and monitor a limited set of potential indicators, thus creating difficulties in incorporating more holistic perspectives. For example, Nova Scotia's Environmental Monitoring Program only encompasses monitoring of the relationships between aquaculture and the surrounding benthic marine environment (Province of Nova Scotia, 2021). In addition, highly participatory and interdisciplinary CC methods required for a holistic approach (Chapter 2 and 3) will face challenges of being representative and free from bias. Thus, more critical discussion on the processes for decision-making, regulations, and policies will continue to be an important step towards more holistic and sustainable aquaculture.

Finally, this thesis found that the gap in defining and understanding social carrying capacity will continue to be a major roadblock in operationalizing more holistic approaches to carrying capacity (Chapter 2 and 3). While other types of CC are based on the threshold of a single entity (e.g., physical area suitable for physical CC), social CC describes the threshold beyond which aquaculture is not acceptable for society, encompassing multiple actors, interests, and potential spatial scales. Yet, the spatial scale and actors included in what comprises "society" in the previous definition are not inherently clear, and likely variable depending on the scale at which carrying capacity assessments occur (Chapter 3). In addition, this thesis found that social values and perceptions of acceptability varied across spatial scales, and between communities, individuals, and time (Chapters 4 through 6). In the context of providing a single CC recommendation for integrated assessment, no clear understanding exists on how to weigh different measures of acceptance by different actors, nor is it likely appropriate to do so.

7.2.2 The role of CC in aquaculture decision-making

A critical question in understanding the role of carrying capacity emerged as to what decision-making stage is most suitable incorporating holistic approaches to CC. Theoretically, CC is positioned to inform decisions on new farm developments (such as planning and site selection), as well as for "a posteriori" decisions after farms are operational (such as monitoring and evaluation) (**Table 2.1**; Chapter 2). while experts disagreed over the relevance of CC for "a posteriori" policy stages, experts argued CC to be especially suitable for early planning and site selection stages, as well as lease and licensing processes and renewals (93% of agreement among experts; Chapter 3). Experts emphasized these stages as relevant due to the presence of clear place within existing policy processes for including CC considerations, such as during impact assessment and stakeholder engagement (Chapter 3). For example, stakeholder engagement processes during licensing processes can be a natural starting point to consider social limits and gather measures of social carrying capacity through stakeholder perceptions and priorities. Furthermore, existing literature highlights that site selection is naturally linked to carrying capacity through the need to incorporate physical restrictions like pre-existing marine uses and biophysical suitability (Chapter 2). Therefore, CC offers a valuable tool for assessment throughout various planning scales of aquaculture development, from considering a whole potential of available space, to more regional zoning and to selection of individual sites (Salin & Arome Ataguba, 2018). Institutional challenges, however, make applying the concept to other stages, such as monitoring and day-to-day management challenging (Chapter 3). For example, a holistic vision of CC rests on the need for participatory processes, especially in measuring social indicators (Chapter 2 and 3). Yet, insights into aquaculture governance in Nova Scotia find that opportunities for engagement are most often only available during site selection and renewal processes. Likewise, ongoing monitoring often measures few indicators, reflecting a gap in the number of components and indicators measured for more continuous CC monitoring. These challenges do not preclude the importance of considering the multitude of decision-making stages in holistic CC, however, this thesis contends the need to address a multitude of research gaps and would likely require structural or regulatory changes to incorporate CC considerations into a broader range of decision-making stages. Thus, focusing on incorporating HCC into early planning stages for aquaculture development may be a good first step for decision-makers seeking to apply a holistic assessment for aquaculture that is also policy relevant. In addition, applying a holistic vision of CC to planning and site selection stages is critical for better incorporating SCC, which is currently only considered through concepts of social acceptance and SLO after aquaculture operations are in place (Kluger & Filgueira, 2021). Therefore, early planning stages of aquaculture may be a good entry-point for incorporating a more integrated view of aquaculture limits for sustainable salmon aquaculture.

7.2.3 Clarifying the role of carrying capacity within an EAA

While carrying capacity is well-established across multiple fields, findings from the literature (Chapter 2) and expert interviews (Chapter 3) underscore that defining the specific decision-support role for CC is not straightforward but should be explicitly defined. The literature revealed that both in aquaculture and across other fields, CC is often applied indiscriminately to describe its role as a concept, a measure, or a tool/approach (Chapter 2). As a concept, different interpretations of carrying capacity share commonalities in that they highlight the importance of the "system" (e.g., ecosystem, social system, population, etc.) being limited beyond some determinable threshold. Even conceptually, the variation across literature represents a flexible range of applications from limits of natural populations to increased growth, to ecosystem limits reflecting the biophysical resilience of ecosystems, or even very specific applications such as limits of people visiting tourist attractions to maximize tourist experiences (Chapter 2). While this conceptual flexibility presents the opportunity to adapt CC to EAA principles (Chapter 2), confusion over conflated definitions was a major challenge identified (Chapter 3), emphasizing that CC as a concept to support an EAA requires clarification and a degree of widespread uptake in defining the system of interest (CC of what? - e.g., population, ecosystem, aquaculture) and the goal (to do what? E.g., population growth, maintain stable environment, maximize production).

Carrying capacity is also frequently referenced as a measure, representing a quantifiable evaluation of the limits of a system under investigation. This is especially relevant for ecosystem studies, often defining CC through quantitative measures indicating the population abundance or biomass, or in the case of aquaculture, the potential biomass of species for culture (Chapman & Byron, 2018). By this interpretation, holistic CC would produce a quantifiable measure of the maximum safe pressure of activities (biomass, stocking density, or size and number of farms) that maintains a combination of physical, ecological, social, and economic indicators below or above a given level or threshold (Chapter 2). Yet this definition implies the calculation of single holistic CC measure that would require multiple individual measures that are all discernable, quantifiable, and comparable. This thesis identifies numerous procedural and knowledge barriers to implementing such as task (Chapter 2), highlighting the need to develop methods to quantify and integrate indicators across dimensions (Chapter 2). Nevertheless, this thesis argues that while measures of CC are valuable components of CC, mobilizing CC as a "measure" alone is largely unsuitable for application to holistic CC.

Carrying capacity is also described as a tool, or an assessment to evaluate whether the system has exceeded the relevant thresholds. Traditionally, literature in the aquaculture field mobilizes CC as a tool to inform the assessment of specific CC indicators or applications of models labelled as "carrying capacity models" (Chapter 2). This application of CC is restrictive, often mobilized to measuring one or two indicators, focused predominantly on the biophysical or production-related aspects of aquaculture (Chapter 2). In this way, CC is also considered a tool among many in wider decision-making and planning, that also include scenario building, stakeholder engagement, and spatial analysis. Notably, carrying capacity is often positioned as a separate approach from site selection and wider zoning in support of an EAA (Sustainable Fisheries Partnership, 2018). This interpretation presents CC as a stand-alone assessment tool for decision-making similar to how tools like Environmental Impact Assessments are regularly used. In Chapter 3, a consensus-building exercise with experts was used to investigate holistic CC as an assessment tool to evaluate aquaculture against potential limits to ecological, social, and economic systems. This research identified a potential path forward for holistic assessment of CC based on several guidelines and best practices (Chapter 3). Yet, experts identified numerous challenges (**Table 7.1**) facing the effective implementation of a holistic assessment of CC. For example, holistic CC would likely require information gathered from processes external to an assessment, including wider policy goals and stakeholder engagement processes. Effective implementation of holistic CC would thus require CC considerations to be integrated within broader site selection, planning, or operations. Therefore, this thesis argues that to position CC as a holistic assessment tool for EAA will also require a re-orientation of CC as an approach to incorporate limit-based considerations about the environment, society, and economy into sustainable aquaculture planning and decision-making. In conclusion, the evidence from this thesis presents a potential role for holistic CC as both a) a holistic assessment tool to measure aquaculture limits, and b) a wider approach to integrate concepts of limits into broader governance mechanisms that together support a holistic Ecosystem Approach to Aquaculture.

7.3 CLOSING THE GAP ON SOCIAL CARRYING CAPACITY

Across the research outlined in this thesis emerged evidence that can help close the gap on social carrying capacity for aquaculture by providing insights into how to define, measure, and understand social carrying capacity. Recently, social carrying capacity has gained conceptual momentum in aquaculture (Dalton et al., 2017; Kluger & Filgueira, 2021). Additionally, recent empirical work has focused on measuring SCC for aquaculture (Kluger & Filgueira, 2019; Ruiz-Chico et al., 2020c), although SCC remains an emergent field of study in aquaculture (Chapter 2). Most existing CC assessments aim to optimize production or reduce environmental impacts, which is criticized to exclude potential social externalities of aquaculture development (Kluger & Filgueira, 2021), highlighting the necessity of social CC for more sustainable aquaculture. Similarly, findings from this thesis demonstrate that theoretically and practically, defining and understanding social carrying capacity indicators and thresholds remain a major roadblock to operationalizing a holistic CC approach. In Chapter 2, the review of the relevant literature demonstrated that little research has focused on defining "limits" in relation to social aspects of aquaculture, which is critical for operationalizing notions of carrying capacity. In addition, a lack of consistency on the appropriate scale, measurements and tools in the literature has led to a diverse and inconsistent application of the concept. Aquaculture and carrying capacity experts further substantiated these findings (Chapter 3), highlighting the requirement for substantial research on social limits and indicators, and the need to advance qualitative and quantitative tools to measure social aspects of CC. Therefore, social carrying capacity remains an emerging concept in aquaculture, and a critical area for future research.

Most commonly, social carrying capacity definitions follow Inglis et al.'s (2000) broad definition of "levels at which farm development impairs or conflicts with other human use." (e.g., Anaïs et al., 2020; McKindsey et al., 2006). Yet, other authors have expanded this definition in different ways (e.g., Byron et al., 2011b; Dalton et al., 2017), sometimes including governance and economic aspects. A comprehensive review of CC literature (Chapter 2) highlighted the need to clarify the definitions and uses for social carrying capacity, reflecting a lack of a formally accepted definition. Likewise, experts underscored the importance of defining concepts and terms in carrying capacity assessments, including social carrying capacity (Chapter 3). Yet, the interviews demonstrated experts were not in agreement on a formal definition of social carrying capacity. Experts considered existing broad-level definitions of SCC in the literature to be too "vague", but experts considered more detailed definitions inappropriate because of the contextual nature of the social aspects of aquaculture. As a result, this thesis argues that delineating social carrying capacity remains difficult. The findings from this research, however, emphasize that social carrying capacity is not just about perception of social impacts, but that acceptance is a feature of broader perceptions about the legitimacy of aquaculture governance and trust in aquaculture decision-makers (Chapter 6). Theoretically, this work (Chapter 2) argues that SCC is based on both empirical measurements of social impacts and understanding social acceptance (SA). Yet, even empirical measurement of social impacts ultimately relies on societal perceptions and acceptability. Furthermore, SCC is strongly interlinked with other CC types (**Figure 2.4**) with social values and cultural considerations as inherent determinations of thresholds relevant to all CC components (Chapter 2). Therefore, this thesis proposes a broad definition of social carrying capacity as: "the social acceptability of social, ecological, physical, and production limits, as dependent on social values and contexts.". Based on this definition, the thresholds for SCC indicators could be defined as the point at which the relevant social, ecological, physical, or production limits are no longer considered "acceptable" by relevant stakeholders. While this definition can be considered vague, it is presented as a flexible and designed to serve as a common understanding of how to position SCC within a more holistic CC assessment.

This definition has implications for the measurement of SCC as depending on measuring social acceptability across various potential indicators dependent on social values. In this way, SCC is inherently subjective, determined by the acceptability of various indicators by relevant stakeholders depending on the type of limit and contexts. By this definition, measures of SA of different limits would require drawing from a combination of scientific, industry, policy, and social expertise depending on the indicator of concern. For example, acceptability of production limits may reflect the desired threshold that is acceptable by industry, given the relevant regulatory environment. Yet, this definition recognizes that different limits may exist across different stakeholder groups. For example, governments, NGOs, and scientists may have different levels of "acceptable" limits of ecological indicators such as disease risk depending on their values, priorities, and understandings. Therefore, applying SCC in decision-making contexts would require measuring the acceptability of aquaculture across different stakeholder groups. In addition, this definition also reinforces the importance of SCC embedded within relevant contexts, thus the needed to including multiple stakeholders according to the relevant scale of assessment. Considering SCC as highly relevant across multiple scales of assessment, including both locally and within larger, regional contexts (Chapter 3), perceptions of those in communities of place (i.e., local salmon farming areas) and broader communities of interest (e.g., public), as well as government and industry stakeholders, are relevant for evaluating social acceptability and thus SCC (Mather & Fanning, 2019).

This research provides some insights into what could be considered an appropriate measure of "acceptability". The research in Chapter 4 applied quantitative measures of public acceptability based on subjective responses to Likert-scale questions of opinion. This work tested three measures of opinion and found that responses measured the same phenomenon (e.g., social acceptance). Therefore, public acceptance thresholds could be potentially measured through either a rating of i) general opinion to aquaculture, ii) support for development locally, or iii) perception of benefit-risk trade-offs. In addition, findings from community acceptance research (Chapter 6) provide evidence to support expressions of trust (including confidence) in aquaculture (especially governments) were the greatest predictor of acceptance ratings (Appendix D.10). Therefore, measures of trust may be appropriate for evaluating SCC, although how to do so empirically warrants future research. Furthermore, despite recognition of the need for SCC to reflect multiple perspectives and different social groups and stakeholders, critical questions remain on how to weigh considerations for a single "measure" of SCC. However, this thesis contends that this question should remain a policy decision that is mobilized on a case-by-case basis given the context that the CC assessment is embedded.

Thus, this thesis argues that the social carrying capacity can be operationalized through measurement and knowledge of different driving factors on social acceptance to aquaculture. Synthesizing work across chapters, we present a conceptual model of predictors of social acceptance highlighting the key drivers and their interactions that emerged from this work (**Figure 7.1**). This conceptual model outlines social acceptance as influenced by complex interactions between demographic characteristics, contextual factors, perceptual factors, and trust. Social acceptance is presented here as a uniform concept meant to reflect either individual or collective judgements of aquaculture across multiple potential scales (e.g., of the market, technology, or local operations), acknowledging that social acceptance will manifest differently across different roles, and by different actors (e.g., Wüstenhagen et al., 2007). This conceptual model offers a starting point for further research into these complex relationships with social acceptance, yet also presents some preliminary indicators and considerations for understanding social carrying capacity.

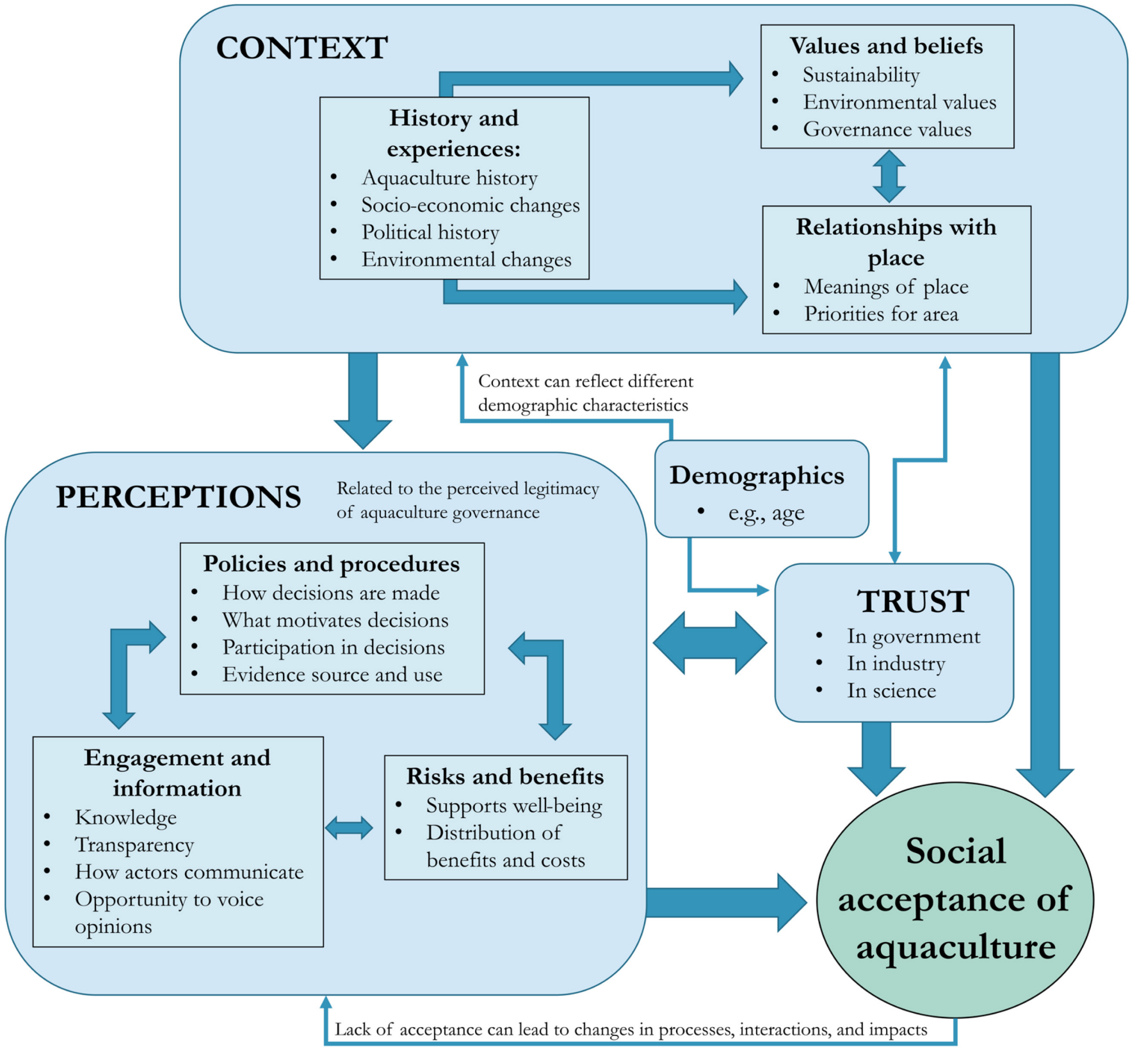

Figure 7.1 Conceptual model of social acceptance of aquaculture, exploring key drivers, and their interactions.

Geographic variability of responses in public opinion (Chapter 4) and case study areas (Chapter 5) highlights important local and regional variation in social thresholds. Furthermore, the influence of history and experiences with aquaculture on shaping trust and perceptions of salmon farming within communities (Chapter 6) highlights the dynamic nature and temporal variability in acceptability, and determination of social thresholds. This geographic and temporal variability underscores the inherently contextual nature of social attitudes and subsequent evaluations of aquaculture acceptability. Compared to other forms of carrying capacity that aim to identify a few key indicators based on which is most likely to cause a tipping point in the ecosystem, SCC indicators would need to be identified on a case-by-case basis based on which is most valued, describing "relative" thresholds (Chapter 3). The relevance of "relative" thresholds is emphasized by the findings from local salmon farming areas (Chapter 5), where case study areas expressed different perceptions of aquaculture based on their local history, environmental values, and sense of place. Likewise, ongoing social acceptance research highlights the importance of values and place in aquaculture perceptions and conflicts (Ford et al., 2022; Murray & D'Anna, 2015). This reinforces the need to better understand the value dimensions related to aquaculture to develop indicators of SCC.

Reinforcing findings across earlier aquaculture perception research (Billing, 2018; Ertör & Ortega-Cerdà, 2015; Mazur & Curtis, 2006; Salgado et al., 2015; Trueman et al., 2022), this work found that public and community attitudes were driven by perceptions of both the aquaculture industry and its governance, including decision-making processes, how individuals are engaged, and their understanding of risks and benefits (**Figure 7.1;** Chapter 6). This thesis connects these perceptual factors to concepts of *governance legitimacy*, formally defined as "a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs and definitions." (Suchman, 1995). In this way, the concept of legitimacy may serve to operationalize measurement of social acceptance (Bjørkan & Eilertsen, 2020) recognizing the influence of perceptions of aquaculture governance on aquaculture acceptability. While mobilizing the concept of legitimacy into measures of SA and SCC warrant further empirical research, indicators of legitimacy may prove more meaningful than simple measures of opinion, such as determining opinion towards risks or benefits. This is because legitimacy intertwines social values and aspects of well-being that are currently not well incorporated into planning and policy for aquaculture (Campbell et al., 2021).

This thesis also offers new insights into the influence of trust on social acceptance, and thus as an important part of SCC. Previously, trust in both government and industry has been considered an essential feature of local social licence to operate (SLO) in both aquaculture (e.g., Billing, 2018; Mazur & Curtis, 2006; Salgado et al., 2015) and other resource sectors (e.g., Gaede & Rowlands, 2018; Wiersma & Devine-Wright, 2014; Zhang et al., 2014). This thesis reinforces earlier studies and expands this connection to the more encompassing concept of social acceptance, recognizing that trust is not just a determinant for attitudes reflecting the relationships and interpersonal trust between local actors, but also reflects broader perceptions of institutional trust in government organizations, scientific institutions, and corporations (Chapter 6). In both public and local community studies (Chapters 4-6), trust emerged as a powerful predictor of different social responses, with distrust being a strong determinant of opposition. As a result, this thesis presents trust as a cross-cutting issue deeply intertwined with how individuals perceive and understand aquaculture and their subsequent judgements of acceptability of the sector.

7.4 A WAY FORWARD FOR HOLISTIC CARRYING CAPACITY

Despite emerging research in aquaculture CC, few studies have attempted to adjust CC models and frameworks to EAA principles (Byron et al., 2011b; Kluger et al., 2016; Silva et al., 2011). To address this gap, this work first outlined a research agenda (Chapter 2), which can provide a guide for decision-makers and scientists to advance the knowledge and tools to support more holistic management that considers limits of complex social-ecological systems. Chapter 2 presents a research agenda based on curating meaningful information based on holistic principles including: recognizing system complexity, responding to policy needs, applying adaptive frameworks, and embracing interdisciplinarity to advance more holistic assessments of carrying capacity. In Chapter 3, subject-matter experts further validated the relevance of these principles, highlighting specific implications for building a holistic carrying capacity approach for assessment of salmon aquaculture (**Table 7.2**).

Table 7.2 Summary of overarching principles guiding a holistic carrying capacity and future research actions to support the principles

Principles	Implications for CC	Potential research actions
Consideration for system complexity and scale	• Consideration of multiple temporal and spatial scales of application • Consideration of dynamic changes to indicators	• Greater knowledge of the interactions and effects of aquaculture on other aquatic users • Quantification of far-field effects for CC estimations • Measuring variation of indicators across space and time
Policy-relevant	• Participatory and inclusive of stakeholders throughout • Transparent and clear, including all necessary information	• Selection of policy-relevant indicators to management contexts • How participatory processes can support CC estimation
Being adaptive and iterative	• Respond to changes over time • Enable regular re-assessment	• Consideration of potential uncertainties that can influence CC • Influence of cumulative and potential long-term changes to indicators (e.g., such as from climate change)
Embracing interdisciplinarity	• Consider physical, ecological, social, governance aspects • Integration of different aspects and their interactions	• Methods to integrate disparate data types and methods • Understanding and defining social limits and indicators • Exploring ecosystem services for assessing aquaculture limits

Together, the findings of this work help chart a way forward for holistic carrying capacity (HCC) as an assessment tool and as an approach for sustainable, ecosystem-based management of salmon aquaculture. Concurrent with expert consensus (Chapter 3), this thesis defines the holistic assessment of carrying capacity for aquaculture as:

> An evaluation of proposed and/or current aquaculture operations against the acceptable limits, as defined through consultation with stakeholders, of the components of the social, ecological, and economic environment in which aquaculture is embedded.

Drawing from the key conceptual principles stated above (**Table 7.2**), this thesis proposes a set of practical guidelines and recommendations for building a holistic approach to CC for assessment of aquaculture limits in decision-making (**Table 3.2**). Findings across this thesis underscore the need to move away from industry-focused approach to carrying capacity towards an inclusive vision that incorporates social values, contexts, priorities, and concerns of multiple stakeholders in relevant policy and decision-making contexts.

To guide practical applications of HCC as an assessment tool, evidence gathered in this thesis can be synthesized to present a broad approach to aquaculture decision-making that incorporates concepts of CC. This thesis contends that holistic carrying capacity can conceptually be viewed as a series of embedded "lenses" which serve to frame, define, and contextualize an interdisciplinary set of measures, including the 1) policy setting, 2) social values and 3) limits of the aquaculture social-ecological system (**Figure 7.2**). This marks a distinction from past work to integrate multiple types of carrying capacity for decision-making, which propose a largely linear, hierarchical approach to determining the carrying capacity of an area (e.g., McKindsey, 2012). The approach proposed here is a conceptual viewpoint of HCC reflecting broad considerations for decision-makers, to supplement the practical best practices (**Table 3.2** and step-wise process for HCC developed in Chapter 3 (see **Figure 3.3**). Linking to the step-wise process in Chapter 3, both a consideration of the policy setting and social values "lenses" would occur in Stage 1 (planning), whereas consideration of limits is most linked with Stage 2 (analysis). The following conceptual approach is described below by largely positioning HCC as a part of traditional, top-down governance, whereby HCC would be integrated within government-led policy processes. This was considered given expert recommendations on the most practical and useful entry point for HCC (Chapter 3). Yet, the general conceptual viewpoint could theoretically also be implemented through more participatory, bottom-up applications, which would notably introduce a distinct framing across the embedded "lenses" of the approach.

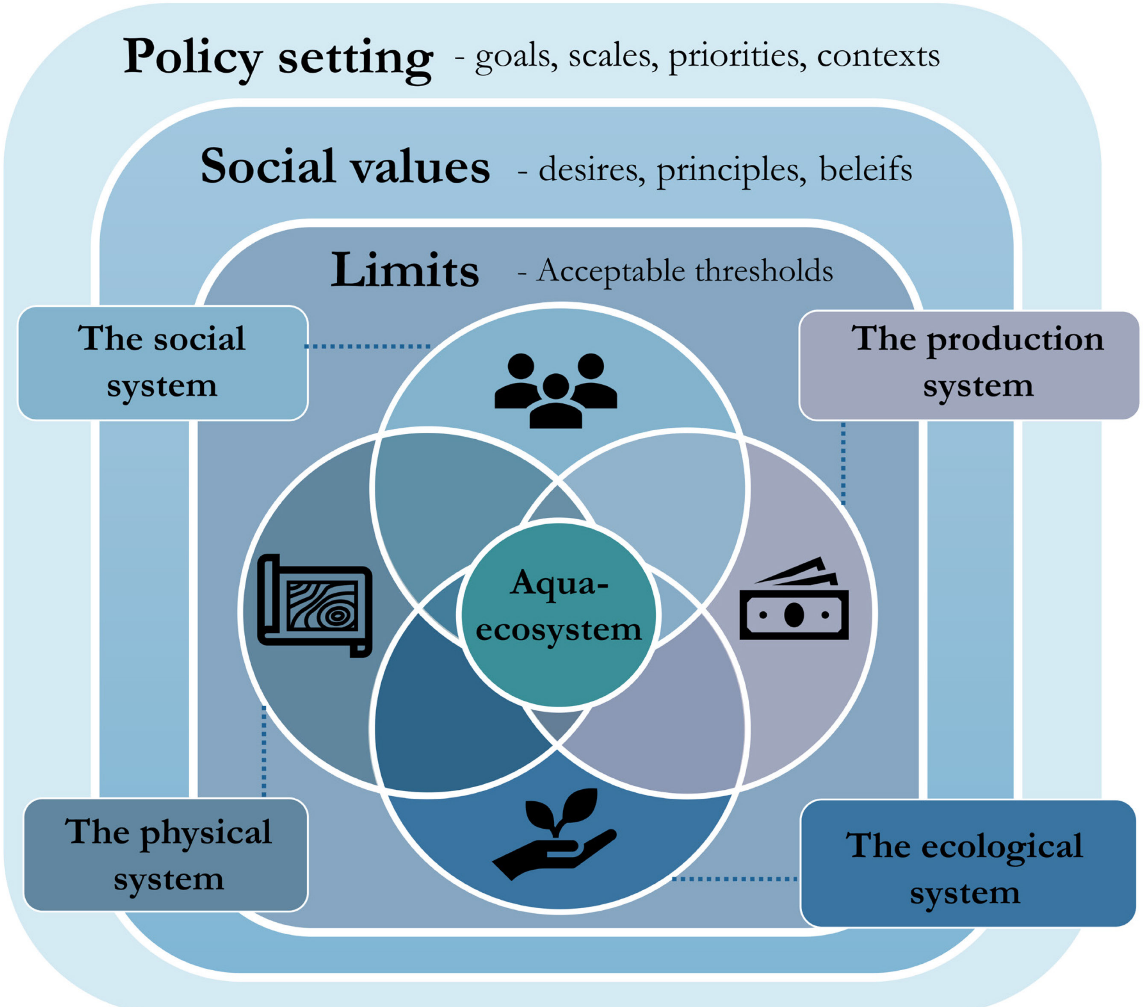

Figure 7.2 Visualizing HCC considerations across overlapping "lenses" placing limits across multiple subsystems of the aquaculture social-ecological system within relevant social values, as distinguished across specific policy settings.

7.4.1 Carrying capacity through the policy setting lens

Traditionally, the determination of policy goals and priorities is often part of broader site selection processes, occurring as a distinct step before CC assessments. Rather, this thesis suggests policy implications as the first decision-making lens that managers and planners could incorporate into any process that aims to apply HCC assessment, including planning and zoning for aquaculture, selecting individual sites, conducting impact assessments, or regular monitoring processes. As experts noted, a clear understanding of the overall objectives of the assessment can improve the legitimacy of the process and is crucial for properly identifying relevant indicators in subsequent steps (Chapter 3). This would involve setting the broad goals of the assessment, including at which stage of aquaculture decision-making the assessment aims to address. This also includes selecting the relevant spatial scales at which to measure information on social values and limits in subsequent stages. Once decision-makers identified the goals and scales of assessment, building the relevant socio-economic and ecological contexts relevant to the identified setting will help guide subsequent steps. Findings from this work demonstrate that the considerations of what is valued, prioritized, and considered acceptable varies across social and geographic contexts (Chapters 4 and 5), emphasizing the role of contextual factors in determining the scale, stakeholders involved, priorities and goals, management objectives, and socially relevant indicators and thresholds. Presenting the policy setting as the first lens positions considerations of limits to be incorporated across all stages of decision-making, including the formulation of policies and regulations, selection of new farm sites, renewals and expansions, and monitoring and enforcement.

7.4.2 Limits as embedded in social values

Applying a systems-thinking approach to aquaculture recognizes that ecosystems in which aquaculture is embedded provide features, services, and benefits, which are valued by society (**Figure 1.1**). Yet, the notion of "values" remains unappreciated in research and policy for aquaculture (Chapter 2). The notion of "values" is broad yet canrefer to a principle and/or measure, associated with a given worldview or cultural context that denotes a preference for a particular state of the world, the importance of something for itself or for others (Pascual et al., 2017).

The inherent inter-linkages between carrying capacity and social values and contexts have recently been recognized and considered a critical consideration for more holistic assessments of CC (Ferreira et al., 2013; McKindsey et al., 2006). Still, earlier frameworks for integrating CC (e.g., McKindsey, 2012) offer considerations of social values only as part of SCC considerations and present its integration as a last step in a hierarchical process, whereby findings can inform other types of CC, but remain distinct. In comparison, this thesis argues social values should rather be placed as an overarching lens in which the indicators and thresholds across all production, physical, social, and ecological systems are embedded. Social values should thus be more than a priority, and more than a necessity (e.g., Kluger and Filgueira, 2021), but a foundation upon which all limits are measured. The central role of social values emerged in part since describing and quantifying what is acceptable for society inherently encompasses ecological and physical CC aspects, as ecological risks, issues of siting, and area use conflicts to name a few, all contribute to opinion and perception of acceptance (Chapter 2). Therefore, social values can not be removed from other CC aspects. In this way, different types of carrying capacity present a circular argument (see Chapter 2; Figure 2.3), requiring an integrated lens to embrace the interconnectedness of aquaculture SES. In this way, bringing social values to the forefront of carrying capacity assessments can also help position CC in support of the EAA's (Soto et al., 2008) first principle that states:

> Aquaculture development and management should take account of the full range of ecosystem functions and services and should not threaten the sustained delivery of these to society.

Early conceptualizations of EAA emphasize a meaning of values as the benefits people receive from the environment, such as those emerging as a product of ecosystem services and functions. Likewise, findings from this research highlight how differences in environmental values can influence how public perceive aquaculture (Chapter 4). Therefore, methods applied in ecosystem services (ES) field may be a viable method for identifying relevant indicators across both ecological, physical, and social systems based on the aspects of the environment most valued by society (Chapters 2). However, experts noted conceptual limitations and confusion around ES approach for carrying capacity, leading to a sense of the ES concept not being ready for operationalization (Chapter 3). Combined with a broader paucity of ES research in the aquaculture literature (Weitzman, 2019), this thesis suggests the need for further research to investigate how to incorporate ES evaluations into aquaculture decision-making and estimations of carrying capacity. However, most ES valuation techniques applied in aquaculture measure economic values (through monetary indicators) (Weitzman, 2019), while findings from social acceptance research underscored the additional relevance of non-instrumental, non-monetary values about the environment, especially around relational values (Chapter 4). Chapter 5 and 6 further reinforce the relevance of non-monetary values, as social acceptance was also motivated by conflicts across not only material well-being, but also subjective and relational well-being. Therefore, conceptualizations of well-being likely include not only material benefits and costs, but also emotional, mental, spiritual, cultural, and social aspects of well-being (see Chapter 6). The relevance of well-being has implications for measuring carrying capacity considering the EAA's second principle:

> Aquaculture should improve human well-being and equity for all relevant stakeholders.

Therefore, before the measurement of individual indicators and thresholds for carrying capacity, an understanding of the social values relevant to the identified policy setting and context is necessary for ensuring that subsequent measurements reflect what is most relevant to society. This inherently involves measuring the perceptions and priorities of relevant stakeholders to what is acceptable as a function that is broader than aquaculture, rather reflecting the surrounding ecological and socio-economic contexts. Since determining social values inherently requires participatory methods to capture societally relevant priorities and values, this step would bring stakeholder involvement into assessments early on. This helps mobilize a key recommendation by experts (Chapter 3) and reflects increasing recognition of the need to adopt participatory processes and stakeholder engagement for more accountable aquaculture and marine planning (Galparsoro et al., 2020; Tiller & Richards, 2015; Tompkins et al., 2008). Still, measuring social values for aquaculture remains a critical roadblock in applying holistic carrying capacity. Therefore, future work is needed to explore the measurements of social values, such as potentially through an index of social value (Costa-Pierce, 2021) as has been done in resource use fields (e.g., Manfredo et al., 2021) to incorporate social context into management decisions.

7.4.3 The case for socially determined limits of aquaculture

The most central consideration for HCC inherently involves the limits that define the social-ecological system in which aquaculture is embedded, given the relevant policy setting and social values. Placing limits at the innermost consideration reflects the need to recognizes that all thresholds are "relative" based on social values, priorities and understandings, and definitions of what is considered "acceptable". A holistic understanding of carrying capacity recognizes that aquaculture operates as a complex social-ecological ecosystem ("aqua-ecosystem", per Costa-Pierce, 2010) that are embedded within a larger social context. This thesis underscores the relevance of considering limits across different sub-systems, including:

- **The physical system**: reflecting geographic availability in consideration of other marine uses, and suitability in terms of fish growth and health
- **The production system:** involves economic considerations to meet relevant industry and social goals, including ensuring profitability of farms, and availability of resource and personnel in area
- **The ecological system**: ensuring that aquaculture does not create ecological damage that degrades the system's resilience and natural functions
- **The social system**: involves benefits and risks to material, relational, and social well-being of society

This approach is similar to Tett et al., (2015)'s model of "socially determined carrying capacity", focusing on different "licenses", or "permissions" required for sustainability, including economic, ecological, and social licenses embedded within the aquaculture social-ecological system. Here, we suggest that HCC does not involve measuring individual carrying capacity "types" (such as physical, production, ecological and social carrying capacity), but that HCC involves understanding limits across various systems, reinforcing the language of EAA to support the "sustainability of interlinked social-ecological systems" (Soto et al., 2008). This subtle difference in language purposefully distances itself from CC epistemologies because of traditional CC language, which has been conceptually inconsistent (Chapter 2), confusing, and unclear by experts (Chapter 3). In addition, the shift in language can support the policy relevance for HCC assessments, emphasizing the need for clarity and transparency of language that a diversity of stakeholders can understand and apply (**Table 7.2**).

Determining and measuring limits remains at the core of HCC, which experts identified as an important, yet challenging consideration (Chapter 3). Given the breadth of potential indicators across all systems, a complete set of indicators should ideally represent key features that are the most systematically and scientifically relevant and credible (Chapter 3). Experts (Chapter 3) agreed that assessments should use a combination of universal and context-specific indicators, highlighting the need to identify indicators based on social values and priorities specific to the relevant policy setting. In this way, this involves selecting which components within each system (e.g., species or habitats in the ecological system) of an area are important and set acceptable limits of change for each. Yet, a main guiding recommendation included the need for indicators for HCC to balance features such as cost, relevance, reliability, and complexity (**Table 3.5**). The relative weighting of these features across indicators becomes an important part of HCC assessments, which will undoubtedly rely on social values captured by the relevant stakeholders to the given assessment. These considerations highlight the relevance of measuring what motivates measures of social acceptance to both identify indicators and indicate the "acceptable" limit of those valued indicators. Therefore, this thesis makes the case for socially determined limits across multiple systems within the "aqua-ecosystem" for holistic, sustainable aquaculture.

7.5 SHIFTING TO MORE HOLISTIC GOVERNANCE

The recommendations, guidelines, and approaches presented in this Chapter and throughout the thesis were guided with the intention to the policy-relevant, and thus fit largely within existing policy structures. From a practical perspective, existing site selection and lease/licensing procedures are likely most suitable entry points for integrating holistic carrying capacity assessments, since these procedures provide some practical entry points for more thorough assessment, broad stakeholder engagement, and consideration of policy goals required for HCC. However, existing government structures remain largely unsuited for implementing the ideas around social carrying capacity, or the approach to HCC presented above. Likely, ideas around HCC may need to be implemented in a piecemeal fashion, integrating ideas of socially determined limits throughout various decision-making structures, including during proponent scoping of new sites, administrative lease and licensing, or engagement initiatives and efforts. Yet, both aquaculture and marine planning and management continue to struggle with adequate community engagement. Ongoing research and technical advances may continue to open the door for application of HCC to other decision-making contexts in the coming years. As a result, the insights and conclusions presented here remain largely theoretical, presenting an ideal vision for CC for more holistic decision-making.

However, insights from this work highlight a broader structural governance challenge that will be critical to overcome for more holistic, sustainable planning for aquaculture and marine ocean governance. For instance, the HCC approach presented here relies on a process to be flexible and recognize the dynamic nature of the social-ecological system, thus reinforcing the need for an adaptive perspective. For example, the definition of SCC presented here is likely quite vulnerable to political reforms, demographic changes, economic shifts, and changing worldviews. Therefore, applications of SCC must be open to re-interpretation. Yet, adaptive management remains a challenge to implement practically. While this research presents insights to better understand and define social carrying capacity, the implementation of SCC in a standard, practical way remains challenging and complex. The findings from this work highlight that social carrying capacity is inherently subjective, determined by opinion, legitimacy, and/or trust. However, there remain an overarching lack of consideration for attitude and perception data within aquaculture decision-making, echoing broader challenges in marine planning and management.

The findings across this thesis reinforce the presence of external institutional barriers to implementing the holistic vision, approaches, and tools for aquaculture carrying capacity (also, see Chapter 3). The limitations and challenges identified in this current chapter underscore a critical overarching limitation of current governance mechanisms for adequately incorporating more holistic perspectives of limits and sustainability. While growing interest in aquaculture to support more Blue Economy initiatives, in many areas including Canada (DFO, 2022), strategies remain largely focused on economic growth and improving natural and social capital, framing the oceans as "development spaces" (UN, 2014). Yet, these Blue Economy initiatives still largely operate within governance mechanisms for aquaculture that favor top-down approaches implemented through government rulemaking (Campbell et al., 2021). Top-down governance has been criticized to fail to adequately consider the place-based nature of aquaculture, reflecting a broader "people-policy" gap (Krause et al., 2015) that insufficiently considers the nuance and complexity of notions of well-being and social impact. In contrast, emerging ideas around "Blue Communities" emphasize participatory and collaborative decision-making for aquaculture, with the overarching goal of increasing well-being (Campbell et al., 2021). The "Blue Communities" governance approach suggests a re-orientation of institutional arrangement and goals based on social goals, priorities, and values. This approach may in fact be more in line with principles outlined in the EAA and the required shift that may make governance structures inherently more suited for incorporating ideas around holistic carrying capacity.

7.6 RESEARCH LIMITATIONS AND DIRECTIONS FOR FUTURE WORK

This thesis applied a primarily empirical (rather than theory-driven) approach to answering the research questions. In a desire to capture a range of complex, interdisciplinary aspects, this thesis began exploring several factors, recognizing the diversity of potential considerations and avenues of inquiry. For example, in Chapter 4, the number of variables explored was weighed against the potential response rate, as participation in surveys decreases with the complexity and length of surveys. As a result, many opportunities for future empirical work to validate and reinforce findings remain.

Structural policy limitations appear to be a key challenge to operationalizing holistic assessments of aquaculture. Further investigating how local aquaculture policy structures can integrate holistic concepts and approaches like the EAA can provide necessary insight into how to create useful decision-support tools that incorporate the concepts of this thesis. In Nova Scotia, this could include a more in-depth analysis of information, tools, and knowledge available to identify practical limitations and opportunities to apply more participatory, adaptive, and interdisciplinary methods highlighted in this thesis.

Additional research opportunities also exist to expand the knowledge base of several topics relevant to CC, including drawing insights from a wider range of interests, demographics, and scales. While the subject-matter experts used to develop the set of holistic carrying capacity guidelines (Chapter 3) included only English-language proficient participants, further research could expand the participant pool to other languages and thus encompass additional salmon-farming nations and expertise. Likewise, social acceptance research (Chapters 4 through 6) focused on a Nova Scotia perspective, applying a combination of convenience sampling (Chapter 4) and purposive sampling (Chapter 5 and 6) to reach a population of highly interested participants. While Nova Scotia was used as the backdrop to explore social limits of aquaculture, this thesis was designed as a grounded theory research approach and applied mixed-methods research to enhance the generalizability of this work to theory, drawing from multiple data sets and explorative, in-depth case study comparisons to produce valuable insights to advance theoretical assumptions on social acceptance. To this end, given the goal of generalization to theory rather than to populations, the findings from this work can not be considered representative of the views and perceptions of all Nova Scotians. This work thus provides theoretical assumptions that act as a starting point for decision-makers to consider a range of potential factors in their local decision-making processes. Incidentally, probabilistic approaches (e.g., random sampling survey) may be a path forward to substantiate the theoretical considerations presented here by enabling the generalization of findings to populations of interest in practical decision-making scenarios. In addition, further research could explore the attitudes of aquaculture among a wider public audience and additional stakeholder groups to further the understanding of the social limits to an area, especially to validate these findings across different contexts and populations. Therefore, research investigating a wider range of factors, contexts, and considerations could continue to refine the theoretical insights presented in this work, further enhancing the generalizability of findings to advance the theoretical and practical application of holistic CC.

In positioning carrying capacity towards a more holistic assessment of aquaculture in line with an EAA, further work could investigate how concepts, frameworks, and tools from other ecological and conservation fields could integrate with CC and EAA principles. For example, exploration into approaches such as ecosystem service valuation may offer potential tools to integrate interdisciplinary aspects of CC (Chapters 2 and 3), and suitable to integrate principles of the EAA (Willot et al., 2019). In addition, this thesis points to the potential relevance of research on the interaction between aquaculture and societal values, perceptions of legitimacy, and consequences for well-being, and how they can relate to acceptable thresholds for aquaculture (Chapter 5 and 6). Thus, there is a significant opportunity to continue to draw in and adapt approaches and frameworks from disciplines beyond aquaculture to build tools and approaches for sustainable, fair, and legitimate aquaculture decision-making. In due course, future research in these areas could contribute to improving our understanding of what defines the acceptable limits of aquaculture for the environment, economy, and society. While this thesis identifies some early steps to building more holistic assessments of aquaculture limits, continuing this line of work could ultimately strengthen our ability to build more sustainable aquaculture governance.

7.7 CONCLUSIONS

This thesis demonstrates carrying capacity in aquaculture as a mature field of study of ongoing relevance and scientific interest but also contends that generating a holistic assessment to inform salmon aquaculture governance continues to be a challenge theoretically, logistically, and institutionally in many parts of the world, including Atlantic Canada. Findings from this work outline a potential role for carrying capacity as both a tool for holistic assessment and as an approach to integrate concepts of limits into wider aquaculture planning, siting, and decision-making. This thesis also contributes to knowledge on social aspects of aquaculture, which can be positioned to start closing the gap on social carrying capacity by suggesting some operational ways to define and measure socially acceptable limits in the context of relevant social values. Results from this thesis were synthesized to present a path forward for understanding and defining holistic carrying capacity of aquaculture. Therefore, this thesis presents a conceptual decision-making approach by which policy makers and planners can consider diverse measures of environmental, economic, and social limits within multiple decision-making processes. Encompassing the advantages of carrying capacity concepts and tools, the proposed approach reconsiders the definition of limits of holistic carrying capacity assessment more in line with the Ecosystem Approach to Aquaculture. Reinforcing the role of social values and context in shaping holistic limits across physical, production, ecological and social systems can be a first step to re-orienting carrying capacity for more holistic, sustainable, and socially acceptable governance of salmon aquaculture.

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APPENDIX A. CHAPTER 2 RESEARCH MATERIALS

A.1 Alignment of carrying capacity research pillars to key ecosystem-based management principles. (Appendix I from Weitzman & Filgueira, 2019)

Where research pillars presented may address various common ecosystem-based principles. This table demonstrates that the research agenda proposed was not created independently of the criteria and concepts discussed within the EBM literature. This table also demonstrates no single pillar covers all principles, and that the research agenda should advance multiple pillars to be comprehensive to EBM concepts.

	Research pillars				
Ecosystem-based principles (from Long et al., 2015; Soto et al., 2008)	*Recognizing system complexity*	*Responding to policy needs*	*Applying adaptive framework*	*Embracing interdiscipl-inarity*	*Curating meaningful information*
Consider ecosystem connections	x			x	
Appropriate spatial and temporal scales	x				
Adaptive management			x		
Use of scientific knowledge					x
Stakeholder involvement	x	x	x	x	x
Integrated management	x			x	
Account for dynamic nature of ecosystems	x		x		
Ecological integrity and biodiversity					x
Coupled social-ecological systems	x			x	x
Decisions reflect societal choice		x		x	
Distinct boundaries	x				x
Interdisciplinarity	x	x		x	x
Acknowledge uncertainty	x		x		
Acknowledge ecosystem resilience	x				x
Effects on other ecosystems/activities	x	x		x	
Precautionary approach	x		x		
Consider cumulative impacts			x		

APPENDIX B. CHAPTER 3 RESEARCH MATERIALS

B.1 Recruitment e-mail for Round 1

Dear _____,

My name is Jenny Weitzman and I am an Interdisciplinary PhD candidate at Dalhousie University in Halifax, Nova Scotia. I am inviting you to participate in a research study on carrying capacity for aquaculture with the aim to develop a holistic framework for carrying capacity for salmon aquaculture in Atlantic Canada.

This research is being conducted by myself and is part of a larger research programme on sustainable aquaculture funded through the Ocean Frontier Institute and Dalhousie University. I have attached a Summary Document outlining the details of this study, including what you will be asked to do and any potential risks and benefits to you.

Your participation in this study is completely voluntary and your responses will be kept anonymous. Your knowledge and expertise would contribute greatly to improving our understanding of how to operationalize ecosystem-based management for aquaculture and improve planning and decision-making for salmon aquaculture.

Should you agree, you will be asked to provide between one to two hours of your time to participate in a semi-structured interview, in addition to two rounds of electronic follow-up questionnaires. Questionnaires are expected to take between 15 to 20 minutes. Briefly, you will be asked questions regarding your expertise and opinions of the information, methods, and approaches to carrying capacity. Your views and expertise will be used to help develop a series of guidelines for carrying capacity in support of holistic decision-making for salmon aquaculture in Atlantic Canada. Interviews will ideally occur face-to-face, in person, at a location and time that is suitable to you. If in-person interviews are not possible, you may be asked to participate in a telephone interview. The first round of questionnaires will e-mailed to you in early 2020 and will be completed in a fillable PDF form.

You may participate in this study if you are currently, or have previously (within the last 5 years) been directly or indirectly involved with the management or planning related to marine aquaculture, or with generating knowledge to inform decision-making. You must possess a baseline knowledge of carrying capacity concepts, to a level you would be comfortable expressing your opinions about them. You must also be familiar with salmon aquaculture activities and be able to communicate your opinions about them.

Thank you very much for considering this request. If you would like to participate, or have any questions about this study, please e-mail or contact me at jenny.weitzman@dal.ca.

Best wishes and I look forward to hearing from you soon,

Jenny Weitzman

B.2 Research summary document and informed consent form

Project title
Assessing opportunities and challenges for carrying capacity methods, indicators, and decision needs in aquaculture

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Introduction

We invite you to take part in a research study being conducted by Jenny Weitzman, an Interdisciplinary PhD student at Dalhousie University. Your participation in this research is entirely your choice and your results will be kept strictly anonymous. You may choose to withdraw from the study at any time. There will be no impact on your employment if you decide not to participate.

The study is described below, as is what you will be expected to do and the any benefits and risks you might experience. Your participation in this study may not directly benefit you, but will contribute to knowledge to support ecosystem-based management of aquaculture and help build a more holistic framework for sustainable decision-making and planning for salmon aquaculture within Atlantic Canada.

If you have any questions about this study, feel free to ask as many questions as you like. If you have questions later, please do not hesitate to contact Jenny Weitzman.

Purpose and Outline of the Research Study

This research looks at the concept of carrying capacity to inform decision-making of salmon aquaculture. In particular, this study aims to identify the challenges and opportunities for carrying capacity to support ecosystem-based management of salmon aquaculture, with a particular focus on Atlantic Canada. Through interviews with decision-makers, researchers, and practitioners, this study will explore opinions and understanding of carrying capacity by key informants to explore how different indicators, methods, and tools can be used to support holistic assessment of salmon aquaculture for planning and decision-making. This will rely on different perspectives on how to measure carrying capacity that considers a combination of ecological, social, and economic pressures, and values. The outcomes of this research study will help identify relevant indicators and methods for carrying capacity assessment of salmon aquaculture, which will be applied to the adaptation of guidelines for holistic ecosystem-based assessment of carrying capacity. This research is part of a larger study on carrying capacity to support societally endorsed and sustainable aquaculture sector in Atlantic Canada conducted under the Ocean Frontier Institute in Halifax, Nova Scotia.

Who Can Take Part in the Research Study

You may participate in this study if you are currently, or have been previously (within the last 5 years) directly or indirectly involved with either i) management and/or planning that may involve aquaculture activities, or i) generating knowledge or information that can be used in aquaculture decision-making. You must possess a baseline knowledge of salmon aquaculture activities, to a level you would be comfortable expressing your opinions about them. You must also be familiar with the concept of carrying capacity and be able to communicate your understanding about the concept, its approaches, outputs, and influence.

What You Will Be Asked to Do

To help us identify suitable information and methods for carrying capacity to support ecosystem-based management, you will be asked to participate in a Delphi exercise. The Delphi technique seeks to obtain consensus on the opinions of experts, through a series of interviews and structured questionnaires. As part of the process, the responses from each round are fed back in summarized form to the participants who are then given an opportunity to respond again to the emerging data. The Delphi approach is therefore an iterative multi-stage process designed to combine opinion to reach an approximate group consensus on a given topic.

The first round consists of an interview that will take approximately one to two hours to complete. Interviews will consist of questions focused around topics such as i) how carrying capacity fits within the broader decision-making context, ii) the methods used in assessment and analysis of carrying capacity, and iii) what should be included and considered in carrying capacity assessments. In this way, questions aim to elicit your opinions on both on decision-making needs and priorities, as well as identify desirable options to improve decision-making, meet stakeholder needs, or overcome problems.
The interview will be completed at a time and location of your choosing. If you are unable to meet with the lead researcher in person, a telephone interview may be scheduled. If you provide your consent, the interviews will be audio-recorded to analyze the responses further following the interview.

Following interviews, your responses will be aggregated and analyzed to identify major themes, as well as a potential set of indicators, methods and concepts to guide the development of a holistic framework for carrying capacity. In early 2020 (~Feb-Mar), you will be asked to fill out and return an electronic follow-up questionnaire as round 2 of the Delphi approach. The questionnaire will only take about 15-20 minutes of your time. The questionnaire will consist of questions that may ask you to state your preference for, or opinions about a list of potential indicators and methods that could be applied to carrying capacity. Once all questionnaires have been analyzed and aggregated, you will be contacted again (date TBD, tentatively May 2020) with aggregated results from round 2, and given the opportunity to respond again to the questionnaire.

Possible Benefits, Risks and Discomforts

Participating in this study will not directly benefit you, but your opinions and views may help us learn things that could benefit others. Your opinions and viewpoints expressed in this study will be used to help generate a set of guidelines for holistic ecosystem-based assessment of carrying capacity. This will directly feed into other parts of this research study, and directly inform the design of a structured interview schedule for Atlantic Canada to validate the proposed methods and indicators. Ultimately, your views and opinions will help identify important variables to consider when building a comprehensive framework for aquaculture carrying capacity that could be used by decision-makers for site selection, planning, and monitoring of salmon aquaculture. Your expertise could also help better understand how to leverage new approaches and tools for integrated assessment of aquaculture impacts that consider an integrated view of the ecological, social, and economic aspects of aquaculture. Ultimately, this work can support ongoing research efforts to build a framework for societally-endorsed, sustainable aquaculture with targeted information for Atlantic Canada, as well as broader conclusions for global applicability.

The risks associated with this study are minimal. The risk of potential misrepresentation of your organization's values and opinions will be minimized through the publication of summary results only. The publication of this research will not identify individuals or organizations. Your comfort and preferences for meeting spots will be accommodated if you do not wish to conduct the interview at your location of employment. If you at any point become fatigued, bored or uncomfortable with the interview process, you may terminate the process.

Compensation / Reimbursement

We thank you for your time and involvement, but will not be able to provide any compensation for your participation in this study.

How your information will be protected

Your personal information, including your name, e-mail, phone number and organization affiliation will be kept for internal records and contacting purposes only. Your identity and participation in this study will be known only by the lead researcher.

When results are shared to participants for rounds 2 and 3 of the Delphi exercise, only group results will be shared. Following the completion of the study, we will describe and share our group findings in a research paper and for educational purposes at conferences or university presentations. The only identification information about yourself or your company affiliation will occur in the form of broad stakeholder affiliation (example: researcher, environmental group, government etc…). If you provide your consent to be quoted directly, your responses will be kept anonymous, and your name or company affiliation will not be used in direct quotes from interviews. Quotes will also be carefully screened to remove any contextual information that could potentially identify you.

This means that ***you will not be identified in any way in our reports***.

The research team that has access to your information has an obligation to keep your information private. We will use a participant number (not your name) in our written and computerized records so that the information you provide is not associated with your name or organization. All your identifying information will be kept in a separate file, in a secure place. All electronic records will be kept secure in a password-protected, encrypted file on an external USB device. If the interview is audio-recorded, the recording will be destroyed immediately after analysis. All the raw data from interviews and questionnaires, as well as any files containing any personal information will be retained for a maximum duration corresponding to the publication of the researcher's PhD thesis (estimated May 2021).

If You Decide to Stop Participating

You are free to leave the study at any time. If you decide to stop participating at any point in the study, you may decide whether you want the information you have contributed to be removed or if you will allow the use of that information. You can decide up to three months following your interview if you want us to remove your data. After that time, it will become impossible for us to remove it. Likewise, you may decide up to three months following your follow-up questionnaires if you want us to remove your data.

How to Obtain Results

We will provide you with a brief summary of group results when the study is complete. The results of this study will also be published as part of a PhD doctoral thesis which will be made available through Dalhousie's online catalogue of published theses. Please note, no individual responses, with the exception of quotes (with prior consent) will be provided in order to maintain confidentiality.

Questions

We would be happy to answer any questions or concerns you may have about your participation in this research. Please contact Jenny Weitzman (902-209-2935, jenny.weitzman@dal.ca) at any time. We will contact you if any new information emerges which could affect your decision to participate.

This research study has been reviewed and approved by the Research Ethics Board at Dalhousie University. If you have any ethical concerns regarding your participation in this research or in the research study, you may contact Research Ethics, Dalhousie University at (902) 494-1462, or e-mail: ethics@dal.ca (and reference REB file # 2019-4756).

Informed Consent Form

Project Title:
Assessing opportunities and challenges for carrying capacity methods, indicators, and decision needs in aquaculture

Lead Researcher:
Jenny Weitzman [PhD Candidate]
Marine Affairs Program, Dalhousie University, Halifax, Nova Scotia
T: (902) 209-2935 | E: jenny.weitzman@dal.ca

Other researchers:
Dr. Ramon Filgueira [supervisor]
Marine Affairs Program, Dalhousie University, Halifax, Nova Scotia

Dr. Jon Grant [supervisor]
Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

Print name

I, ____________________________ have read the Summary Document that outlines the explanation and purpose of this research study, including how my information will be used and protected. I have been given the opportunity to discuss the study and my questions have been answered to my satisfaction. I understand that I have been asked to take part in a Delphi exercise that consists of a semi-structured interview and two follow-up questionnaires that will occur at a location acceptable to me. I understand that by signing below, I am agreeing to take part in this study. I understand that I am providing ongoing consent for my participation in both an interview and follow-up questionnaires. I understand that my responses will be kept anonymous and my information confidential. I understand that my participation is voluntary and that I am free to withdraw at any point in the study, until three months after my interview and/or questionnaire is completed.

_________________________________ ____________
Signature *Date (dd/mm/yy)*

I agree that my interview may be audio-recorded. ☐Yes ☐No

I agree that direct quotes from my interview may be used without identifying me. ☐Yes ☐No

_________________________________ ____________
Signature *Date (dd/mm/yy)*

B.3 List of definitions provided to participants prior to interview

Definitions

The following list provides simple definitions for the main concepts that will be explored within interviews. The provided definitions are to help familiarize participants with concepts, and to clarify the intention of the concepts as they relate to the present study.

Ecosystem approach to aquaculture (EAA)

The Ecosystem Approach to Aquaculture (EAA) emerged in 2008 as an approach to management, and is currently defined as "a strategy for the integration of aquaculture within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems." (Soto et al., 2008). It provides a planning and management framework to guide governments and producers simultaneously embrace environmental, socio-economic, and governance objectives of the sector. The EAA was largely based off the Ecosystem Approach to Fisheries and aims to adhere to similar ecosystem-based management objectives.

Carrying capacity

Carrying capacity (CC) for aquaculture can be broadly defined as the magnitude of aquaculture activity an area can tolerate before unacceptable change (or impact) occurs. Assessments of carrying capacity are often interested in measuring or estimating whether current or proposed aquaculture activities are below, at, or above the capacity of the surrounding area. CC is often divided into four functional categories (McKindsey et al., 2006):
physical carrying capacity — the total area of marine farms that can be accommodated in the available physical space,
production carrying capacity — the stocking density of farmed species at which harvests are maximized,
ecological carrying capacity — the stocking or farm density which causes unacceptable ecological impacts,
social carrying capacity — the level of farm development that causes unacceptable social impacts.

Ecosystem services

Ecosystem services are broadly defined as the benefits that people obtain from ecosystems (MA, 2003). The concept became popularized with the Millennium Ecosystem Assessment, which defines ecosystem services to include provisioning services (food, water, etc.), regulating services (regulation of flood, disease etc.), supporting systems (habitat provision, nutrient cycling, etc.), and cultural services (recreational, spiritual, etc.).

Expert judgement

Expert judgment is a term that refers to a technique in which the opinions of experts in a given area or sector are used to make estimates, judgements, or decisions related to a certain issue or topic. In expert judgement, estimates about a given problem are often elicited by one to several experts and aggregated to offer consensus on a 'best estimate' (Hemming et al., 2017).

References

Hemming, V., Burgman, M. A., Hanea, A. M., McBride, M. F., & Wintle, B. C. (2017). A practical guide to structured expert elicitation using the IDEA protocol. *Methods in Ecology and Evolution*, 9(1), 169–180. https://doi.org/10.1111/2041-210X.12857

McKindsey, C. W., Thetmeyer, H., Landry, T., & Silvert, W. (2006). Review of recent carrying capacity models for bivalve culture and recommendations for research and management. *Aquaculture*, *261*(2), 451–462. https://doi.org/10.1016/j.aquaculture.2006.06.044

MA (Millennium Ecosystem Assessment), 2003. Ecosystems and Human Well-being: A framework for assessment. Island Press, Washington, DC. Available from: http://pdf.wri.org/ecosystems_human_wellbeing.pdf

Soto D, Aguilar-Manjarrez J, Hishamunda N, eds. (2008) Building an ecosystem approach to aquaculture. FAO/Universitat de les Illes Balears Expert Workshop. 7–11 May 2007, Palma de Mallorca, Spain. FAO Fisheries and Aquaculture Proceed- ings. No. 14. FAO, Rome. Available from: http://www.fao.org/3/a-i0339e.pdf

B.4 Demographic information sheet completed by participants

Demographic information

We are collecting some basic information to help profile your particular area of expertise. This information will not be used to identify you.

Four-digit identification code:

____

Current occupation title (*e.g. researcher, analyst, PhD candidate etc.*):

____

Current employment sector (*e.g. government, academia, consulting, etc.)*:

____

The following questions aim to understand your professional experience relevant to the interview questions.

In column A, please indicate how many years of professional or postgraduate experience you have for each topic (e.g. 3.5 years). If you have no relevant experience, please enter "0".

In column B, please rate your knowledge between 1 and 10:

0 – no prior knowledge or understanding
1 – basic understanding (e.g. you have read reports, new articles, but no working knowledge/study experience)
5 – intermediate understanding (e.g. you have relevant work or postgraduate research experience)
10 – specialist understanding (e.g. you regularly collect data, prepare or sign off on reports, give advice to the public or clients on this topic)

Topics	**A (years experience)**	**B (self-rating) 0-10**
Marine finfish (salmon) aquaculture		
Carrying capacity		
Aquaculture decision-making		
Ecosystem-based management (or EAA)		
Ecosystem services		
Aquaculture-environment interactions		
Socio-economics of aquaculture		

B.5 Round 1 Interview questions

Interview Questions

Introduction

1. Could you please briefly describe to me your background and expertise related to aquaculture?

Area 1: Informing decision-making with carrying capacity

2. What do you think about ecosystem-based approaches to managing aquaculture?

3. What do you think needs to happen so that management and development decisions can better support ecosystem-based objectives?

4. In your view, how well are aquaculture management and development decisions informed by carrying capacity? Why or why not?

Area 2: Types of information and data needed to evaluate carrying capacity

5. In your view, what is/are the most important *social* issues that should be assessed to understand the limits of aquaculture practices?

6. In your view, what is/are the most important *ecological* issues that should be assessed to understand the limits of aquaculture practices?

7. In your view, what is/are the most important factors influencing farm-scale *production* aspects that should be included in carrying capacity assessments?

8. What types of physical or spatial considerations should be included in assessing the limits of aquaculture practices?

Area 3: Methods to measure and monitor carrying capacity

9. Do you feel that the current ways of measuring or monitoring aquaculture activities are adequate to answer questions related to ecosystem-based management? Why or why not?

10. How do you think that levels of acceptable change or impact should be determined to inform carrying capacity or regulations?

11. In recent years, the ecosystem services approach has gained popularity to bring together social and ecological aspects related to development decisions. Do you think applying ES concepts and methods are appropriate for assessing the carrying capacity of aquaculture? Why or why not?

12. In recent years, using experts to elicit judgements and help guide decisions has gained popularity in many policy fields. Do you think expert judgement has a role to play in carrying capacity assessments? Why or why not?

13. In addition to including government and industry, do you think there is a role for engaging with local interest groups (like NGOs) and communities within carrying capacity assessments?

Conclusions

14. Is there anything else you would like to say about carrying capacity or its role in ecosystem-based decision-making (or EAA)?

15. Do you have any recommendations for individuals I should speak to about this topic [*for recruitment*]?

B.6 Round 2 Recruitment e-mail

Good morning,

I hope this message reaches you safe and healthy.

You are a part of a group of experts who completed the first of 3 rounds of consultation on carrying capacity for salmon aquaculture. Our goal is to generate consensus on what should be considered good practices to guide the development of a holistic framework to support decision-making of salmon aquaculture. **This second (of three) round focuses on validating recommendations for more holistic carrying capacity assessments based on the topics you raised, and suggestions made in round one interviews.**

Your input is extremely important to ensure that the guidelines emerging from this study reflect the opinions of individuals involved with aquaculture in different roles and regions.

We estimate that you will need around 1 hour to complete this questionnaire.

Attached to this e-mail you will find a fillable PDF that you can directly enter and save your answers. You can find a summary of the composition of the expert panel and some findings from Round 1 in the appendices attached.

On the first page of the questionnaire, you will be asked to provide an ID code which will be used solely to know who completed the questionnaire. Your **unique ID code** is:

We would greatly appreciate if you could complete and return the questionnaire within **two weeks**, no later than April 6, 2020. If you need more time to complete the questionnaire, please reach out and request an extension.

We are extremely grateful for your continued participation in this research and for your valuable time.

Sincerely,

Jenny Weitzman
IDPhD candidate,
Marine Affairs Program, Dalhousie University

B.7 Round 2 Questionnaire and Appendix sent to participants

Holistic carrying capacity for salmon aquaculture
Building consensus on a framework for holistic carrying capacity

The goal of this process is to build consensus on what should be considered best practices for using carrying capacity to holistically inform decisions about salmon aquaculture planning and management. This work is a valuable part of a PhD thesis at Dalhousie University. Your answers and recommendations are extremely important and represent one of many experts from around the world who have been contacted to offer some general principles that are relevant to thinking about aquaculture carrying capacity more holistically.

The present questionnaire was generated through themes that emerged from the **Delphi Round 1** interviews. Statements and topics in this questionnaire were based on ideas and themes that experts expressed. To see a summary of who participated in Round 1, see Appendix i.

From the Round 1, experts expressed a range of opinions on the role of carrying capacity for more holistic management. They also identified a number of challenges both with implementing a more ecosystem approach to aquaculture and with carrying capacity. An overview of these challenges can be found in Appendix B. Where relevant, the processes and criteria found in this Round 2 questionnaire aim to respond to these challenges.

Instructions

During this **Round 2** questionnaire, please answer questions based on your own experiences. Where possible, try to direct your answers based on relevance to *marine net-pen salmon aquaculture*.

This questionnaire has four sections.

- **Section 1** - You will be asked to provide your opinions on the criteria and steps in the carrying capacity assessment process in support of holistic assessment of aquaculture.
- **Section 2** – You will be asked about what issues and data are important for measuring different aspects of carrying capacity.
- **Section 3** – You will be asked questions about the process for selecting relevant indicators and thresholds for carrying capacity.
- **Section 4** – In the last section, you will be asked for your opinion on the most suitable methods and tools for data collection and analysis of carrying capacity information.

The final stage of the Delphi (Round 3) will present a proposed framework for assessing carrying capacity in support of more holistic approach to salmon aquaculture management.

Please enter your unique ID code (provided in the Round 2 e-mail invitation)**: 0000**

Feel free to provide any comments on findings from Round 1
(content of questionnaire or appendices : for example, expert panel composition, or whether your perspective is well represented)

Click or tap here to enter text.

Section 1 – A process for a holistic assessment of carrying capacity

In the context of this research, we define a framework as "a structured set of ***guidelines, information,*** *and* ***tools*** *to guide the comprehensive assessment of carrying capacity for aquaculture". Given the diversity of ways that carrying capacity has been applied to inform decision-making, a shared framework to situate carrying capacity information could provide a general reference document for decision-makers and stakeholders to situate carrying capacity assessments within a more holistic approach to aquaculture decision-making and management.*

From the literature and round 1, we identified a number of important **criteria** to support an effective and holistic carrying capacity process. Please rank in order of importance (from 1 to 7) the criteria you would recommend for framework development, with 1 being the most important.

__ Being flexible
__ Being adaptive and iterative
__ Being inclusive/participatory (engaging all relevant stakeholders in process)
__ Being transparent and clear
__ Being interdisciplinary (consider all aspects (physical, ecological, social, economic, governance)
__ Consider multiple scales (space and time)
__ Being context-based (situated within the relevant social, economic, and ecological contexts and objectives of CC assessment)

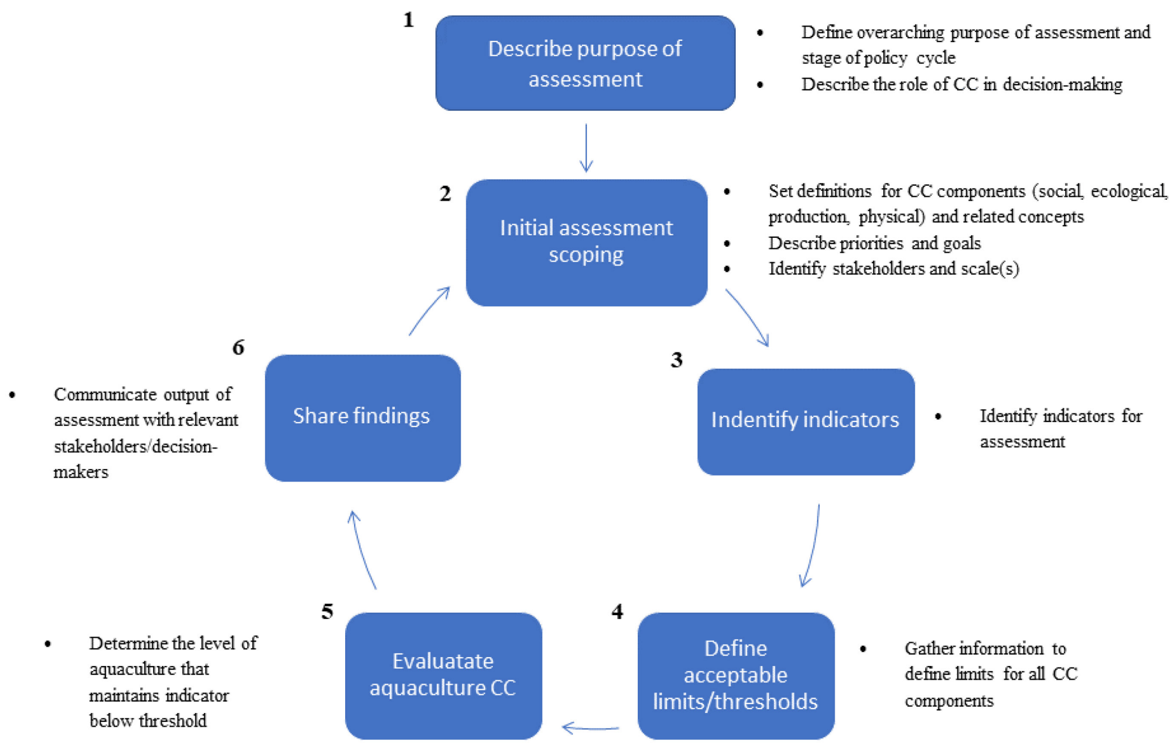
Are any of these criteria that you would consider <u>not essential</u>? Are there any <u>other</u> criteria (than those listed above) for carrying capacity processes that you deem very important? If so, which one(s) and why?

Please rate how important you feel it is to that a carrying capacity framework include **clear guidance** on the following aspects of a carrying capacity assessment.

	Not at all important	Somewhat important	Important	Moderately important	Very important
Definitions of all relevant terms (carrying capacity, holistic, etc.)	☐	☐	☐	☐	☐
Delineation of relevant scale(s) to apply CC assessment	☐	☐	☐	☐	☐
Processes to select who gets involved and how	☐	☐	☐	☐	☐
Strategies to identify factors to assess and indicators to choose	☐	☐	☐	☐	☐
Information required to support CC assessment	☐	☐	☐	☐	☐
List of tools and methods to gather information	☐	☐	☐	☐	☐
Structure/process for actors to choose appropriate tools	☐	☐	☐	☐	☐
Processes to communicate CC throughout assessment	☐	☐	☐	☐	☐

Are there any <u>other aspects</u> (than those listed above) for carrying capacity processes that you think it is very important to provide clear guidance on? If so, which one(s) and why?

Overall, a holistic carrying capacity assessment is a tool for decision-makers that involves an evaluation of the limit of aquaculture use in a given context over which alteration due to aquaculture becomes unacceptable. From our findings, we propose a framework for assessment based on six steps:



Would you add any <u>other steps</u>? Do you think any of these steps are <u>not essential</u>? If so, which one(s) and why?

Click or tap here to enter text.

From your perspective, which step(s) need to be <u>emphasized</u>? Why?

Click or tap here to enter text.

Would you modify any of these steps or the order in which these are presented? If so, please explain.

Click or tap here to enter text.

At what part or parts of the policy process for salmon aquaculture decisions do you think a framework to guiding holistic carrying capacity should cover? Please select all that apply.

- ☐ Initial site selection and scoping
- ☐ Obtaining leases for new development (impact assessments etc.)
- ☐ Day to day management
- ☐ Lease renewal
- ☐ Ongoing monitoring
- ☐ Carrying capacity is relevant to all stages within the policy process
- ☐ Other (please describe): Click or tap here to enter text.

Defining terms relevant to carrying capacity

From the literature and round 1, carrying capacity is often defined and understood in different ways, depending on the purpose it is used for, and discipline it is applied to. To be used to support more holistic way of managing salmon aquaculture, a framework should ideally define the relevant terms included in the framework.

Please rate to what degree you feel it is important that a framework provide a clear definition of the following concepts that relate to carrying capacity and holistic assessments.

	Not at all important	Somewhat important	Important	Moderately important	Very important
Carrying capacity	☐	☐	☐	☐	☐
Types of carrying capacity (e.g. social CC, ecological CC…)	☐	☐	☐	☐	☐
Holistic	☐	☐	☐	☐	☐
Acceptable change (i.e., threshold)	☐	☐	☐	☐	☐
Indicator	☐	☐	☐	☐	☐
Ecosystem	☐	☐	☐	☐	☐

Are there any <u>other</u> terms of concepts that were not mentioned above, but you feel are essential to define in a CC framework? If so, which one(s)?

Click or tap here to enter text.

Based on the literature and findings from round 1, we have proposed general definition for a number of concepts related to carrying capacity of aquaculture. For the following concepts and terms, please how appropriate you believe the definitions to be, in the context of holistic carrying capacity assessment.

	Not at all	Not very much	Somewhat	A moderate amount	Very much
Holistic approach An approach that considers aquaculture as a whole social-ecological system, including the social, ecological, economic, and governance contexts, and the interactions of the parts	☐	☐	☐	☐	☐
Carrying capacity (overall) Level of aquaculture that does not degrade the condition of the important social, economic, or ecological system components beyond an acceptable limit	☐	☐	☐	☐	☐
Production carrying capacity the level of aquaculture at which production biomass is maximized	☐	☐	☐	☐	☐
Physical carrying capacity The geographic area that is suitable and available for aquaculture	☐	☐	☐	☐	☐
Ecological carrying capacity The maximum level of aquaculture that does not cause unacceptable ecological impacts	☐	☐	☐	☐	☐
Social carrying capacity The level of aquaculture that does not cause unacceptable social impacts	☐	☐	☐	☐	☐

Do you have any suggestions to edit any of the above-mentioned definitions? If so, please provide alternate definitions you believe to be more appropriate.

Click or tap here to enter text.

Identifying the relevant scale(s) of assessment

A carrying capacity assessment will be as broad or as restricted as the scale that it is evaluated at. While most traditional CC assessments have focused only on evaluating aquaculture at the farm-scale, multiple scales could be considered.

These types of scales can be summarized in ***scale domains****. Broadly, for salmon farming, these can be divided into:*

Type of scale	Local area	Large area	Regional area	National area	Global
Ecological scale	Salmon cage or farm	Basin, bay ('ecosystem')	Multiple bays	Industry-wide	
Jurisdictional scale	Community or municipality	Cluster of communities, county etc.	Large zone for aquaculture, or province	Country	
Geographic scale	< 1km^2	10 - 20 km^2	100s - 1000s km^2		

Do you believe it is appropriate to conduct a holistic assessment of carrying capacity based on a single scale?

☐ Yes
☐ No
☐ I do not know

Please complete the following matrix by entering a number from 1 to 5 based on the degree of suitability that you believe the following scales are for assessment of aquaculture at each of the components of the social-ecological system.

1 = not at all; 2 = very little; 3 = somewhat; 4 = a moderate amount; 5 = a great deal.

	Ecological	Social	Physical	Production
Local	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5
Large area	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5
Regional	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5
National	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5
Global	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5

From the literature and round 1, we identified a number of **variables** that can help determine the appropriate scale for a CC assessment. Please rank in order of importance (from 1 to 5) the variables you think are most important in selecting the appropriate scale, with 1 being the most important.

Select a rank	The pressing issues and priorities of the area
Select a rank	The purpose of the CC assessment
Select a rank	The definition of the "ecosystem" to be managed (site, region, industry)
Select a rank	The stakes and actors in the system
Select a rank	The knowledge and tools available to effectively assess

Are any of these criteria that you would consider not essential? Are there any other criteria (than those listed above) for carrying capacity processes that you deem very important? If so, which one(s) and why?

Click or tap here to enter text.

Selecting who to include in the carrying capacity process

An actor is any individual involved with the execution of the carrying capacity process. A stakeholder is an individual who is affected by the outcomes of the process.

Please state how you agree or disagree with the following guidelines for involving actors and stakeholders within a carrying capacity assessment.

	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
Actors involved with the CC assessment should represent diverse knowledge forms and disciplines	☐	☐	☐	☐	☐
It is essential to clearly define roles and responsibilities of each actor in the process, assuming that not all actors will have the same responsibilities	☐	☐	☐	☐	☐
Chosen stakeholders should include representation from stakeholders beyond the local scale	☐	☐	☐	☐	☐

Stakeholders should be selected based on their 'stake' (demonstrated investment and interest in participating)	☐	☐	☐	☐	☐
Stakeholders need to be included throughout the CC process (at all steps)	☐	☐	☐	☐	☐

Please complete the following matrix by entering a number from 1 to 5 based on the degree of involvement you feel each of the following actors should have in a holistic CC assessment.

1 = no involvement whatsoever; 2 = very little; 3 = somewhat; 4 = a moderate amount; 5 = a great deal.

Roles	Government	Scientists	Public interest groups (e.g. NGOs)	Local community	Other marine users (fisheries, tourism etc.)
Leading CC assessment	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5
Setting priorities for assessment	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5
Identifying indicators	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5
Setting acceptable thresholds	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5
Providing expertise or knowledge	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5
Communicating outputs	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5	Select 1 to 5

Are there any <u>other</u> actors (other than those mentioned above) that you feel play an important role in the carrying capacity process? In addition, are there any <u>other</u> roles (other than those mentioned above) that you believe any of the given actors (or otherwise) could contribute to the CC process? If so, which one(s), and why?

Click or tap here to enter text.

<u>Section 2 – Carrying capacity information</u>

To evaluate whether aquaculture operations exist within the carrying capacity of the social-ecological system, requires gathering information about various objectives across social, economic, ecological, and governance dimensions. This section aims to understand what types of information are most relevant to calculating the limits of aquaculture in a given assessment, and what issues are most important.

For the following, please indicate how important you think each factor/issue is for evaluating the carrying capacity of salmon farming.

Production carrying capacity

	Not at all important	Somewhat important	Important	Moderately important	Very important
Water quality	☐	☐	☐	☐	☐
Hydrodynamics (to calculate flushing/ water renewal etc.)	☐	☐	☐	☐	☐
Water temperature	☐	☐	☐	☐	☐
Growth rate	☐	☐	☐	☐	☐
Estimated yield	☐	☐	☐	☐	☐

Production costs	☐	☐	☐	☐	☐
Resource availability (personnel, infrastructure, etc.)	☐	☐	☐	☐	☐
Profits	☐	☐	☐	☐	☐

Are there any other production considerations (than those listed above) that you deem very important for understanding physical carrying capacity? If so, which one(s) and why?

Click or tap here to enter text.

Physical carrying capacity

	Not at all important	Somewhat important	Important	Moderately important	Very important
Space available (and/or allocated) to aquaculture	☐	☐	☐	☐	☐
Proximity to infrastructure (ports, roads, etc.)	☐	☐	☐	☐	☐
Proximity to sensitive habitats	☐	☐	☐	☐	☐
Proximity to other users (e.g. tourism, fisheries, recreation…)	☐	☐	☐	☐	☐
Space between farms and cages	☐	☐	☐	☐	☐
Environmentally suitable sites	☐	☐	☐	☐	☐

Are there any other physical considerations (than those listed above) that you deem very important for understanding physical carrying capacity? If so, which one(s) and why?

Click or tap here to enter text.

Social carrying capacity

	Not at all important	Somewhat important	Important	Moderately important	Very important
Employment and income generation	☐	☐	☐	☐	☐
Provision of benefits to communities	☐	☐	☐	☐	☐
Social justice and equity	☐	☐	☐	☐	☐
Provision of infrastructure and amenities	☐	☐	☐	☐	☐
How aquaculture affects user interests (competing industries)	☐	☐	☐	☐	☐
Use of landscape (tourism, recreation, etc.)	☐	☐	☐	☐	☐
Opportunities for engagement and input	☐	☐	☐	☐	☐
Quality of industry interaction/engagement with communities	☐	☐	☐	☐	☐
Interactions with indigenous groups	☐	☐	☐	☐	☐
Transparency of information	☐	☐	☐	☐	☐
Influence on societal narrative with landscape	☐	☐	☐	☐	☐
Influence on cultural identities and sense of place	☐	☐	☐	☐	☐
Aesthetic value (viewshed, noise etc.)	☐	☐	☐	☐	☐
Impacts on environment and species of interest	☐	☐	☐	☐	☐

	Not at all important	Somewhat important	Important	Moderately important	Very important
Fish health/animal welfare concerns	☐	☐	☐	☐	☐
Food health and safety	☐	☐	☐	☐	☐

Are there any <u>other</u> social interactions (than those listed above) that you deem very important for understanding social carrying capacity? If so, which one(s) and why?

Click or tap here to enter text.

Ecological carrying capacity

For the following, please rate how important you feel it is to measure each of the following potential activities, stressors, and effects of salmon aquaculture in relation to measuring the ecological carrying capacity.

	Not at all important	Somewhat important	Important	Moderately important	Very important
ACTIVITIES					
Placement of site infrastructure	☐	☐	☐	☐	☐
Industrial equipment and resources use (fuel etc.)	☐	☐	☐	☐	☐
Site and stock management	☐	☐	☐	☐	☐
Feed use and composition	☐	☐	☐	☐	☐
STRESSORS					
Addition/alteration of habitat structure	☐	☐	☐	☐	☐
Release of nutrients	☐	☐	☐	☐	☐
Release of organic material	☐	☐	☐	☐	☐
Release of chemicals	☐	☐	☐	☐	☐
Alteration of light and noise	☐	☐	☐	☐	☐
Addition of litter	☐	☐	☐	☐	☐
Escape of fish into environment	☐	☐	☐	☐	☐
Spread of diseases and pests	☐	☐	☐	☐	☐
EFFECTS					
Change in wild fish populations/communities	☐	☐	☐	☐	☐
Changes in oxygen concentration in benthos	☐	☐	☐	☐	☐
Introduction of non-native species	☐	☐	☐	☐	☐
Change in wild fish health	☐	☐	☐	☐	☐
Change in suspended sediments	☐	☐	☐	☐	☐
Water quality changes	☐	☐	☐	☐	☐
Changes in substrate composition	☐	☐	☐	☐	☐

Are there any <u>other</u> activities, stressors, or effects (than those listed above) for carrying capacity processes that you deem very important? If so, which one(s) and why?

Click or tap here to enter text.

Research priorities

Of the following list of issues, please rank the importance of each of the following research priorities regarding the **information needed** to advance how we evaluate aquaculture from a holistic perspective.

	Not at all important	Somewhat important	Important	Moderately important	Very important
Societal benefits and risks	☐	☐	☐	☐	☐
Societal understandings and perceptions	☐	☐	☐	☐	☐
Interactions across full aquaculture life cycle	☐	☐	☐	☐	☐
Cumulative effects of multiple farms	☐	☐	☐	☐	☐
Multi-stressor effects of aquaculture and other industries	☐	☐	☐	☐	☐
Effects on wild fish populations	☐	☐	☐	☐	☐
Beyond-farm ecosystem impacts	☐	☐	☐	☐	☐
Ecosystem variability information	☐	☐	☐	☐	☐
Aquaculture and pathogen interactions	☐	☐	☐	☐	☐
Genetic aspects of aquaculture	☐	☐	☐	☐	☐
Fish health and welfare	☐	☐	☐	☐	☐

Section 3 -Evaluating carrying capacity – indicators and thresholds of acceptable change

Selecting relevant indicators

An indicator is broadly a variable that can be measured over time that reveals meaningful change. For carrying capacity, it is a variable/factor that is relevant to a change in some component of the ecological, social, or economic system we are interested in (for example, benthic health might be measured against indicators of organic enrichment). A holistic carrying capacity assessment will require a set of indicators relevant to the issues to assess whether aquaculture is exceeding the acceptable threshold.

Concerning the selection of indicators, please select which option you feel is the most suitable for a holistic CC assessment.

- ☐ Universal indictors (which can be used across the world in different CC assessments and could come from a bank of ready-to-use indicators)
- ☐ Using context-specific indicators (which can be generated iteratively between actors)
- ☐ A combination of universal and context-specific indicators
- ☐ I am not sure

Concerning the selection of a set of indicators, please state to what degree do you agree or disagree with the following options concerning the selection of indicators for use in a holistic CC assessment.

	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
Indicators should focus on the key processes that drive the system	☐	☐	☐	☐	☐
Indicators should focus on the most limiting factors in the system	☐	☐	☐	☐	☐
Indicators should focus on high-risk areas	☐	☐	☐	☐	☐
Indicators should focus on those features we understand, and can predict and quantify reasonably well	☐	☐	☐	☐	☐
Set of indicators chosen should balance objectives holistically	☐	☐	☐	☐	☐

From the literature and results of round 1, we identified a number of **criteria** for selecting the carrying capacity indicators for a more holistic assessment. Please rank in order of importance (from 1 to 8, with 1 being the most important) the criteria you would recommend for framework development.

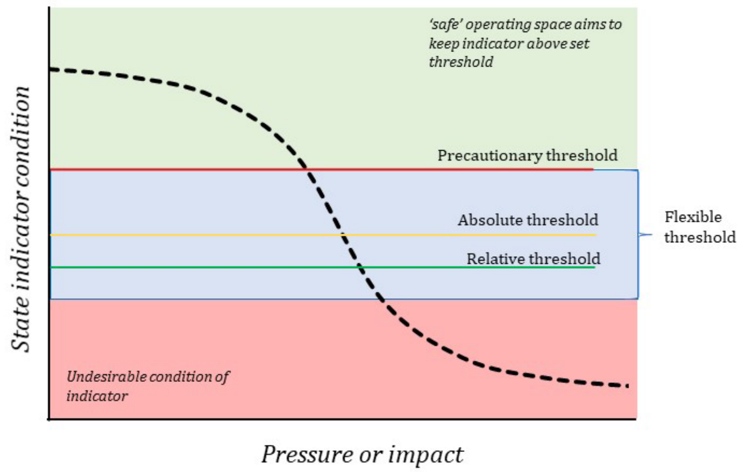
Select a rank	Relevant to specific management objectives and priorities
Select a rank	Ease of measuring – tools, approaches are available to measure
Select a rank	Feasible
Select a rank	Relate to changes specifically due to aquaculture
Select a rank	Reliable – produces consistent results
Select a rank	Relevant to the scale of interest
Select a rank	Data available to assess indicator
Select a rank	Valid among users and stakeholders

Are there any criteria listed above that you do not think are essential? Are there any other criteria (other than the ones above) that you would think are very important? If so, which one(s) and why?

Click or tap here to enter text.

Determining levels of acceptable change (thresholds)

Once carrying capacity indicators have been selected, indicator thresholds are used to determine whether the indicator level is acceptable or not. These "thresholds of acceptable change "are also the 'reference point' to evaluate indicators against the given objective. In the literature, various types of thresholds can be employed.



Hypothetical thresholds for acceptable change in a carrying capacity indicator, showing how different

Absolute thresholds reflect a natural (or 'biological') tipping point in the system. For ecological indicators, this could represent the point beyond which a system changes states. These are sometimes referred to as 'biological thresholds'.

Relative thresholds reflect what is acceptable, as determined by societal norms, perceptions or goals. These are also referred to as 'cultural thresholds'.

Flexible thresholds present a range of values for indicators, which can be calculated as the confidence interval of a calculated threshold, or to reflect multiple levels of risk (e.g. specific values for 'low', 'medium', or 'high' risk).

Precautionary thresholds set what is acceptable lower than calculated threshold, or the lower range of flexible threshold.

Please select the type of thresholds do you think is most appropriate to use when evaluating the carrying capacity of aquaculture. Please select only one answer.

A ☐ Absolute thresholds
B ☐ Relative thresholds
C ☐ Flexible thresholds
D ☐ Precautionary thresholds
E ☐ A combination of different thresholds depending on the indicator and/or context

We have identified a number of **criteria** to help determine which type of threshold to select for a given indicator. If you selected E (combination) above, please rank the following criteria from 1 to 4 in order of importance in selecting the relevant threshold, with 1 being the most important.

Select a rank Capacity to monitor and enforce thresholds
Select a rank Uncertainty of threshold
Select a rank Component, issue, or indicator selected
Select a rank Ability to measure (data, resources)

Are there any criteria listed above that you do not think are essential? Are there any other criteria (other than the ones above) that you would think are very important? If so, which one(s) and why?

Click or tap here to enter text.

Section 4 – Tools and methods for assessing carrying capacity

The assessment of carrying capacity relies on a number of tools and approaches aimed at identifying indicators, understanding the system, or assessing aquaculture against chosen indicators.

A holistic CC assessment will likely require a combination of tools and approaches to measure various indicators and issues identified for assessment. From the literature and round 1, we identified a number of **criteria/variables** that can be used to guide the selection of appropriate tools. Please rank the following variables from 1 to 6 in order of importance in selecting the relevant tools to use, with 1 being the most important.

Select a rank	Priorities and goals for CC assessment
Select a rank	Indicator(s) chosen for assessment
Select a rank	Data availability
Select a rank	Expertise of end-users
Select a rank	The needs of relevant scale(s)
Select a rank	Resources (money, time) needed to apply

Are there any criteria listed above that you do not think are essential? Are there any other criteria (other than the ones above) that you would think are very important? If so, which one(s) and why?

Click or tap here to enter text.

From the literature and round 1, we identified a **number of tools** for supporting carrying capacity assessments. Please rate how suitable and/or relevant you feel the following tools would be in supporting the assessment of some or multiple components of the carrying capacity of salmon aquaculture.

	Not at all suitable	Slightly suitable	Somewhat suitable	Moderately suitable	Very suitable
Ecological/production models	☐	☐	☐	☐	☐
Spatial models	☐	☐	☐	☐	☐
Risk assessment	☐	☐	☐	☐	☐
Life cycle analysis	☐	☐	☐	☐	☐
Ecosystem service valuation	☐	☐	☐	☐	☐
Scenario-building	☐	☐	☐	☐	☐
Expert judgement	☐	☐	☐	☐	☐
Mapping (GIS)	☐	☐	☐	☐	☐
Qualitative surveys or interviews	☐	☐	☐	☐	☐

Are there any other tools or approaches (other than those listed above) that you think would be relevant for evaluating carrying capacity? If so, which one(s) and why?

Click or tap here to enter text.

In addition to the criteria above, we identified a number of **criteria** that contribute to a useful tool to support decision-making. Please rank the following criteria from 1 to 6 in order of importance in selecting the relevant tools to use, with 1 being the most important.

Select a rank	Simple to apply
Select a rank	Can be understood by wide audience
Select a rank	Suitable/accessible to relevant end-users
Select a rank	Consider and/or reflect management measures
Select a rank	Offer clear messages
Select a rank	Affordable data collection and implementation

Are there any criteria listed above that you do not think are essential? Are there any other criteria (other than the ones above) that you would think are very important? If so, which one(s) and why?

Click or tap here to enter text.

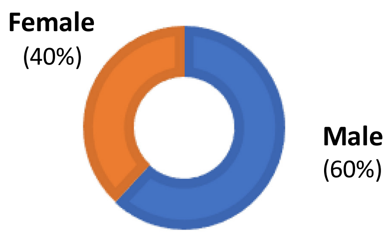
Research priorities

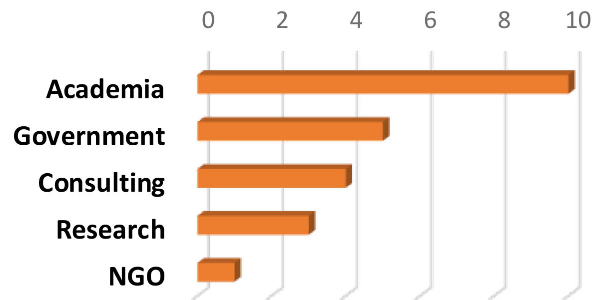
Of the following list of issues, please rank the importance of each of the following research priorities for advancing the **methods and tools** for a holistic assessment of carrying capacity.

	Not at all important	Somewhat important	Important	Moderately important	Very important
Refinement of models to improve spatial resolution	☐	☐	☐	☐	☐
Refinement of models to improve temporal resolution	☐	☐	☐	☐	☐
Approaches to determine far-field or whole-ecosystem effects	☐	☐	☐	☐	☐
Continued validation of tools in new environments/contexts	☐	☐	☐	☐	☐
Methods to integrate multiple aspects of carrying capacity (social, economic, ecological)	☐	☐	☐	☐	☐
Quantitative methods to determine social carrying capacity	☐	☐	☐	☐	☐
Qualitative methods to determine social carrying capacity	☐	☐	☐	☐	☐

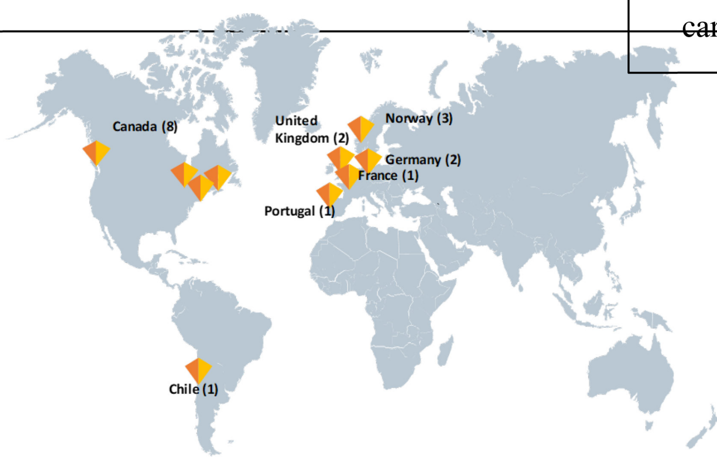
Appendix i – Findings from Round 1 interviews

You are one of **21** experts interviewed

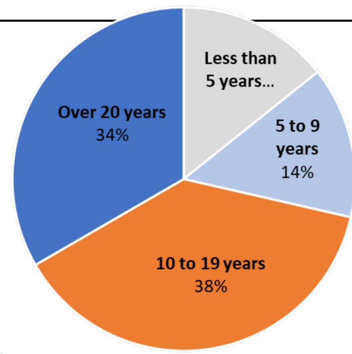




Experts live in different parts of the world!

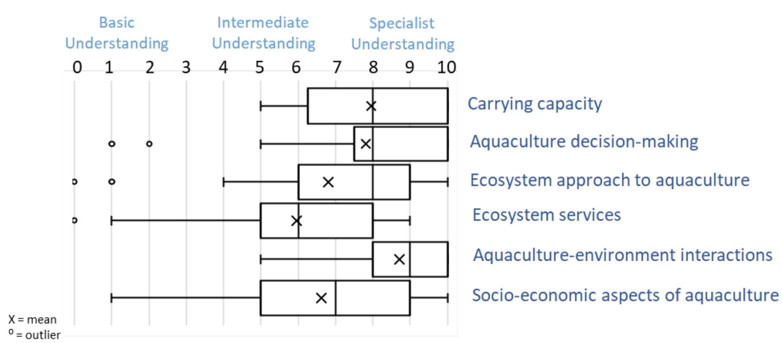


You are highly experienced with carrying capacity



> 80% participants had at least intermediate expertise across all topics

> 60% participants have interdisciplinary expertise



Thank you for being a part of this group!

Appendix B – Features that contribute to the challenge with advancing holistic approaches to carrying capacity

1	**Vague and inconsistent definitions**
	Ambiguous definition of terms (e.g. 'carrying capacity', 'sustainability', 'ecosystem-based approach') create confusion and misuse
	It is not clear what we are measuring the carrying capacity "of"
	Relevant 'holistic' terminology (e.g. 'sustainability', 'ecosystem-approach', 'ecosystem-based') are often conflated with each other
2	**Complexity and ambiguity of scales**
	A farm-centered, operator-centered approach is not enough to adequately consider ecological or social aspects
	The scale of processes is often larger than what we are able (resources) to, or are mandated to manage
	We do not have a good decision-making mechanism to determine the appropriate scale and stakes for the processes that we are interested in
3	**Missing or inappropriate data**
	Lack of practical tools and guidelines for implementation of more holistic approaches
	Having a holistic view is limited by our knowledge and data on several important aspects (e.g. social aspects, far-field interactions)
	Often the data we need for a more holistic assessment is not being collected in the first place (e.g., social indicators, far-field data)
	Complex or comprehensive approaches require substantial amount of data which is often not available
	We need more information and knowledge about the interactions between (social, economic, ecological) components to bring the holistic approach to management
4	**Lack of enabling governance**
	Other political priorities often outweigh practically adopting and implementing more holistic approaches to carrying capacity
	Governments do not have the capacity (adequate funding or resources) to effectively understand, manage, or monitor for all the necessary components
	Aquaculture is often not properly or consistently allocated within governance system
	These approaches (holistic management, or carrying capacity) are often not applied because they are not a required part of the legislative process for aquaculture
	Truly considering other users and wider impacts requires a broader view of management and governance that does not keep aquaculture in a box
5	**Biases, agendas, and political barriers**
	It may take many years to adopt more adaptive and holistic approaches because policy change is slow
	Current governance employs a reactive approach that responds to emerging issues rather than a proactive approach that is needed of holistic approaches
	Agendas and political interests make multi-stakeholder processes complex and difficult to achieve consensus or common vision
	Personal opinions and interests can enter bias into social assessments

B.8 Summary of Round 2 sent to participants in Round 3

Summary of Delphi Round 2 Findings

71% (15/21) of Round 1 participants were also able to complete Round 2. Thank you so much!

Have we reached consensus?

Yes, on many issues! Group consensus was determined beforehand to be reached when:

- Over 75% of experts share ratings within a two-point range (Table1).

Table 1. Descriptive category assigned to ratings on a 5-point Likert Scale

Likert two-point range	Category *
1-2	Not important, relevant, or suitable
2-3	Low
3-4	Medium
4-5	High
*On scale of importance, relevance, or suitability	

Your main comments on Round 2 were:

- That ranking-type questions were challenging since in cases, many variables might have equal importance[1].
- Many of the answers would depend on the specific scale, indicators, and purpose of the CC assessment so may be difficult to generalize

DEFINING A FRAMEWORK FOR HOLISTIC CARRYING CAPACITY

We proposed a number of overarching principles to guide holistic carrying capacity. Yet, the ranking was unclear, and so this question was re-formatted for evaluation in Round 3.

You agreed that it was highly important that the carrying capacity framework include clear guidance on:

- Strategies to identify indicators (93%[2])
- Definitions of relevant terms (87%)
- Process to communicate information (87%)
- Delineation of scale (80%)

You also agreed that the framework should provide guidance in particular for:

- Initial site selection and scoping (93%)
- Obtaining leases for new development (93%)

SPECIFIC RECOMMENDATIONS TO INCLUDE IN A FRAMEWORK

Defining terms relevant to carrying capacity

The terms that were agreed to be highly important to clearly define included:

- Carrying capacity (87%)
- Indicator (87%)
- Acceptable change (threshold) (80%)

From the definitions proposed, **none** of the definitions reached consensus. In particular, the panel greatly disagreed on the suitability of the definitions for carrying capacity (overall), physical CC, and social CC.

Your comments highlighted:

- The need to add more specificity to definitions
- The need to reference the literature from which definitions are drawn
- The need to modify definitions to suit different user-groups and purposes of the CC assessment

[1] As a result, ranking questions were not analyzed and were re-formatted for inclusion in Round 3

[2] Percentages in brackets represent the percent of participants who shared that rating

Scale of assessment

The large-area domain was consistently agreed of high relevance across all CC types, although local was also agreed to be highly relevant.

Table 2. The degree of relevance agreed on by most participants for the scale relevant to each type of carrying capacity.

	Local area	Large area	Regional area	National area	Global
Production CC	High - 87%	High - 86%	*High -64%*	*Med – 46%*	*Not relevant – 50%*
Physical CC	High - 87%	High - 86%	*Low 64%*	*Not relevant 54%*	Not relevant- (75%)
Ecological CC	*High -67%*	High - 100%	*NA*	*Low -62%*	*High -54%*
Social CC	*High -64%*	High - 100%	High - 86%	*Med – 69%*	*Low -50%*

*Grey boxes indicate lack of consensus

Selecting who to include in the process

The panel agreed on two guidelines for involving stakeholders in the carrying capacity assessment process. These included:

1. Actors should represent diverse knowledge forms and disciplines (93%)
2. It is essential to clearly define roles and responsibilities (87%)

Regarding specific roles and responsibilities, you agreed that **government and researchers** should have high degree of involvement, but that carrying capacity assessment process should also involve all other stakeholder groups.

Table 3. The degree of involvement agreed on by most participants regarding how each stakeholder group should be involved in various roles regarding CC assessment.

Roles	Government	Researchers	Public interest groups	Local community	Other users
Leading CC assessment	High - 77%	High - 85%	*Medium - 54%*	*Medium - 54%*	*Medium - 54%*
Setting assessment priorities	High - 77%	*Medium - 62%*	*Medium - 69%*	*High - 61%*	Medium - 77%
Identifying indicators	High - 77%	High – 92%	*Medium - 69%*	*Medium - 69%*	*Medium - 69%*
Setting thresholds	High - 77%	*Medium - 46%*	*High - 69%*	*High - 61%*	*High - 69%*
Providing expertise	*Medium - 69%*	High – 100%	Medium - 77%	*Medium - 54%*	*Medium - 62%*
Communicating outputs	High – 92%	*High - 54%*	Medium - 77%	Medium - 77%	*Medium - 69%*
Monitoring/re-evaluating	High - 77%	High – 85%	*Medium - 62%*	Medium - 77%	*Low – 58%*

*Grey boxes indicate lack of consensus

Your comments also highlighted:

- That the roles will depend on the purpose of the CC assessment and indicators
- Need to clarify what is meant by each stakeholder group

Carrying capacity information

The panel agreed that many of the included factors/issues were highly important for evaluating carrying capacity.

Physical CC (3 of 9 factors)

- Habitat – water quality (93%)
- Habitat – hydrodynamics (80%)
- Proximity to sensitive habitats (80%)

Production CC (2 of 5 factors)

- Habitat that promotes growth rate (93%)
- Habitat that guarantees fish welfare (93%)

Social CC (12 of 15 factors)

- Employment and income (79%)
- Provision of benefits (86%)
- Social justice and equity (93%)
- Interaction with other users (79%)
- Opportunities for engagement (86%)
- Quality of industry engagement (79%)
- Interactions with indigenous (77%)
- Transparency (93%)
- Cultural identities (86%)
- Impacts environment (93%)
- Fish health welfare (86%)
- Food health and safety (93%)

Ecological CC (13 of 19 factors)

- Placement of site infrastructure (86%)
- Use and composition of feed (80%)
- Addition of habitat structure (80%)
- Release of nutrients (80%)
- Release organic material (87%)
- Release chemical (87%)
- Escape fish into environment (80%)
- Spread of disease (100%)
- Change in wild fish population (80%)
- Change in wild fish health (87%)
- Introduction non-native (80%)
- Water quality changes (80%)
- Changes in oxygen concentration benthos (80%)

Factors related to the production and economic conditions of aquaculture had on average lower levels of importance, although experts did agree on their importance. For example, this included factors like proximity to infrastructure, production costs, resource availability, and use of equipment and resources.

Your comments also highlighted:

- Factors/issues (especially those for social and ecological CC) will likely be very different depending who you ask and the specific circumstances, such as the definition of acceptability and purpose of the CC assessment
- The need to add more nuances to some factors (e.g. employment generation – positive or negative? Long term or short term?)

Indicators and Thresholds

You agreed that it was highly important to include the following considerations when selecting indicators:

- Focus on high-risk issues (86%)
- Focus on changes that can be pinpointed to aquaculture (86%)
- Link to management objectives (79%)
- Based on trade-offs in cost, relevance, reliability and complexity (79%)

The following considerations were also agreed to have medium importance:

- Allow measurements across large areas (79%)
- Select fewer, key indicators (77%)

While the majority of experts agreed that all types of thresholds were highly suitable for evaluating carrying capacity, consensus was only reached for the suitability of precautionary thresholds (79%).

Your comments also highlighted that:

- The 'important' variables (considerations) relevant to selecting indicators may likely change and should be identified via scoping exercise
- All types of thresholds may be relevant depending on the indicator

Tools for assessing CC

We proposed several variables that could be used to guide the selection of appropriate tools for use in carrying capacity. Yet, ranking was unclear, so this question was reformatted for evaluation in Round 3.

Consensus was gained that the tools that were highly suitable were:

- Production models (79%)
- Spatial ecological models (93%)
- Risk assessment (100%)
- Expert judgement (86%)

You also agreed that mapping (79%) and qualitative surveys/interviews (93%) were moderately suitable.

Your comments highlighted:

- The need to include other forms of qualitative research methods (like focus groups, media analysis) and quantitative social research methods (models and mapping) that may also be relevant to evaluating carrying capacity for aquaculture

RESEARCH GAPS

The following areas were agreed to have high importance for further research to improve the information needed to support the evaluation of carrying capacity:

- Cumulative effects (100%)
- Societal benefits and risks (93%)
- Societal understanding and perceptions (87%)
- Beyond-farm ecosystem effects (80%)
- Aquaculture-pathogen interactions (87%)

Regarding specific priorities for advancing the methods to evaluate carrying capacity, you agreed that the following were very important:

- Methods to combine social, economic and ecological CC (93%)
- Quantitative methods to determine social CC (93%)
- Qualitative methods to determine social CC (93%)

B.9 Round 3 Questionnaire

Holistic carrying capacity framework: Building consensus

This is the last, third round of the Delphi study. The goal of this process is to build consensus on what should be considered best practices for using carrying capacity to holistically inform decisions about salmon aquaculture planning and management. This work is a valuable part of a PhD thesis at Dalhousie University.

Instructions

On this first page, you may provide comments on the summary of Round 2 findings if you wish (found in Round 2 Appendix).

Then, we will ask your opinion regarding a set of recommendations for holistic CC assessment based on the results from Round 2.

This questionnaire has four sections:

- **Section 1** is aimed at *clarifying responses* from Round 2 that were unclear
- **Section 2** is aimed at *validating recommendations* from which consensus was attained during Round 2.
- **Section 3** presents some *additional propositions* based on your answers and comments from Round 2
- **Section 4** asks you to select between *three options* for what should be contained in a final framework for holistic carrying capacity.

The information collected in this final Round 3 will be used to put together a generalized shared framework for assessing carrying capacity in support of more holistic approach to salmon aquaculture management.

Please enter your unique ID code :

Please provide comments on the summary of Round 2 findings

Page **1** of **6**

Section 1: Clarifications from Round 2

During Round 2, some questions were unclear. To address your comments, the following questions are designed to clarify some of the items from the previous round.

Presented below are several potential overarching principles that can guide how carrying capacity assessments are situated within more holistic approach to aquaculture decision-making. For the following, please rate how important you feel it should be to include each **criteria/principle**.

	Not at all important	Somewhat important	Important	Moderately important	Very important
Being flexible (can be broadly applied to different contexts and situations)	○	○	○	○	○
Being adaptive and iterative (respond to changes over time)	○	○	○	○	○
Being inclusive/participatory (engaging all relevant stakeholders in process)	○	○	○	○	○
Being transparent and clear (understandable and includes all necessary information for all relevant stakeholders)	○	○	○	○	○
Being interdisciplinary (consider all aspects: physical, ecological, social, economic, political, governance)	○	○	○	○	○
Consider multiple scales (space and time)	○	○	○	○	○
Being aware of contexts (situate assessments within the relevant legislative and socio-economic contexts and priorities)	○	○	○	○	○

While the suitability of most tools proposed reached consensus, the panel was divided on the use of ecosystem service valuation. **Please select the option that best represents how you feel ecosystem services concepts and methods could be used as part of carrying capacity assessments.**

○ Not useful; currently, too many challenges and is not relevant for carrying capacity assessments
○ Could be useful, but would only be moderately suitable in some circumstances or for some indicators
○ Quite suitable for consideration in holistic carrying capacity assessments

The tools used in carrying capacity assessment will likely vary depending on the context of the assessment. For the following **criteria**, please rate how important you feel each should be considered in selecting the appropriate tool(s) to use in carrying capacity assessments.

	Not at all important	Somewhat important	Important	Moderately important	Very important
Priorities and goals of the CC assessment	○	○	○	○	○
Indicator(s) chosen for assessment	○	○	○	○	○
Data availability	○	○	○	○	○
Accessibility of tool (ability/expertise needed to use tool)	○	○	○	○	○
The ability to communicate outputs	○	○	○	○	○
Resources (money, time) needed to apply	○	○	○	○	○

Section 2: Recommendations based on consensus from Round 1

The following recommendations were developed using your responses and comments from previous rounds. All these items have already reached consensus. **Please comment on whether you think any modifications to the recommendations are needed.** Focus on what is written in **bold letters.** Only when needed, look at bullet points for more details. Please refer to the summary of Round 2 findings if needed.

	Recommendation	Modifications needed?
Definitions	**1. Carrying capacity assessments should clearly define all relevant terms and concepts for carrying capacity evaluation.** • Definitions should be specific and relevant to the user-groups and focus/purpose of the carrying capacity assessment • All definitions should be justified with relevant reference to literature or source • In particular, relevant terms include carrying capacity, indicator, and acceptable change.	
Scale	**2. Holistic carrying capacity assessments need to evaluate aquaculture at both the local scale and the scale of the 'ecosystem'.** • In addition to the local area scale (farm, cage, community etc.), the physical, production, social, economic, and ecological of the larger area domain (at the wider basin or bay-scale) need to be included.	
Selecting who to involve	**3. Carrying capacity assessments should be designed in a way that enables the local community and relevant stakeholders throughout the CC process** • Should ensure that all relevant groups are adequately represented and given opportunities to input and participate in the process • Involved or considered at all stages and steps of the process • Including processes for ongoing communication and feedback	
	4. Actors involved in the CC assessment should represent diverse knowledge forms and disciplines. • Include representatives with knowledge of social, economic, and ecological expertise • This may also include local and/or indigenous knowledge	
	5. Carrying capacity assessments should clearly define the roles and responsibilities of each actor and stakeholder group, assuming not all actors/stakeholders will have the same responsibilities. • Roles and responsibilities will vary depending on the contexts, purpose of the CC assessment, and/or the indicators chosen	
Identifying indicators	**6. Indicators selected should prioritize changes that can be directly pinpointed to aquaculture** • Aquaculture does not need to be the primary cause of changes, but should be demonstrated to contribute to the changes	
	7. Carrying capacity assessments should focus on selecting a few, key indicators.	
	8. Carrying capacity assessments should ensure that indicators chosen link to management objectives and societal priorities	
	9. Indicators selected should prioritize issues that are predicted to be higher-risk	
	10. Indicators to include in carrying capacity assessments should be selected through discourse between all relevant stakeholders and actors.	

	11. Indicators to include in carrying capacity assessments should be selected through trade-offs in cost, relevance, reliability, and complexity • Cost - based on the money, time, and human resources needed to measure, monitor, and assess a given indicator • Relevance - the degree to which indicators link to management objectives, and can indicate changes pinpointed to aquaculture • Reliability – the degree to which we can understand and predict the indicator reasonably well • Complexity – based on the degree of data, expertise, etc. needed to measure • Relative weights of each features (e.g. trade-offs) determined through scoping	
Tools	**12. A holistic assessment of carrying capacity will require the utilization of a combination of quantitative and qualitative tools.** • Considering a broad array of tools to measure both ecological and socio-economic data	
Communication	**13. The outputs of carrying capacity assessments should be designed in a way that is understandable and clear to all stakeholders involved.**	
	14. Communication of outputs throughout the carrying capacity process should be a joint-responsibility between all involved actors and stakeholders.	

Section 3: Recommendations needing further consensus

The following recommendations were derived from answers in Round 2. While these items were all considered highly important, we did not obtain consensus on them yet. The aim of this section is therefore to see if consensus can be reached on these additional recommendations.

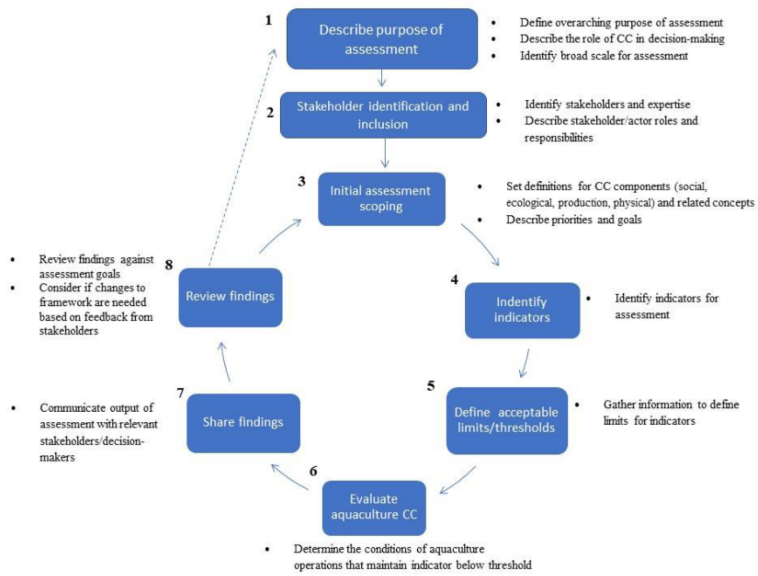
Please state whether you agree or disagree with the recommendations below. Please feel free to comment if you think there are modifications needed to any of the recommendations. Focus on what is written in **bold letters.** Only when needed, have a look at the bullet points for further details.

Recommendations	Do you agree?	Modifications needed?
15. It is essential that a framework for carrying capacity assessment include a structure for different actors to select appropriate tools for evaluation. • A process/structure that describes the different tools available, and outlines the relevant advantages/disadvantages • Process can also include how each tool is used, the resources and information required, etc.	○ Agree ○ Disagree	
16. It is essential that a framework for carrying capacity assessment include processes and guidance on which stakeholders and actors get involved and how	○ Agree ○ Disagree	
17. Carrying capacity assessments should be re-evaluated following initial site development. • For example, in the case of lease renewal • Should therefore enable a process for ongoing monitoring of indicators	○ Agree ○ Disagree	
18. Definitions for the individual types of carrying capacity (e.g., social, ecological, production, physical) should be generated by consensus with all stakeholders involved in the process • Specific definitions for carrying capacity types are crucial for the success of implementation, but the nuances of local settings and the specific goals of the CC assessment will influence how these are defined • Case-specific definitions of these terms are therefore more appropriate than broad all-encompassing definitions	○ Agree ○ Disagree	

19. It is essential to clearly define what is meant by "holistic" in the context of a carrying capacity assessment for aquaculture	○ Agree ○ Disagree	
20. A holistic carrying capacity assessment can be defined as : an evaluation of proposed and/or current aquaculture operations against the acceptable limits, as agreed on through consultation with stakeholders, of the components of the social, ecological, and economic environment in which aquaculture is embedded.	○ Agree ○ Disagree	
21. The scales at which individual indicators are measured should be determined by the specific goals of the carrying capacity assessment	○ Agree ○ Disagree	
22. The goals and priorities for the carrying capacity assessment should be determined through consultation with relevant stakeholders. • This should be a joint process involving both government, communities, and other interest groups	○ Agree ○ Disagree	
23. Stakeholders included in carrying capacity assessments should correspond to the relevant scale(s) of the assessment	○ Agree ○ Disagree	
24. The selection of stakeholders should include consideration for their individual 'stakes' (demonstrated investment and interest in participating)	○ Agree ○ Disagree	
25. Carrying capacity assessments should use both a combination of universal indicators and context-specific indicators • Universal indicators include those well-established, and are generally applicable across the world (e.g., unemployment rate) • Context-specific indicators can be generated iteratively between actors, and may be specific to the local contexts of the area	○ Agree ○ Disagree	
26. Carrying capacity assessments should prioritize indicators that are demonstrated to be the limiting factors in the system	○ Agree ○ Disagree	
27. Set of indicators for carrying capacity assessments should balance objectives holistically • Include indicators across social, economic, ecological, and governance features • Therefore, CC assessments should not rely on indicators that only represent one dimension (e.g., only ecological)	○ Agree ○ Disagree	
28. Setting acceptable thresholds should be determined through consultation and agreement across all relevant stakeholders	○ Agree ○ Disagree	

29. All types of thresholds are potentially relevant for carrying capacity assessment, but will vary depending on the indicator chosen
• Types of thresholds include:
  • Absolute thresholds: reflect natural tipping point in system.
  • Relative thresholds: reflect what is acceptable by societal norms and perceptions
  • Flexible thresholds: present a range of values for indicators
  • Precautionary thresholds: set what is acceptable lower than calculated threshold
• CC assessments should also provide a clear justification and definition for the use of a given type of threshold based on the specific indicator
	○ Agree
	○ Disagree	

In Round 2, we presented a generalized **stepwise process** to guide holistic carrying capacity assessments. Based on your feedback, we have modified the general process that considers the principles, concepts and steps covered in previous rounds.



Do you think this stepwise process needs any further modifications?

Section 4: Putting together the framework for holistic carrying capacity assessment

A shared framework for holistic carrying capacity assessment could serve as a generalized reference document for decision-makers and stakeholders to situate carrying capacity assessments within a more holistic approach to aquaculture management.

Please tell us whether you agree or not with each of these three options for inclusion in a shared framework for holistic CC assessment. Please select 'strongly agree' for only one option.

		Strongly agree: This is my first choice	**Agree:** This is not my first choice, but I would use it if a larger proportion of the panel prefers it	**Disagree:** I don't like this option
Option A	The recommendations gathered as part of this process (pages 2-5) alone are sufficient as a shared framework for holistic CC assessments	○	○	○
Option B	The stepwise process alone (with additional details on each step) is sufficient as a shared framework for holistic CC assessments	○	○	○
Option C	The recommendations AND stepwise process should be combined into a shared framework for CC assessments.	○	○	○

Thank you for completing the Delphi Round 3 questionnaire. Please review all your answers carefully, and make sure no answers are left blank. When you are satisfied with your answers, please return the filled form by saving this file with the **four-digit unique ID code.**

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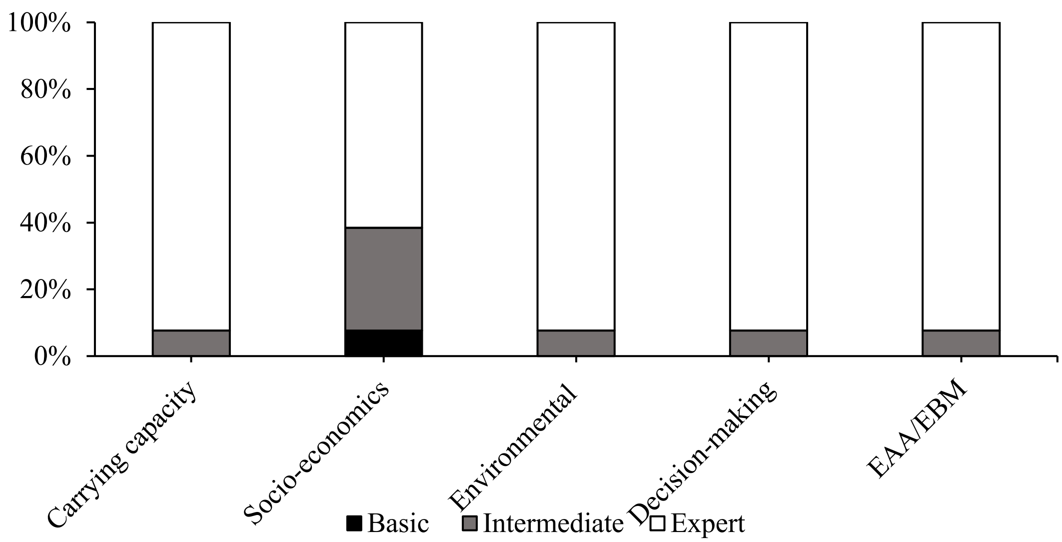
B.10 Description of expert participants - Supplemental I from publication

Supplemental I: Description of expert participants
Characteristics of experts participating in Delphi study.

Baseline characteristics	Round 1 N(%)	Round 2 N(%)	Round 3 N(%)
Number of participants who completed the round	21 (100)	16 (76.2)[i]	13 (81.3)[i]
Country			
Canada	9 (42.9)	5 (31.3)	4 (30.8)
Norway	3 (14.3)	3 (18.8)	2 (15.4)
U.S.A.	2 (9.52)	2 (12.5)	2 (15.4)
United Kingdom (Scotland)	2 (9.52)	1 (6.3)	0 (0)
Germany	2 (9.52)	2 (12.5)	2 (15.4)
Chile	1 (4.76)	1 (6.3)	1 (7.69)
Portugal	1 (4.76)	1 (6.3)	1 (7.69)
France	1 (4.76)	1 (6.3)	1 (7.69)
*Sector**			
Academia (across disciplines)	10 (47.6)	6 (37.5)	5 (38.5)
Government	5 (23.8)	4 (25.0)	4 (30.8)
Consulting	5 (23.8)	4 (25.0)	4 (30.8)
Research institute	3 (14.3)	3 (18.8)	2 (15.4)

*For sector, one participant met two relevant sectors
[i] In Rounds 2 and 3 %N indicative of retention rate from previous round, but % on other categories relative to N of the representing round.



Self-rated expertise of experts (based on Round 3 expert panel).

B.11 Final best-practice recommendations – Supplemental II

Aspect of CC	Recommendation
Definitions of concepts and terms	
1	It is essential to define and refer to the essential concepts related to the assessment, including holistic, carrying capacity, indicator, and acceptable change (threshold) • Definitions should be specific and relevant to the user-groups and focus/purpose of the carrying capacity assessment • All definitions should be justified with relevant reference to literature or source
Inclusion of relevant scale(s)	
2	Assessments should include all scales relevant to the social-ecological system. • In addition to the local area scale (farm, cage, community etc.), the physical, production, social, economic, and ecological of the larger area domain (at the wider basin or bay-scale) may need to be included.
3	The scales included in the assessment should be determined by the specific goals and contexts of the carrying capacity assessment
Depth and breadth of stakeholder involvement	
4	Carrying capacity assessments should be designed to engage the relevant stakeholders to participate throughout the CC process as appropriate •Should ensure that all relevant groups are adequately represented and given opportunities to input and participate in the process •Involved or considered at all stages and steps of the process •Including processes for ongoing communication and feedback
5	Carrying capacity assessments should clearly define the roles and responsibilities of each stakeholder, recognizing that not all stakeholders will have the same responsibilities. •Roles and responsibilities will vary depending on the contexts, purpose of the CC assessment, and/or the indicators chosen
Identifying and assessing carrying capacity	
6	Carrying capacity assessments should focus on selecting as few, important indicators as relevant to the assessment objectives and priorities
7	Indicators to include should be selected by balancing trade-offs in cost, relevance, reliability, and complexity •Cost - based on the money, time, and human resources needed to measure, monitor, and assess a given indicator •Relevance - the degree to which indicators link to management objectives, and can indicate changes pinpointed to aquaculture •Reliability – the degree to which we can understand and predict the indicator reasonably well •Complexity – based on the degree of data, expertise, etc. needed to measure •Relative weights of each features (e.g. trade-offs) determined through scoping
8	Carrying capacity assessments should use both a combination of universal indicators and context-specific indicators

9	Multiple types of thresholds are potentially relevant for CC assessment, but will vary depending on the indicator chosen •Types of thresholds include: •Absolute thresholds: reflect natural tipping point in system. •Relative thresholds: reflect what is acceptable by societal norms and perceptions •Flexible thresholds: present a range of values for indicators •Precautionary thresholds: set what is acceptable lower than calculated threshold •CC assessments should also provide a clear justification and definition for the use ofa given type of threshold based on the specific indicator
10	A holistic assessment of carrying capacity requires using a combination of quantitative and qualitative tools and information •Considering a broad array of tools to measure both ecological and socio-economic data

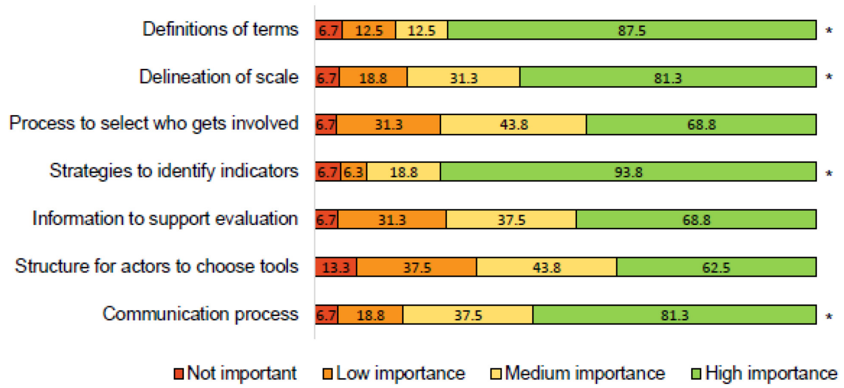
B.12 Results of Delphi Rounds – Supplemental III

Supplemental III: Results of Delphi Rounds

Round 2 Questionnaire

Question 1 – *Ranking type question removed from analysis and re-structured for Round 3 due to participant's difficulties answering question*

Question 2 - Please rate how important you feel it is to that a carrying capacity framework include clear guidance on the following aspects of a carrying capacity (CC) assessment.



Are there any other aspects for carrying capacity processes that you think it is very important to provide clear guidance on? If so, which one(s) and why? – *Open ended comments*

Question 3 - Overall, a holistic carrying capacity assessment is a tool for decision-makers that involves an evaluation of the limit of aquaculture use over which changes become unacceptable. From our findings, we propose a framework for assessment based on seven steps [presented a figure with preliminary steps]

A. Would you add any other steps? Do you think any of these steps are not essential? Would you modify the order? Explain. - *Open ended comments*

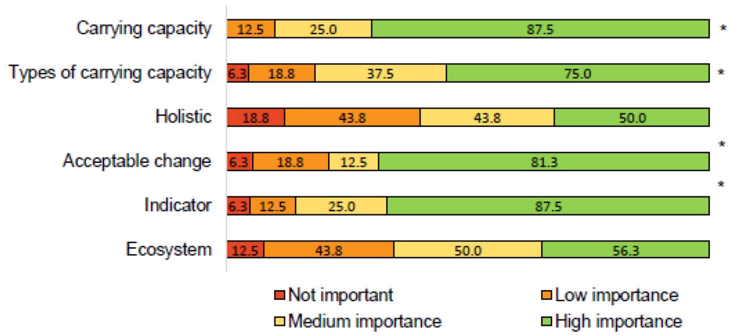
B. From your perspective, which step(s) need to be emphasized? Why? - *Open ended comments*

Question 4 - At what part or parts of the policy process for salmon aquaculture decisions do you think a framework to guiding holistic carrying capacity should cover? Please select all that apply.

Options	**# of participants selected**	**% consensus**
A. Initial site selection and scoping	15	93.8*
B. Obtaining leases for new development	15	93.8*
C. Day to day management	7	43.8
D. Lease renewal	11	68.8
E. Ongoing monitoring	11	68.8
F. Other – *open ended comments*	5	

*Indicate results where consensus was attained (≥75% agreement by experts)

Question 5 - Please rate to what degree you feel it is important that a framework provide a clear definition of the following concepts that relate to carrying capacity and holistic assessments



Are there any other concepts you feel are essential to define in a CC framework? If so, which one(s)? – *Open ended comments*

Question 6 - Based on the literature and round 1, we have proposed general definitions for several concepts related to carrying capacity of aquaculture. For the following concepts and terms, please indicate how appropriate you believe the definitions to be.

	Not at all relevant	Low relevance	Medium relevance	High relevance
Holistic approach An approach that considers aquaculture as a whole social-ecological system, including the social, ecological, economic, and governance contexts, and the interactions of the parts	25.0	31.3	31.3	68.8
Carrying capacity (overall) Level of aquaculture that does not degrade the condition of the important social, economic, or ecological system components beyond an acceptable limit	18.8	37.5	43.8	43.8
Production carrying capacity The level of aquaculture at which production biomass is maximized	6.3	31.3	50.0	56.3
Physical carrying capacity The geographic area that is suitable and available for aquaculture	0.0	37.5	50.0	50.0
Ecological carrying capacity The maximum level of aquaculture that does not cause unacceptable ecological impacts	0.0	25.0	50.0	56.3
Social carrying capacity The maximum level of aquaculture that does not cause unacceptable social impacts	18.8	31.3	43.8	50.0

Do you have any suggestions to edit any of these definitions? – *Open ended comments*

Question 7 - Please complete the following matrix by entering a number from 1 to 5 based on the degree of relevance that you believe the following scales are for assessment of aquaculture at each of the components of the social-ecological system.

A. Production Carrying capacity	Not at all relevant	Low relevance	Medium relevance	High relevance
Local area	0.0	12.5	12.5	87.5*
Large area	0.0	13.3	53.3	86.7*
Regional area	13.3	40.0	60.0	60.0
National area	21.4	50.0	42.9	35.7
Global area	53.8	23.1	23.1	30.8

B. Physical Carrying capacity	Not at all relevant	Low relevance	Medium relevance	High relevance
Local area	0.0	12.5	25.0	87.5*
Large area	0.0	13.3	40.0	86.7*
Regional area	40.0	60.0	40.0	33.3
National area	50.0	42.9	42.9	21.4
Global area	76.9*	23.1	7.7	15.4

C. Ecological Carrying capacity	Not at all relevant	Low relevance	Medium relevance	High relevance
Local area	12.5	37.5	37.5	62.5
Large area	0.0	0.0	20.0	100.0*
Regional area	13.3	46.7	46.7	53.3
National area	35.7	57.1	50.0	21.4
Global area	35.7	50.0	50.0	28.6

D. Social Carrying capacity	Not at all relevant	Low relevance	Medium relevance	High relevance
Local area	6.7	33.3	40.0	66.7
Large area	0.0	0.0	13.3	100.0*
Regional area	6.7	13.3	33.3	80.0*
National area	14.3	42.9	71.4	42.9
Global area	53.8	53.8	38.5	23.1

Question 8 - *Ranking type question removed from analysis and re-structured for Round 3 due to participant's difficulties answering question*

Question 9 - Please state how you agree or disagree with the following guidelines for involving actors and stakeholders within a carrying capacity assessment.

Statement	No agreement (Likert 1-2)	Low agreement (Likert 2-3)	Medium agreement (Likert 3-4)	High agreement (Likert 4-5)
Actors involved with the CC assessment should represent diverse knowledge forms and disciplines	0.0	6.3	43.8	93.8*
It is essential to clearly define roles and responsibilities of each actor, assuming not all actors will have the same responsibilities	0.0	18.8	62.5	81.3*
Actors should represent relevant stakeholders	12.5	31.3	56.3	62.5
Chosen stakeholders should include representation from stakeholders beyond the local scale	6.3	31.3	68.8	62.5
Stakeholders should be selected based on their 'stake' (demonstrated investment and interest in participating)	31.3	56.3	56.3	37.5
Stakeholders need to be included throughout the CC process (at all steps)	0.0	25.0	56.3	75.0*

Question 10 - Please complete the following matrix by entering a number from 1 to 5 based on the degree of involvement you feel each of the following actors/stakeholders should have in a holistic CC assessment.

A. Leading CC assessment	Not at all relevant	Low relevance	Medium relevance	High relevance
Government	0.0	21.4	35.7	78.6*
Researchers	7.1	7.1	28.6	85.7*
Public interest groups (e.g. NGOs)	42.9	50.0	57.1	21.4
Local community	28.6	50.0	57.1	28.6
Other marine users	42.9	35.7	57.1	35.7

B. Setting priorities for assessment	Not at all relevant	Low relevance	Medium relevance	High relevance
Government	0.0	28.6	42.9	71.4
Researchers	14.3	64.3	64.3	35.7
Public interest groups (e.g. NGOs)	21.4	50.0	71.4	42.9
Local community	14.3	35.7	42.9	64.3
Other marine users	14.3	57.1	78.6*	42.9

C. Identifying indicators	Not at all relevant	Low relevance	Medium relevance	High relevance
Government	7.1	21.4	64.3	78.6*
Researchers	7.1	0.0	28.6	92.9*
Public interest groups (e.g. NGOs)	21.4	57.1	71.4	35.7
Local community	14.3	35.7	71.4	57.1
Other marine users	21.4	42.9	71.4	42.9

D. Setting acceptable thresholds	Not at all relevant	Low relevance	Medium relevance	High relevance
Government	7.1	21.4	14.3	78.6*
Researchers	14.3	35.7	42.9	50.0
Public interest groups (e.g. NGOs)	28.6	21.4	28.6	64.3
Local community	14.3	35.7	28.6	57.1
Other marine users	21.4	28.6	50.0	64.3

E. Providing expertise or knowledge	Not at all relevant	Low relevance	Medium relevance	High relevance
Government	14.3	50.0	71.4	50.0
Researchers	0.0	0.0	7.1	100.0*
Public interest groups (e.g. NGOs)	7.1	57.1	71.4	42.9
Local community	21.4	50.0	57.1	42.9
Other marine users	21.4	50.0	57.1	50.0

F. Communicating outputs	Not at all relevant	Low relevance	Medium relevance	High relevance
Government	0.0	7.1	28.6	92.9*
Researchers	21.4	35.7	42.9	57.1
Public interest groups (e.g. NGOs)	21.4	78.6	78.6*	14.3
Local community	14.3	57.1	78.6*	42.9
Other marine users	35.7	71.4	64.3	14.3

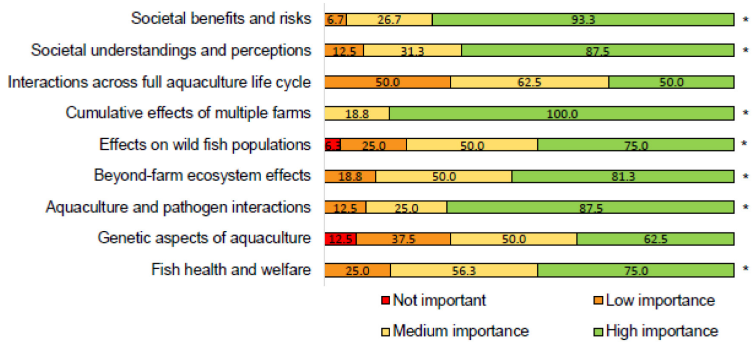
G. Monitoring or re-evaluating indicators	Not at all relevant	Low relevance	Medium relevance	High relevance
Government	7.7	23.1	23.1	76.9*
Researchers	0.0	15.4	46.2	84.6*
Public interest groups (e.g. NGOs)	30.8	61.5	61.5	23.1
Local community	23.1	61.5	76.9*	30.8
Other marine users	41.7	58.3	50.0	25.0

Are there any other actors/stakeholders and/or roles that you believe any of the given actors (or otherwise) could contribute to the CC process? If so, which one(s), and why? – *Open ended comments*

Question 11 - Please indicate how important you think each of the following **factor/issues** are for evaluating the carrying capacity of **salmon farming**.

	Not important	Low importance	Medium importance	High importance	Median
PHYSICAL					
Habitat: Water quality	6.3	0.0	18.8	93.8	5
Habitat: hydrodynamics	12.5	12.5	25.0	81.3	5
Habitat: temperature	25.0	37.5	25.0	56.3	4.5
Habitat: oxygen availability	6.3	18.8	37.5	75.0	5
Habitat: depth	37.5	37.5	31.3	56.3	4
Proximity to infrastructure	31.3	37.5	50.0	43.8	3
Proximity to sensitive habitats	18.8	0.0	0.0	81.3	5
Proximity to other users	18.8	12.5	43.8	68.8	4
Space between farms and cages	18.8	18.8	31.3	68.8	4.5
PRODUCTION					
Habitat that promotes growth rate	0.0	6.7	20.0	93.3	5
Habitat that guarantees fish welfare	0.0	6.7	26.7	93.3	5
Habitat that minimizes local environmental effects	13.3	13.3	33.3	73.3	5
Production costs	26.7	33.3	20.0	60.0	5
Resource availability	26.7	13.3	20.0	73.3	5
SOCIAL					
Employment	0.0	26.7	53.3	73.3	4
Benefits to communities	0.0	13.3	26.7	86.7	5
Social justice	0.0	13.3	20.0	86.7	5
Infrastructure	6.7	46.7	66.7	53.3	4
Interaction with other users	0.0	20.0	33.3	80.0	5
Use of landscape	6.7	40.0	46.7	60.0	4
Aesthetic value	20.0	46.7	46.7	53.3	4
Opportunities for engagement	0.0	13.3	46.7	86.7	5
Quality of industry engagement	0.0	20.0	40.0	80.0	5
Interactions with indigenous	14.3	21.4	42.9	78.6	4
Transparency	0.0	6.7	33.3	93.3	5
Cultural identities	6.7	20.0	46.7	80.0	4
Impacts environment	0.0	6.7	33.3	93.3	5
Fish health welfare	0.0	13.3	53.3	86.7	4
Food health and safety	0.0	6.7	13.3	93.3	5
ECOLOGICAL					
Placement site infrastructure	0.0	13.3	40.0	86.7	5
Use of industrical equipment	13.3	46.7	66.7	46.7	3
Management of site and stock	0.0	26.7	40.0	73.3	5
use and composition of feed	12.5	18.8	50.0	81.3	4
addition of habitat structure	6.3	18.8	37.5	81.3	5
release of nutrients	6.3	18.8	62.5	81.3	4
release organic material	0.0	12.5	56.3	87.5	4
release chemical	6.3	12.5	43.8	87.5	4.5
alteration light and noise	18.8	56.3	68.8	37.5	3
addition of litter	26.7	26.7	53.3	66.7	4
escape fish into environment	12.5	18.8	25.0	81.3	5
spread of disease	0.0	0.0	12.5	100.0	5
change in wild fish population	6.3	25.0	25.0	75.0	5
change in wild fish health	0.0	12.5	25.0	87.5	5

Question 12 - Of the following list of issues, please rate the importance of each of the following research priorities regarding the **information needed** to advance how we evaluate aquaculture from a holistic perspective.



Question 13 - Concerning the selection of indicators, please select the option you feel is the most suitable for a holistic CC assessment.

Option	# of participants	% consensus
Universal indicators (which can be used across the world and could come from a bank of ready-to-use indicators)	1	6.3
Using context-specific indicators (which can be generated iteratively between actors)	4	25.0
A combination of universal and context-specific indicators	10	62.5
I am not sure	1	6.3

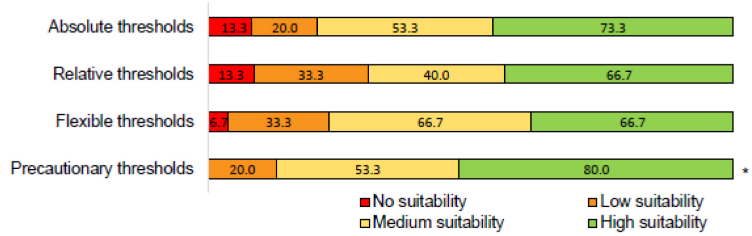
Question 14 - Concerning the selection of a set of indicators, please rate to what degree you feel the following considerations are important regarding the selection of indicators for use in a holistic CC assessment.

Statement	No importance	Low importance	Medium importance	High importance
Indicators should focus on the most limiting factors in the system	0.0	26.7	66.7	73.3
Indicators should focus on high-risk issues	0.0	14.3	35.7	85.7*
Indicators should focus on those features we understand, and can predict and quantify reasonably well	26.7	53.3	46.7	46.7
Indicators should focus on changes we can clearly pinpoint to aquaculture	13.3	6.7	33.3	86.7*
Indicators should link to management objectives and societal priorities	6.7	20.0	40.0	80.0*
Set of indicators chosen should allow frequent monitoring over time	6.7	33.3	60.0	66.7
Set of indicators chosen should balance objectives holistically	13.3	73.3	80.0*	26.7
It is most appropriate to select fewer, key indicators	14.3	28.6	50.0	71.4
Set of indicators should allow measurements across large areas	21.4	50.0	71.4	35.7
Set of indicators should be chosen based on trade-offs between cost, relevance, reliability and complexity	0.0	20.0	66.7	80.0*

Are there any criteria listed above that you do not think are essential? Are there any other criteria that you would think are very important? If so, which one(s) and why? – *Open ended comments*

*Indicate results where consensus was attained (≥75% agreement by experts)

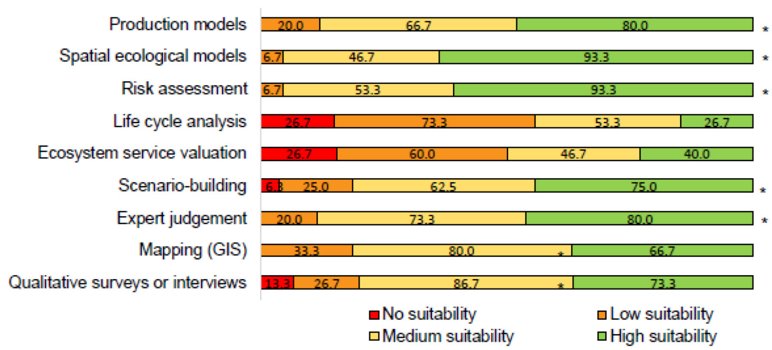
Question 15 - Please rate the degree of suitability you feel the following type of thresholds are for evaluating the carrying capacity of aquaculture.



Question 16 - *Ranking type question removed from analysis and re-structured for Round 3 due to participant's difficulties answering question*

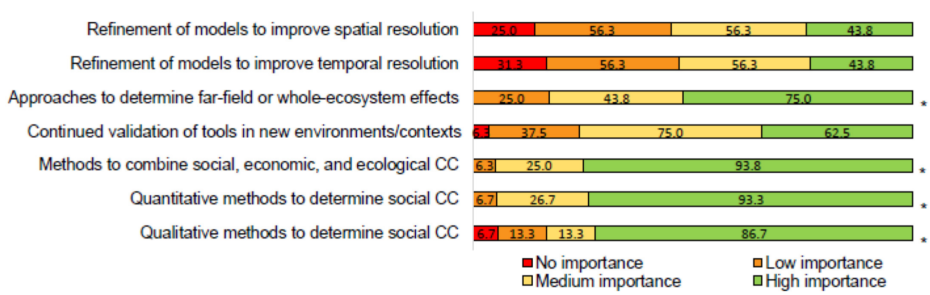
Question 17 - *Ranking type question removed from analysis and re-structured for Round 3 due to participant's difficulties answering question*

Question 18 - We identified a number of tools for supporting carrying capacity assessments. Please rate how suitable and/or relevant you feel the following tools would be supporting the assessment of some or multiple CC components of salmon farming.



Are there any other tools or approaches (other than those listed above) that you think would be relevant for evaluating carrying capacity? If so, which one(s) and why? – *Open ended comments*

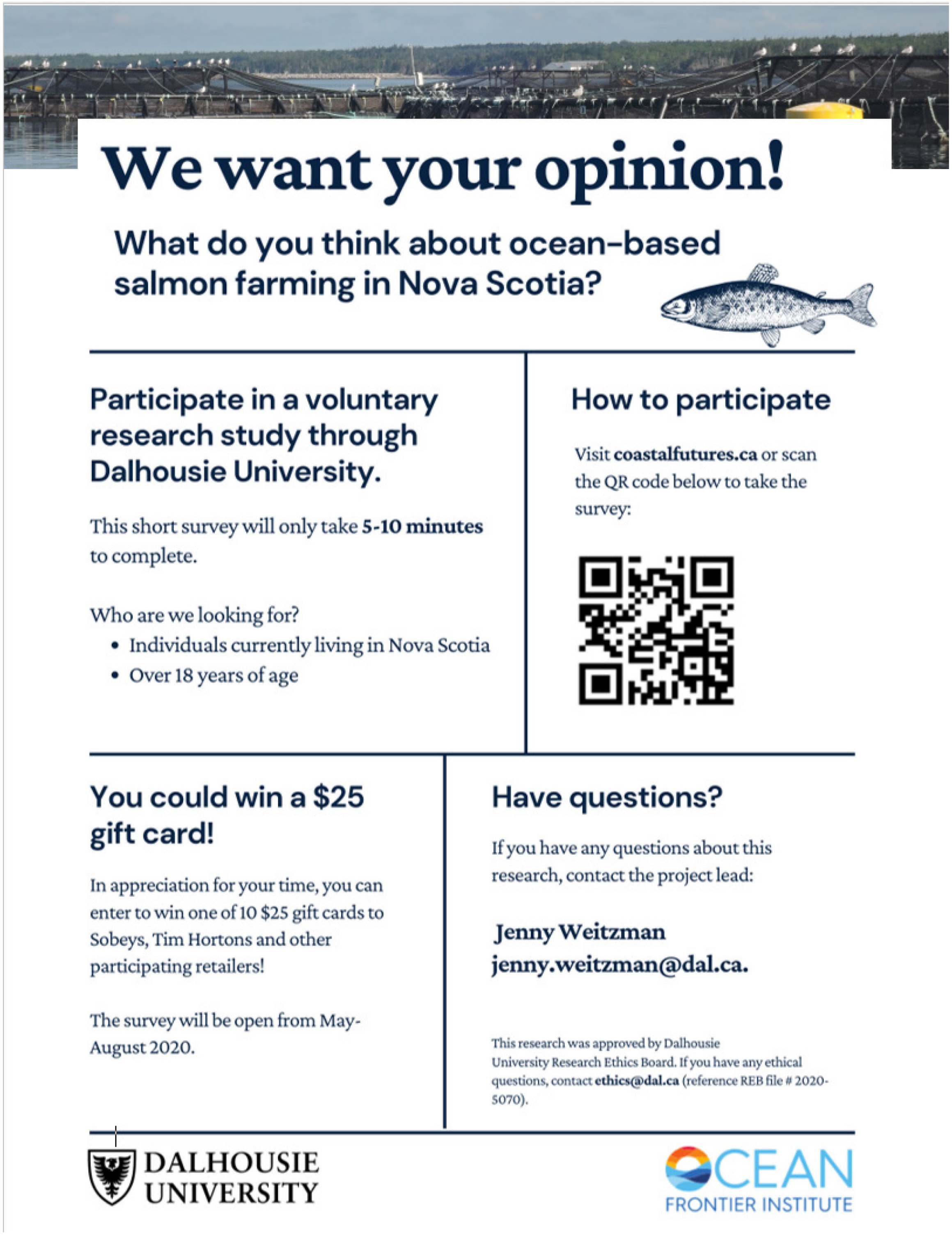
Question 19 - Of the following list of issues, please rate the importance of each of the following research priorities for advancing the methods and tools for a holistic assessment of carrying capacity.



*Indicate results where consensus was attained (≥75% agreement by experts)

APPENDIX C. CHAPTER 4 RESEARCH MATERIALS

C.1 Advertising flyer for recruitment



C.2 Example social media post for recruitment

What do you think about salmon farming in Nova Scotia?

The survey will only take 5 - 10 minutes, and you can win one of ten $25.00 gift cards to a retailer of your choice!

Please pass this along to family and friends in Nova Scotia who you think might be interested. Hope to hear from you and thank you very much!
https://surveys.dal.ca/opinio/s?s=56658

We invite you to participate in a Dalhousie University study to help understand what Nova Scotians know and feel about salmon farming in the province.

This short survey will only take 5 - 10 minutes.

To participate: https://surveys.dal.ca/opinio/s?s=56658

DALHOUSIE UNIVERSITY

OCEAN FRONTIER INSTITUTE

For more information about this study, please contact research lead Jenny Weitzman at jenny.weitzman@dal.ca

This study has been approved by the Dalhousie University Research Ethics Board (REB-2020-5070).

C.3 Online consent page

Survey - Understanding public perception of salmon framing in Nova Scotia

This project is led by Jenny Weitzman, a PhD student at Dalhousie University and is funded through the Ocean Frontier Institute. Your participation is voluntary, and you may withdraw from the survey at any time prior to completion. **No personally identifying information will be collected, and all responses will be confidential.**

This online survey should take about 5 minutes to complete.

The survey will ask you questions related to your values towards the ocean, and your opinions towards salmon farming in Nova Scotia. You will also be asked to provide demographic information about your age, gender, employment and income. If at any time you feel you can't answer a question, or if a question makes you uncomfortable, please feel free to skip it.

For any questions, concerns, or more information about the study, please contact Jenny Weitzman (jenny.weitzman@dal.ca, (902)209-2935). The results of this study will be used for academic purposes **only**. This research has been reviewed according to the Dalhousie University Research Ethics Board (REB). If you have any ethical questions, you can contact them at (902) 494-1462, or e-mail: ethics@dal.ca (and reference REB file # 2020-5070).

Before you begin, please click the following buttons, agreeing that:

- ☐ I have read the above information explaining the study. I understand that participating is my choice, and that I may leave the survey any time before completion.
- ☐ I am at least 18 years of age.
- ☐ I am currently living within Nova Scotia.
- ☐ This is the first time I have completed this survey, either in person or online.

If you have accepted all the items above, please click "Next" to begin the survey. Selecting the "Cancel" button at any time will end the survey.

C.4 Online survey

Farmed salmon public survey

Q1 : Please indicate the city, town, or municipality where you live : _______________

Q2 : Please indicate the description that best matches where you live.

- o Large city
- o Suburb near a large city
- o Small city or town
- o Rural area

Q3 : Approximately how far away is your home from the coast?

- o Waterfront
- o Within 500 metres of the coast
- o Between 500 metres and 1 kilometre from the coast
- o Between 1 and 5 kilometres from the coast
- o Over 5 kilometres from the coast

Q4 : Can you see the ocean from your home?

- o Yes
- o No

Q5 : How much of the year do you live in Nova Scotia?

- o Year-round
- o 6 months to a year
- o 3 to 6 months
- o Under 3 months

Section 2: Values about the ocean/coast

Q6 : Listed below are statements about the relationship between humans and the ocean. For each, please rate your level of agreement or disagreement with the given statements.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Using and developing of our oceans and coasts is necessary for our communities and economies to develop	O	O	O	O	O
We can continue to use the ocean to meet our needs, as long as it does not compromise the ability of future generations to meet their needs	O	O	O	O	O
The balance of nature is strong enough to cope with the impacts of modern industrial activities	O	O	O	O	O
The ocean has plenty of natural resources and we just need to learn how to use them	O	O	O	O	O
The ocean and the ocean life should be protected because they in themselves have the right to exist	O	O	O	O	O
Humans have an inherent right to modify the natural environment to suit our needs	O	O	O	O	O
The ocean and/or coast reflect who we are as a community and/or society	O	O	O	O	O
I often think about some ocean places whose fate I care about, even if I will never use or see them	O	O	O	O	O

1

The health of myself and/or my family is related in one way or another to the ocean	○	○	○	○	○
I have strong feelings about the ocean (including the water, coastal landscape, plants and animals) - these views are part of who I am	○	○	○	○	○
Managing our oceans is an important part of our responsibility to, and so stewardship of the ocean	○	○	○	○	○
We have a responsibility to account for our impacts on the ocean because these impacts can harm other people	○	○	○	○	○
There are coastal places that are very important to me and can not be replaced anywhere else	○	○	○	○	○

Section 3 : Perceptions about aquaculture

Q7 : On average, how often do you eat **fish** (excluding any form of shellfish (e.g. mussels, oysters), or lobster, crab, shrimp)

- More than 3 times a week
- 2 - 3 times a week
- Once a week
- 2 - 3 times a month
- Once a month
- Rarely
- Never

Q8 : Please indicate whether you eat any of the following types of salmon. Select all that apply.

☐ Wild-caught salmon ☐ Farmed salmon ☐ I do not know the type of salmon I eat ☐ I do not eat salmon

Q9: Is there currently a salmon farm in your community or neighbouring community?

○ Yes ○ No ○ I don't know

Q10 : Have you ever visited a salmon farm?

○ Yes ○ No

Q11 : How knowledgeable do you feel about salmon farming?

- No prior knowledge
- Very little knowledge, although I have a basic understanding
- I have some knowledge
- Knowledgeable
- Very knowledgeable

Q12 : Please rate on a scale of 1 to 5 your level of interest in learning more about salmon farming.

Not at all interested				Extremely interested
1	2	3	4	5
○	○	○	○	○

Q13: Which of the following sources do you get information about salmon farming? Please select all that apply.

☐ Government
☐ Aquaculture industry
☐ Science institutions and/or scientists
☐ Science journals and/or magazines
☐ Environmental NGOs
☐ Friends and/or family
☐ News (TV, radio, online)
☐ Social media and websites
☐ Experience and observations
☐ Other (describe): ____________________

Q14 : How would you rate your general opinion towards salmon farming?

- Very positive

- Generally positive
- Neutral or undecided
- Generally negative
- Very negative

Q15: For the following questions, please answer how much you agree or disagree with the statements based on your current understanding of **salmon farming in Nova Scotia**.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I am generally supportive of salmon farming development in Nova Scotia	○	○	○	○	○
We do not have a good enough understanding of the impacts the industry is having on the environment	○	○	○	○	○
I trust that the government is effectively managing the industry in Nova Scotia	○	○	○	○	○
Salmon farming companies in Nova Scotia do not care about addressing concerns of the public and/or stakeholders	○	○	○	○	○
Overall, I think that salmon farming offers benefits that outweigh its impacts	○	○	○	○	○

Q16 : Based on your knowledge, please rate how you feel the salmon farming industry's impacts are on:

	Very negative	Somewhat negative	Neutral	Somewhat positive	Very positive	I don't know
Employment and income	○	○	○	○	○	○
Rural and/or coastal economic development	○	○	○	○	○	○
Nova Scotian and/or Canadian economy	○	○	○	○	○	○
Visual character of ocean/coast	○	○	○	○	○	○
Marine pollution, including rubbish or debris	○	○	○	○	○	○
Ocean and/or coastal access	○	○	○	○	○	○
Community identity and culture	○	○	○	○	○	○
Marine tourism	○	○	○	○	○	○
Other commercial fisheries	○	○	○	○	○	○
Animal welfare	○	○	○	○	○	○
Water quality	○	○	○	○	○	○
Habitat beneath the farms	○	○	○	○	○	○

Spread of disease and pests (sea lice)	O	O	O	O	O	O
Protected or sensitive marine species in the area	O	O	O	O	O	O
Wild salmon populations	O	O	O	O	O	O
Global fish populations	O	O	O	O	O	O

Section 3 : Demographics

Q17 : Please indicate which age group you belong.
- 18-24
- 25-34
- 35-44
- 45-54
- 55 - 64
- 65 or older
- Prefer not to say

Q18 : Please indicate which gender identity you identify with the most.
- Female
- Male
- Other: ____________
- Prefer not to say

Q19 : Please indicate the highest level of education you have attained.
- Less than high school
- High school
- Postsecondary certificate or diploma
- Bachelor's degree
- Above bachelor's degree and professional degrees (Masters, PhD, MD)
- Prefer not to say

Q20 : Please indicate your average annual *household* income (in CAD)?
- Less than $20,000
- $20,000 - $39,000
- $40,000 - $59,000
- $60,000 - $79,000
- $80,000 - $99,000
- Above $100,000
- Prefer not to say

Q21 : Are you, or anyone in your immediate family employed in any of the following marine-related occupations? Please choose all that apply.
- ☐ Fishing
- ☐ Aquaculture
- ☐ Coastal tourism
- ☐ Oil and gas
- ☐ Marine shipping
- ☐ Navy or Coast Guard
- ☐ Coastal construction
- ☐ Marine research
- ☐ Coastal or marine conservation
- ☐ None
- ☐ Other (Describe) ________________________

Thank you for completing this survey. An executive summary of the findings will be posted to our website (https://coastalfutures.ca/) at the completion of the study in December 2020. A full reporting of results will be published as part of a PhD thesis and available at https://dalspace.libraries.dal.

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C.5 Overview of survey variables – Appendix A from publication

Supplemental 1 – Overview of survey questions

This appendix provides the complete questions used in the online survey to assess dependent and explanatory variables. Asterisks indicate variables altered through the data analysis process.

Table A. Variables tested in this study based on different hypotheses about factors influencing social acceptability of aquaculture.

Hypothesis / Category	Independent variable	Type of measure	Levels[a]
Effect of location			
Geographic	Residence type	Categorical	Urban, rural
	Ocean visible from home	Categorical	Yes; No
	Distance from ocean	Categorical	Waterfront – over 5km
Temporal	Residency status	Categorical	Full-time; Part-time
Effect of individual characteristics			
Demographics	Age	Categorical	18-34, 35-54, 55 and older
	Gender	Categorical	Male; Female
	Education	Categorical	High school or below, Secondary degree (bachelor's or diploma), Post-secondary or professional degree
	Household income ($CAD)	Categorical	Less than $20,000, $20,000 to $40,000, $40,000 to $79,000, Above $80,000
Employment	Employment in marine sector	Categorical	Yes; No
Effect of personal value system			
Values	'Relational' value scores	Continuous	PCA factor 1 component scores
	'Human use' value scores	Continuous	PCA factor 2 component scores
Effect of familiarity and exposure			
Knowledge	Knowledge about aquaculture	Ordinal	Poorly knowledgeable, Moderately knowledgeable, Highly knowledgeable
	Interest in learning	Continuous	1 = not at all interested to 5 = extremely interested
Exposure	Salmon farm in community	Categorical	Yes; No; Don't know
	Fish farm visit	Categorical	Yes: No
Consumption	Degree of fish consumption	Ordinal	Low – less than once a month, Medium – monthly basis, High – weekly
	<u>Consumption pattern</u> Eat wild salmon Eat Farmed salmon Unsure of type of salmon Do not eat salmon	Categorical	Yes: No
Effect of trust			
Trust	Trust in government	Ordinal	Untrustful, Undecided, Trustful
	Trust in industry	Ordinal	Untrustful, Undecided, Trustful
	Trust in science	Ordinal	Untrustful, Undecided, Trustful
Effect of perceived risks			
Impacts	Perceived risks	Continuous	Average response to multiple impact categories (1 = very positive, 5 = very negative)

[a]See description below for full and original measurement levels

DEPENDENT VARIABLE(S)

General Opinion*: How would you rate your general opinion towards salmon farming?
Measurement scale: 1 = very negative, 2 = negative, 3 = neutral or undecided, 4 = positive 5 = very positive
* Variable was merged for analysis into three categories where 1 = negative, 2= neutral or undecided, 3 = positive

Level of support for aquaculture development : Please answer how much you agree or disagree with the following statement based on your current understanding of salmon farming in Nova Scotia: Overall, I think that salmon farming offers benefits that outweigh its impacts.
Measurement scale: 1 = strongly disagree, 5 = strongly agree

Perception of risk trade-offs : Please answer how much you agree or disagree with the following statement based on your current understanding of salmon farming in Nova Scotia: Overall, I think that salmon farming offers benefits that outweigh its impacts.
Measurement scale: 1 = strongly disagree, 5 = strongly agree

EXPLANATORY VARIABLES

Effect of location

Geographic

Residence Type : Please indicate the description that best matches where you live.*
Measurement scale: a) Large city, b) Suburb near a large city, c) Small city or town, d) Rural area
*For comparative analysis, this variable was merged where 1 = urban (a, b, or c) and 2 = rural (d)

Distance to ocean/coast : Approximately how far away is your home from the coast?
Measurement scale: a)Waterfront, b) Within 500 metres of the coast, c) Between 500 metres and 1 kilometre from the coast, d)Between 1 and 5 kilometres from the coast, e) Over 5 kilometres from the coast

Ocean visible from home : Can you see the ocean from your home?
Measurement scale: 0 = no; 1 = yes

Temporal

Residency status: How much of the year do you live in Nova Scotia?*
Measurement scale: a)Year-round, b) 6 months to a year, c) 3 to 6 months, d) Under 3 months
*For analysis, variable was condensed to either 1 = part time (a), 2 = full time (b,c, or d)

Effect of individual characteristics

Demographics

Age* : Please indicate which age group you belong.

Measurement scale: a) 18 – 24; b) 25 – 34; c) 35 – 44; d) 45 – 54; e) 55 – 64; f) 65 and older; g) Prefer not to say

*For analysis, age was merged into three categories where 1 = 18-34, 2 = 35-54, 3 = 55 and older

Gender* : Please indicate which gender identity you identify with the most.

Measurement scale: a) Male; b) Female; c) Prefer not to answer; d) Other (describe)

* Given low numbers of responses to c and d, condensed into 1 = male, 2 = female

Education* : Please indicate the highest level of education you have attained.

Measurement scale: a) Less than high school; b) High school; c) Postsecondary certificate or diploma; d) Bachelor's degree; e) Beyond bachelor's degree and/or professional degree (Masters, PhD, MD, JD etc.); f) Prefer not to say

*For analysis, education was merged so that 1 = High school or below (a or b), 2 = Secondary degree (bachelor's or diploma) (c or d), 3 = Post-secondary or professional degree (e)

Income* : Please indicate your average annual household income (in CAD).

Measurement scale: a) Less than $20,000; b) $20,000 to $39,000; c) $40,000 to $59,000; d) $60,000 to $79,000; e) $80,000 to $99,000; f) Above $100,000; g) Prefer not to say

*For analysis, income was merged where 1 = Less than $20,000 (a); 2 = $20,000 to $40,000 (b); 3 = $40,000 to $79,000 (c or d); 4 = Above $80,000 (e or f)

Employment

Employed in marine sector* : Are you, or anyone in your immediate family employed in any of the following marine-related occupations? Please select all that apply.

A. Fishing
B. Aquaculture
C. Coastal tourism
D. Marine oil and gas
E. Marine shipping
F. Navy or Coast Guard
G. Coastal construction
H. Marine research
I. Coastal or marine conservation
J. Other

Measurement scale : 0 = no; 1 = yes

*New employment variable was created to reflect whether respondent selected 1 or more of the above ; 0 = not employed (none of A through J selected); 1 = employed (at least 1 selected)

Effect of personal value system

Values*

Listed below are statements about the relationship between humans and the ocean. For each, please rate your level of agreement or disagreement with the given statements.

	Statement	Category	Variable
A	Using and developing of our oceans and coasts is necessary for our communities and economies to develop	Instrumental	Economic (development)
B	We can continue to use the ocean to meet our needs, as long as it does not compromise the ability of future generations to meet their needs	Instrumental	Use (loss)
C	The balance of nature is strong enough to cope with the impacts of modern industrial activities	NEP	Balance of nature
D	The ocean has plenty of natural resources and we just need to learn how to use them	NEP	Limits of nature
E	The ocean and the ocean life should be protected because they in themselves have the right to exist	Intrinsic	Nature's rights
F	Humans have an inherent right to modify the natural environment to suit our needs	Intrinsic	Human rights
G	The ocean and/or coast reflect who we are as a community and/or society	Relational	Community identity
H	I often think about some ocean places whose fate I care about, even if I will never use or see them	Relational	Wild
I	The health of myself and/or my family is related in one way or another to the ocean	Relational	Health and wellbeing
J	I have strong feelings about the ocean (including the water, coastal landscape, plants and animals) – these views are part of who I am	Relational	Self identity
K	Managing our oceans is an important part of our responsibility to, and so stewardship of the ocean	Relational	Responsibility/ stewardship
L	We have a responsibility to account for our impacts on the ocean because these impacts can harm other people	Relational	Harm to other people
M	There are coastal places that are very important to me and can not be replaced anywhere else	Relational	Important of place

Measurement scale: 1 = strongly disagree, 5 = strongly agree

* Component scores from PCA analysis were calculated for Factor 1 and 2 (see results)

Effect of familiarity and exposure

Knowledge

Knowledge about aquaculture : How knowledgeable do you feel about salmon farming?*
Measurement scale: a) No prior knowledge; b) Very little knowledge, although I have a basic understanding; c) I have some knowledge; d) Knowledgeable; e) Very knowledgeable

*For analysis, knowledge was merged where 1 = Poorly knowledgeable (a or b); 2 = Moderately knowledgeable (c); 3 = Highly knowledgeable (d or e)

Interest in learning : Please rate on a scale of 1 to 5 your level of interest in learning more about salmon farming.

Meaurement scale: 1 = not at all interested; 5 = Extremely interested

Q: Which of the following sources do you get information about salmon farming? Please select all that apply.

A. Government
B. Aquaculture industry
C. Science institutions and/or scientists
D. Science journals and/or magazines
E. Environmental non-profit groups
F. Friends and/or family
G. News (radio, TV, online)
H. Social media and/or websites
I. Experience and/or observations
J. Other (Describe)

Measurement scale : 0 = no; 1 = yes

Exposure

Salmon farm in community : Is there currently a salmon farm in your community or neighbouring community?

Measurement scale: 0 = no; 1 = yes; 2 = I don't know

Visit to salmon farm: Have you ever visited a salmon farm?

Measurement scale: 0 = no; 1 = yes

Consumption

Degree of fish consumption : On average, how often do you eat fish (excluding any form of shellfish (e.g. mussels, oysters), or lobster, crab, shrimp)?*

Measurement scale: a) More than 3 times a week; b) 2 to 3 times a week; c) Once a week; d) 2 to 3 times a month; e) Once a month; f) Rarely; g) Never

*Degree of consumption was merged where 1 = Low – less than once a month (f or g); 2 = Medium – monthly basis (d or e), 3 = High – weekly (a,b, or c)

Choice of salmon consumed: Please indicate whether you eat any of the following types of salmon. Select all that apply.*

Measurement scale: a) Wild-caught salmon; b) Farmed salmon; c) I do not know the type of salmon I eat; d) I do not eat salmon

*Four new variables were created each option above to reflect respondent's selection, where 1 = selected; 0 = not selected

Effect of trust

Trust *

Please answer how much you agree or disagree with the following statement based on your current understanding of salmon farming in Nova Scotia:

Trust in science : We do not have a good enough understanding of the impacts the industry is having on the environment

Trust in Government : I trust that the government is effectively managing the industry in Nova Scotia

Trust in Industry : Salmon farming companies in Nova Scotia do not care about addressing concerns of the public and/or stakeholders

Measurement scale: 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree

*Trust in Science and Trust in Industry were reversed for consistency of analysis, then categories were merged and re-named for all three trust variables so that 1 = untrustful (strongly disagree or disagree); 2 = undecided (neither agree nor disagree); 3 = trustful (agree or strongly agree)

Effect of perceived risks

Perceived risks* : Based on your knowledge, please rate how you feel the salmon farming industry's impacts are on:

A. Employment and income
B. Rural and/or coastal economic development
C. Nova Scotian and/or Canadian economy
D. Visual character of ocean/coast
E. Marine pollution, including rubbish or debris
F. Ocean and/or coastal access
G. Community identity and culture
H. Marine tourism
I. Other commercial fisheries
J. Fish welfare
K. Water quality
L. Habitat beneath the farms
M. Spread of disease and pests (sea lice)
N. Protected or sensitive marine species in the area
O. Wild salmon populations
P. Global fish populations

Measurement scale: 0 = I don't know; 1 = very negative; 2 = somewhat negative; 3 = neutral; 4 = somewhat positive; 5 = very positive

*For analysis, a new variable representing the average of respondent's rating to A through P above was created, removing 0 (I don't know). This new impact variable was reversed (so that 1 = very positive and 5 = very negative) so that an increase in variable would be associated with higher perception of risks

C.6 Detailed survey responses – supplemental B from paper

Appendix B– Detailed survey responses

Table A. Sample size and completion rates for each survey question, based on a total of 495 respondents. Completion rates were all over 97% or higher, except those for individual characteristics. Multiple-select questions (non-exclusive) are not included since completion rate cannot be calculated.

Survey variables/questions	Sample size (n)	Number who did not respond	Completion rate (%)
Opinion			
General opinion about salmon farming	485	10	98.0%
Trade-offs	485	10	98.0%
Support for salmon farming development	483	12	97.6%
Effect of location			
Residence type (urban or rural)	494	1	99.8%
Ocean visitble from home	495	0	100.0%
Distance from ocean	494	1	99.8%
Residency status	495	0	100.0%
Effect of individual characteristics			
Age	470	25	94.9%
Highest level of education	468	27	94.5%
Gender	457	38	92.3%
Average annual household income (CAD)	408	87	82.4%
Effect of values			
Instrumental - Economic development	489	6	98.8%
Instrumental - Use and loss	491	4	99.2%
NEP - Balance of nature	493	2	99.6%
NEP - Limits of nature	491	4	99.2%
Intrinsic - Human's rights	490	5	99.0%
Intrinsic - Nature's rights	490	5	99.0%
Relational - Community identity	492	3	99.4%
Relational - Wild places	490	5	99.0%
Relational - Health and wellbeing	490	5	99.0%
Relational - Self identity	492	3	99.4%
Relational - Responsibility and stewardship	488	7	98.6%
Relational - Harm to other people	492	3	99.4%
Relational - Importance of place	488	7	98.6%
Effect of familiarity and exposure			
Salmon farming knowledge	491	4	99.2%
Interest in learning	490	5	99.0%
Presence of salmon farm in community	490	5	99.0%
Visit to salmon farm	491	4	99.2%
Degree of fish consumption	494	1	99.8%

Effect of trust			
Trust in Government	485	10	98.0%
Trust in Industry	485	10	98.0%
Trust in Science	484	11	97.8%
Effect of perceived risks			
Employment and income	480	15	97.0%
Rural and/or coastal economic development	480	15	97.0%
Nova Scotian and/or Canadian economy	481	14	97.2%
Visual character of ocean/coast	482	13	97.4%
Marine pollution, including rubbish or debris	481	14	97.2%
Ocean and/or coastal access	478	17	96.6%
Community identity and culture	480	15	97.0%
Marine tourism	481	14	97.2%
Other commercial fisheries	478	17	96.6%
Fish welfare	479	16	96.8%
Water quality	478	17	96.6%
Habitat beneath the farms	481	14	97.2%
Spread of disease and pests (sea lice)	481	14	97.2%
Protected or sensitive marine species	480	15	97.0%
Wild salmon populations	481	14	97.2%
Global fish populations	480	15	97.0%

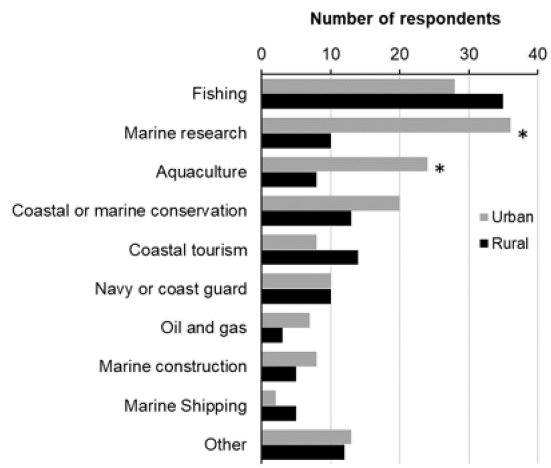

Figure A. Number of participants employed or have anyone in their immediate family employed in various marine-related occupations (N = 170 participants selected one or more response). Asterisks represent significant difference in proportions among urban and rural groups ($p < 0.05$).

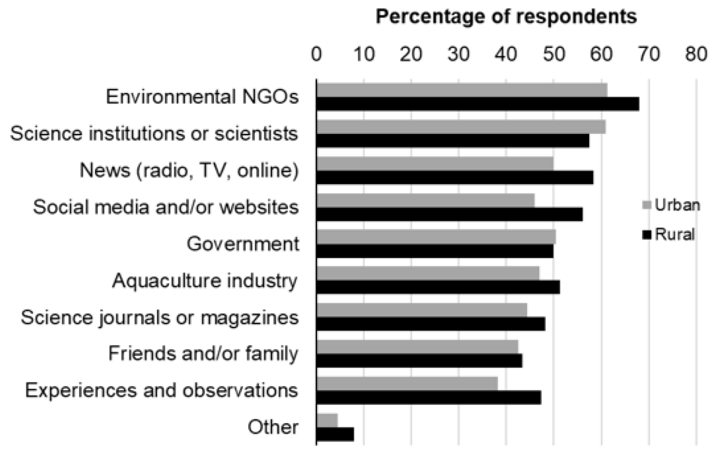

Figure B. Percentage of urban and rural respondents selecting various sources of aquaculture information.

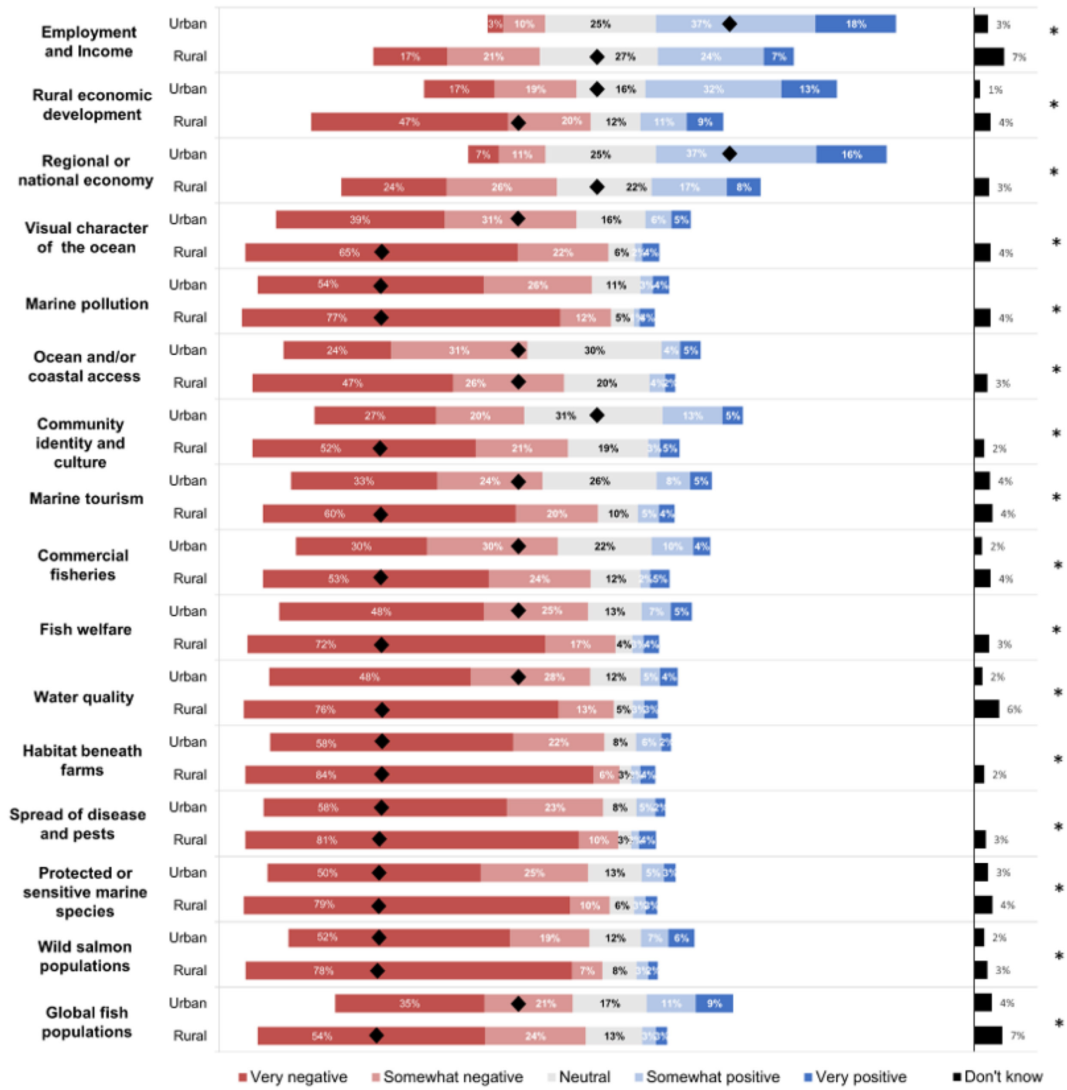

Figure C. Percentage of urban and rural respondents rating aquaculture's impacts on several socioeconomic and ecological aspects. Diamonds represent medians while asterisks represent significant differences between groups. Respondent's who were not sure is inset on right for visualization.

C.7 Comparative statistics – Supplemental C from paper

Appendix C – Comparative statistics (urban vs. rural)

Table A. Statistics for 5-point Likert-scale survey question asking participants to state their level of agreement towards various value statements about the ocean and coast. Medians are based on Likert responses where 1 = Strongly disagree, 3 = Neither agree nor disagree, 5 = Strongly agree. Mann-Whitney U test scores compared median responses between groups, based on visually similar distribution of responses

Variable	Statement	Residence type	n	Median	Mean	Std. deviation	Mann-Whitney U	p-value
Instrumental_Economic Development	Using and developing of our oceans and coasts is necessary for our communities and economies to develop	Urban	262	4	3.55	1.205	25707.0	0.009
		Rural	226	4	3.24	1.306		
Instrumental_Useand loss	We can continue to use the ocean to meet our needs, as long as it does not compromise the ability of future generations to meet their needs	Urban	264	4	4.14	1.033	28089.5	0.229
		Rural	226	4	3.99	1.187		
NEP_Balance	The balance of nature is strong enough to cope with the impacts of modern industrial activities	Urban	265	1	1.82	1.115	25685.0	0.002
		Rural	227	1	1.55	0.937		
NEP_Limits	The ocean has plenty of natural resources and we just need to learn how to use them	Urban	264	3	2.98	1.241	29646.0	0.902
		Rural	226	3	2.96	1.299		
Intrinsic_NatureRights	The ocean and the ocean life should be protected because they in themselves have the right to exist	Urban	264	5	4.47	0.845	29178.5	0.699
		Rural	225	5	4.40	0.963		
Intrinsic_HumanRights	Humans have an inherent right to modify the natural environment to suit our needs	Urban	264	1	1.79	1.081	26970.0	0.048
		Rural	225	1	1.64	1.044		
Relational_Community Identity	The ocean and/or coast reflect who we are as a community and/or society	Urban	265	4	4.29	0.833	29227.0	0.616
		Rural	226	4	4.25	0.875		
Relational_WildPlaces	I often think about some ocean places whose fate I care about, even if I will never use or see them	Urban	265	4	4.23	0.934	31495.0	0.201
		Rural	224	5	4.35	0.818		

Variable	Statement	Residence type	n	Median	Mean	Std. deviation	Mann-Whitney U	p-value
Relational_Health Wellbeing	The health of myself and/or my family is related in one way or another to the ocean	Urban	265	4	4.20	0.967	31731.5	0.149
		Rural	224	5	4.36	0.819		
Relational_SelfIdentity	I have strong feelings about the ocean (including the water, coastal landscape, plants and animals) – these views are part of who I am	Urban	265	5	4.48	0.754	32230.0	0.087
		Rural	226	5	4.58	0.696		
Relational_Responsibili ty	Managing our oceans is an important part of our responsibility to, and so stewardship of the ocean	Urban	263	5	4.62	0.704	30500.0	0.388
		Rural	224	5	4.65	0.725		
Relational_Harmto Others	We have a responsibility to account for our impacts on the ocean because these impacts can harm other people	Urban	265	5	4.72	0.645	30684.0	0.506
		Rural	226	5	4.76	0.562		
Relational_Importance ofPlace	There are coastal places that are very important to me and can not be replaced anywhere else	Urban	264	5	4.55	0.748	31688.0	0.068
		Rural	223	5	4.67	0.663		

Table B. Statistics for 5-point Likert-scale* survey questions for variables related to Opinion, Knowledge and Trust. Mann-Whitney U test scores compared median responses between groups, based on visually similar distribution of responses

Variable	Question/statement	Residence type	n	Median	Mean	Std. deviation	Mann-Whitney U	p-value
Opinion_General	How would you rate your general opinion towards salmon farming?	Urban	263	2	2.41	1.283	19852.5	< .001
		Rural	221	1	1.72	1.058		
Opinion_NS	I am generally supportive of salmon farming development in Nova Scotia	Urban	262	2	2.56	1.426	19877.5	< .001
		Rural	220	1	1.80	1.208		
Opinion_Tradeoffs	Overall, I think that salmon farming offers benefits that outweigh its impacts	Urban	263	2	2.32	1.303	19927.0	< .001
		Rural	221	1	1.65	1.112		
Knowledge_Informed	How knowledgeable do you feel about salmon farming?	Urban	265	3	3.21	1.084	32831.5	.044
		Rural	225	3	3.39	0.934		
Knowledge_Interest	Please rate on a scale of 1 to 5 your level of interest in learning more about salmon farming	Urban	265	4	3.63	1.148	27915.5	.241
		Rural	224	4	3.44	1.345		
Trust_Science	We do not have a good enough understanding of the impacts the industry is having on the environment	Urban	261	4	3.35	1.361	31813.0	.055
		Rural	222	4	3.51	1.571		
Trust_Government	I trust that the government is effectively managing the industry in Nova Scotia	Urban	263	2	2.16	1.150	19424.5	< .001
		Rural	221	1	1.57	1.045		
Trust_Industry	Salmon farming companies in Nova Scotia do not care about addressing concerns of the public and/or stakeholders	Urban	263	4	3.43	1.217	36660.5	< .001
		Rural	221	4	3.92	1.307		

*Median for variable 1 based on a 5-point Likert scale where 1 = Very negative, 3 = Neutral or undecided, 5 = Very positive. Medians for variables 2,3,6,7,8 based on 5-point Likert scale where 1 = Strongly disagree, 3 = Neither agree nor disagree, 5 = Strongly agree. Medians for variable 4 was ranked on a 5-point Likert scale where 1 = very little knowledge, 5 = very knowledgeable. Median for variable 5 was ranked on a 5-point Likert scale where 1 = not at all interested, 5 = extremely interested.

Table C. Statistics for 5-point Likert-scale survey question asking participants to rate how they feel the salmon farming's impacts are on various impact attributes. Medians are based on Likert responses where 1 = Very negative, 3 = Neutral, 5 = Very positive. Original responses to "Don't know" option were removed from further analysis. Mann-Whitney U test scores compared median responses between groups, based on visually similar distribution of responses

Variable	Residence type	n	Median	Mean	Std. deviation	Mann-Whitney U	p-value
Employment and income	Urban	243	4	3.61	1.032	16211.0	< .001
	Rural	210	3	2.82	1.199		
Rural and/or coastal economic development	Urban	252	3	3.06	1.324	16782.0	< .001
	Rural	214	2	2.14	1.355		
Nova Scotian and/or Canadian economy	Urban	250	4	3.46	1.116	16034.0	< .001
	Rural	212	2	2.58	1.262		
Visual character of ocean/coast	Urban	254	2	2.03	1.119	20342.0	< .001
	Rural	219	1	1.57	0.990		
Marine pollution, including rubbish or debris	Urban	255	1	1.75	1.042	21831.5	< .001
	Rural	218	1	1.42	0.939		
Ocean and/or coastal access	Urban	245	2	2.30	1.055	19812.0	< .001
	Rural	213	2	1.87	1.013		
Community identity and culture	Urban	251	3	2.46	1.177	19088.5	< .001
	Rural	218	1	1.86	1.104		
Marine tourism	Urban	251	2	2.24	1.162	19165.5	< .001
	Rural	215	1	1.70	1.079		
Other commercial fisheries	Urban	247	2	2.23	1.123	19090.5	< .001
	Rural	211	1	1.76	1.071		

Variable	Residence type	n	Median	Mean	Std. deviation	Mann-Whitney U	p-value
Animal welfare	Urban	254	2	1.93	1.171	20967.5	< .001
	Rural	217	1	1.48	0.972		
Water quality	Urban	252	2	1.86	1.088	20169.5	< .001
	Rural	217	1	1.44	0.946		
Habitat beneath the farms	Urban	251	1	1.67	1.026	21070.0	< .001
	Rural	218	1	1.33	0.927		
Spread of disease and pests (sea lice)	Urban	251	1	1.65	0.987	22019.5	< .001
	Rural	218	1	1.38	0.954		
Protected or sensitive marine species in the area	Urban	251	1	1.80	1.046	20392.5	< .001
	Rural	218	1	1.41	0.927		
Wild salmon populations	Urban	251	1	1.91	1.231	20507.50	< .001
	Rural	216	1	1.42	0.926		
Global fish populations	Urban	243	2	2.34	1.340	19141.0	< .001
	Rural	211	1	1.73	1.007		

Table D. Statistics for dichotomous and multinomial variables, with Chi-square tests of homogeneity and post-hoc z-test of two proportions (where applicable) to explore differences between urban and rural populations.

Variable	Levels	n		z-test (p-value)	Chi-square	p-value
		Urban	Rural			
Ocean visible	Yes	104	131	NA	16.59	< 0.001
	No	162	97			
Distance	Within 500 metres	85	136	< 0.001	47.028	< 0.001
	500 metres to 1 kilometre	70	18	< 0.001		
	Over 1 kilometre	110	74	0.038		
Gender	Female	149	114	NA	0.345	0.557
	Male	104	89			
Age	18-34	97	22	< 0.001	55.2	< 0.001
	35-54	62	42	0.307		
	Over 55	100	146	< 0.001		
Education	High school or below	22	18	NA	2.461	0.292
	Secondary degree (Bachelor's or diploma)	147	134			
	Post-secondary or professional degree	88	58			
Income	Less than $20,000	21	8	NA	5.023	0.17
	$20,000 to $39,000	30	29			
	$40,000 to $79,000	81	69			
	Above 80,000	102	67			
Employed	Yes	104	79	NA	0.977	0.323
	No	163	149			
Degree of fish consumption	Low - less than once a month	48	32	NA	1.412	0.494
	Medium - Monthly basis	74	67			
	High - weekly more than once a week	144	128			

Variable	Levels	n		z-test (p-value)	Chi-square	p-value
		Urban	Rural			
Eat wild salmon	Yes	139	134	NA	2.24	0.134
	No	128	94			
Eat farmed salmon	Yes	87	38	NA	16.508	< 0.001
	No	180	190			
Do not eat salmon	Yes	70	58	NA	0.039	0.844
	No	197	170			
Presence of farm in community	Yes	74	135	NA	32.803	< 0.001
	No	115	63			
Visit to farm	Yes	114	97	NA	0	0.984
	No	151	128			

C.8 Regression model results – Supplementary D from paper

Appendix D – Identifying factors that influence acceptance

Table A. Statistics for the influence of explanatory variables against opinion.
* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. NA – Not applicable (variables scalar so not appropriate for test of group differences). Mann-Whitney U test scores compared median responses between groups, based on visually similar distribution of responses.

Variable	Association (d, τb, or V)		Differences (χ^2 or U)	
Effect of location				
Residence type	0.268	***	21818.5	***
Ocean visible from home	0.064		28151	
Proximity to ocean	0.132	*	8.488	
Effect of individual characteristics				
Age	-0.342	***	85.491	***
Gender	0.185	***	28267	**
Education	0.089		3.448	
Income	0.128	*	8.959	*
Employment	0.211	***	32753.5	***
Effect of personal value system				
'Relationship' value scores	-0.255	***	NA	
'Use' value scores	0.405	***	NA	
Effect of familiarity and exposure				
Aquaculture knowledge	-0.124	***	28.19	***
Interest in learning	0.169	***		
Salmon farm in community	0.126	*	16352.2	*
Fish farm visit	0.15	*	30711	
Degree of fish consumption	0.086		1.226	
Wild salmon consumption	-0.227	***	22907.5	***
Farmed salmon consumption	0.428	***	32123.5	***
Unsure of type of salmon	0.227	***	13783.5	*
Do not eat salmon	0.113	*	20545.5	
Effect of trust				
Trust in science	0.126	**	55.581	***
Trust in government	0.666	***	195.995	***
Trust in industry	0.454	***	127.085	***
Effect of perceived risk				
Perceived risks	0.593	***	NA	

Table B. Test of multicollinearity for independent variables

Coefficients[a]			
Model		Collinearity Statistics	
		Tolerance	VIF
1	Perceived risks	.366	2.731
	'Relationship' value scores	.814	1.229
	'Use' value scores	.659	1.517
	Age=18 to 34	.706	1.417
	Age=35 to 54	.813	1.229
	Farmed salmon consumption = yes	.771	1.298
	Wild salmon consumption = yes	.885	1.130
	Trust in Government = Untrustful	.311	3.214
	Trust in Government = Undecided	.480	2.081
a. Dependent Variable: Merged opinion			

Table C. Model fitting information

Model Fitting Information				
Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	733.109			
Final	355.749	377.360	9	< 0.001
Link function: Logit				

Table D. Test of proportional odds for selected ordinal regression

Test of Parallel Lines[a]				
Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	355.749			
General	342.257	13.492	9	0.142
The null hypothesis states that the location parameters (slope coefficients) are the same across response categories.				
a. Link function: Logit				

Table E. Goodness of fit statistics for best fit model

Goodness of Fit[a]			
	Value	df	Sig.
Pearson Chi-square	878.184	877	1.001
Deviance	355.749	877	0.406
Log Likelihood[b]	-177.875		
Akaike's Information Criterion (AIC)	377.749		
Finite Sample Corrected AIC (AICC)	378.356		
Bayesian Information Criterion (BIC)	422.877		
Consistent AIC (CAIC)	433.877		
Dependent Variable: Merged opinion Model: (Threshold), Age, Trust in Government, Farmed salmon consumption, Wild salmon consumption, 'Relationship' value scores, 'Use' value scores, Perceived risks			
a.Link function: Logit			
b. The full log likelihood function is displayed and used in computing information criteria.			

Table F. Individual test of model effects for fit ordinal model. All variables are significant ($p < 0.05$)

Tests of Model Effects			
Variable	Type III		
	Wald Chi-Square	df	Sig.
Age	8.780	2	0.012
Wild salmon consumption	5.971	1	0.015
Farmed salmon consumption	13.576	1	< 0.001
Trust in Government	6.820	2	0.033
'Relationship' value scores	4.883	1	0.027
'Use' value scores	7.180	1	0.007
Perceived risks	53.256	1	< 0.001
Dependent Variable: Merged opinion Model: (Threshold), Age, Trust in Government, Farmed salmon consumption, Wild salmon consumption, 'Relationship' value scores, 'Use' value scores, Perceived risks			

Table G. Parameter estimates (B) and odds ratios (Exp(B)) for ordinal regression analysis of explanatory variables against opinion

Parameter		B	Std. Error	95% Wald Confidence Interval		Hypothesis Test			Exp(B)	95% Wald Confidence Interval for Exp(B)	
				Lower	Upper	Wald Chi-Square	df	Sig.		Lower	Upper
Threshold	Opinion= Positive	4.513	1.0210	2.512	6.514	19.538	1	< 0.001	91.203	12.329	674.679
	Opinion= Neutral	6.621	1.0783	4.508	8.735	37.709	1	< 0.001	750.990	90.743	6215.197
Age=18 to 34		-0.981	0.3672	-1.701	-0.261	7.138	1	0.008	0.375	0.183	0.770
Age=35 to 54		-1.016	0.4094	-1.818	-0.213	6.152	1	0.013	0.362	0.162	0.808
Age= Over 55		0[a]							1		
Farmed salmon consumption = yes		-1.243	0.3374	-1.904	-0.582	13.576	1	< 0.001	0.289	0.149	0.559
Farmed salmon consumption = no		0[a]							1		
Wild salmon consumption = yes		0.808	0.3308	0.160	1.457	5.971	1	0.015	2.244	1.173	4.291
Wild salmon consumption = no		0[a]							1		
Trust in Government = Untrusful		1.152	0.5266	0.120	2.185	4.789	1	0.029	3.166	1.128	8.887
Trust in Government = Undecided		0.423	0.5351	-0.626	1.472	0.625	1	0.429	1.527	0.535	4.357
Trust in Government = Trustful		0[a]							1		
'Relationship' value scores		0.363	0.1645	0.041	0.686	4.883	1	0.027	1.438	1.042	1.985
'Use' value scores		-0.536	0.2000	-0.928	-0.144	7.180	1	0.007	0.585	0.395	0.866
Perceived risks		1.890	0.2590	1.383	2.398	53.256	1	< 0.001	6.621	3.985	11.000
(Scale)		1[b]									

Dependent Variable: Opinion
Model: (Threshold), Age, Trust in Government, Farmed salmon consumption, Wild salmon consumption, 'Relationship' value scores, 'Use' value scores, Perceived risks

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

C.9 Distribution of survey results by county

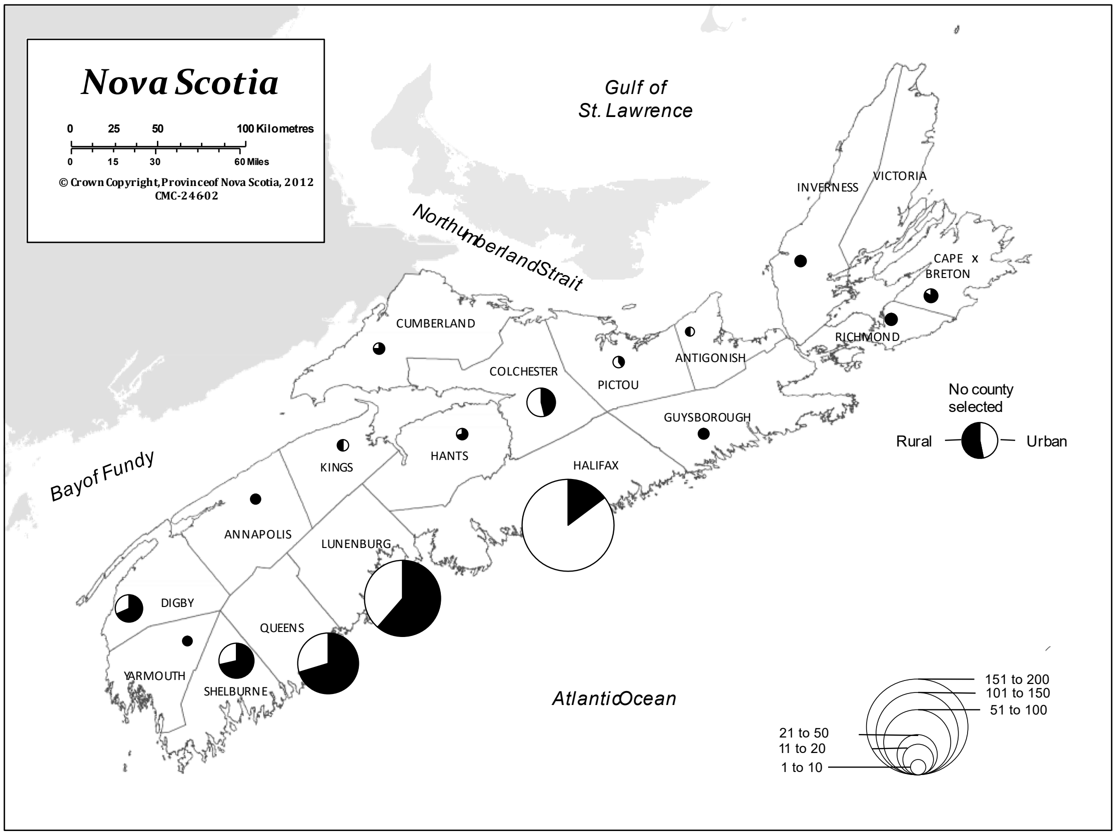

Figure C.1 Location of survey responses by county, where size of pie charts indicates number of respondents, and colours represent rural or urban designation

APPENDIX D. CHAPTER 5 AND 6 RESEARCH MATERIALS

D.1 Methodological flow chart

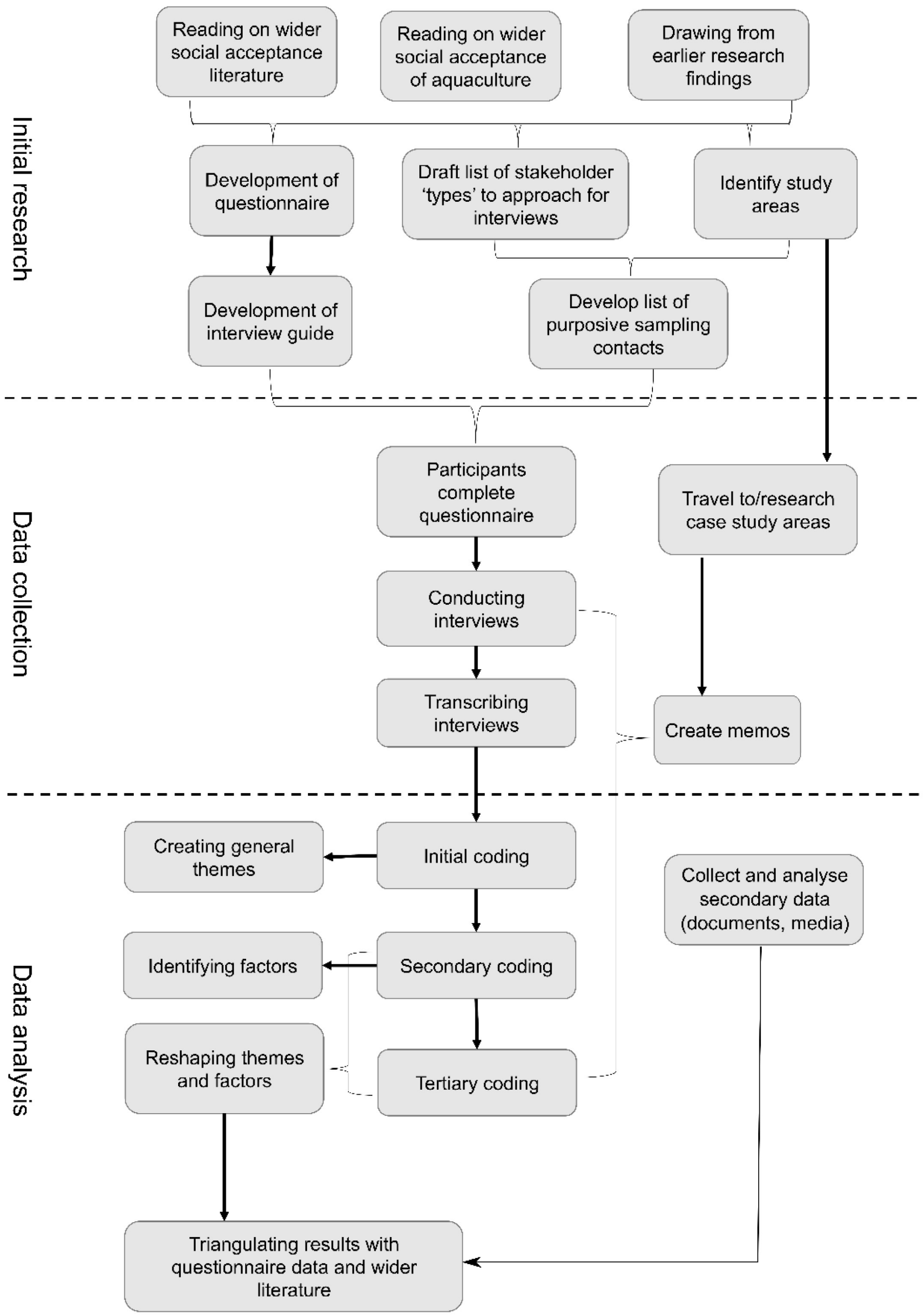

Figure D.1 Full methodological process for local responses to salmon farming conducted in Chapter 5 and 6.

D.2 Recruitment e-mail

Hello,

My name is Jenny Weitzman and I am an interdisciplinary PhD candidate at Dalhousie University (supervised by Jon Grant and Ramon Filgueira).

We are looking for people who may be interested in participating in a research study looking at understanding stakeholder perceptions about salmon farming in Nova Scotia. This research is being conducted by myself and is part of a larger research programme on sustainable aquaculture funded through the Ocean Frontier Institute and Dalhousie University.

Your opinions would contribute greatly to improving our understanding of the social benefits and risks of salmon farming in Nova Scotia.

Who are we looking for?

This research is looking to recruit participants that can represent the perceptions from different stakeholder groups who are affected or concerned with marine salmon farming in [*Insert Community].* To participate, you must possess a baseline familiarity with salmon farming activities around *[Insert Community],* and familiarity with the social and economic contexts of *[Insert Community],* to a level you would be comfortable expressing your opinions about them.

What will you be asked to do?

Should you agree, you will be asked to provide approximately 1 hour of your time to participate in an interview consisting of a questionnaire and follow-up questions. Briefly, you will be asked questions regarding your experiences and opinions of salmon aquaculture relative to *[Insert Community].*

When and where?

The study will run between May and September 2020. Amid the global COVID-19 pandemic, interviews will be conducted either by telephone or remotely using video-calling (Skype, Zoom, etc.). This research complies will all public health advice (Nova Scotia Public Health and Public Health Canada) to ensure participant health and safety.

Interested in participating?

If you are interested in participating, know someone who may be interested in this study, or would like to know more, please e-mail me at jenny.weitzman@dal.ca or call me at (902)209-2935. I have attached a research summary detailing further information about this study. I would be happy to answer any questions or provide further details of this study.

Thank you for your interest,

Jenny Weitzman

Interdisciplinary PhD Candidate
Marine Affairs Program,
Dalhousie University, Halifax, Nova Scotia
Jenny.weitzman@dal.ca | (902)209-2935

D.3 Research study summary and informed consent form

Project title

Understanding stakeholder perceptions of salmon farming: A cross-case comparison in Nova Scotia

Lead researcher

Jenny Weitzman [PhD Candidate]
Interdisciplinary PhD, Marine Affairs Program, Dalhousie University, Halifax, Nova Scotia
E-mail: jenny.weitzman@dal.ca Phone: (902) 209-2935

Other researchers

Dr. Ramon Filgueira [supervisor]
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E-mail: ramon.filgueira@dal.ca
Phone: (902) 414-1218

Dr. Jon Grant [supervisor]
Department of Oceanography, Dalhousie University, Halifax, Nova Scotia
E-mail: jon.grant@dal.ca
Phone: (902) 494-2021

Funding provided by: This study is part of PhD research, funded through the Ocean Frontier Institute. The lead researcher is also funded through a Natural Sciences and Engineering Research Council of Canada Postgraduate Scholarship and a Killam Predoctoral Scholarship.

Purpose and Outline of the Research Study

This research looks at stakeholder attitudes of salmon farming across local communities in Nova Scotia. In particular, this study seeks to compare preferences and opinions across three coastal communities in Nova Scotia where salmon farming development has been considered. A comparative analysis between communities and stakeholders with different opinions of aquaculture will help explore factors that influence the social acceptance or opposition towards aquaculture. The outcomes of this research study will help identify what issues are relevant to stakeholders and identify relevant social indicators of acceptance or opposition towards salmon farming in Nova Scotia. This research is part of a larger PhD project looking at developing a framework to measure and understand the natural, economic, and social limits of salmon aquaculture in Atlantic Canada.

Who Can Take Part in the Research Study

You may participate in this research if you identify with, and feel that you are able to represent the views and experiences of one of the following groups: 1) government, 2) wild-capture fisheries, 3) non-governmental organizations, 4) tourism industry, or 5) salmon farming industry.

To participate, you must possess a baseline familiarity with salmon farming activities around [Insert Community], and familiarity with the social and economic contexts of [Insert Community], to a level you would be comfortable expressing your opinions about them.

What You Will Be Asked to Do

To help us understand how key stakeholders feel about salmon farming in [Insert Community] and what factors influence their attitudes, you will be asked to participate an interview with the lead researcher. During the interview, you will first be asked to complete a self-administered paper questionnaire. You will then be given the opportunity to expand on your responses and identify additional considerations not listed in questionnaires.

The interview will take approximately 1.5 hours to complete. Interviews will consist of questions to related to your i) priorities and interests for coastal development in [Insert Community], ii) experiences with, and understanding of salmon aquaculture in [Insert Community], iii) attitudes towards salmon aquaculture and its various risks and benefits, and iv) preferences for salmon aquaculture development and priorities for improvement of the industry.

Amid the global COVID-19 pandemic, interviews will be conducted remotely by telephone or Skype for Business. This research complies will all public health advice (Nova Scotia Public Health and Public Health Canada) to ensure participant health and safety. If advice allows, interviews may also occur face-to-face, in person, at a location and time that is suitable to you.

Possible Benefits, Risks and Discomforts

Participating in this study will not directly benefit you, but your opinions and views may help us learn things that could benefit you or others. Your opinions, viewpoints, and experiences shared in this study will contribute to knowledge about how different stakeholders perceive salmon aquaculture across coastal communities, and help generate recommendations to improve decision-making and planning for salmon aquaculture in Nova Scotia.

The risks associated with this study are minimal. Salmon farming is a controversial topic in Nova Scotia, and all precautions will be taken to reduce the risks associated. The risk of potential misrepresentation of your organization's values and opinions will be minimized through the publication of summary results only. Given the small size of sampling groups, there is potential risk of re-identification. To minimize this, your responses will be anonymized, and the publication of this research will not identify individuals or organizations. In addition, your comfort and preferences for meeting spots will be accommodated. If you at any point become fatigued, bored or uncomfortable with the interview process, you may terminate the process.

Compensation / Reimbursement

We thank you for your time and involvement, but will not be able to provide any compensation for your participation in this study.

How your information will be protected

Your personal information, including your name, e-mail, phone number and organization affiliation will be kept for internal records and contacting purposes only. Your identity and participation in this study will be known only by the lead researcher.

When results are shared, only aggregated results by broad stakeholder group and community will be shared. Following the completion of the study, we will describe and share our group findings in a research paper and at conferences or university presentations. If you allow us to use quotes, we will carefully screen quotes to remove any contextual information that could potentially identify you, as well as confirm your approval of the quote before publication.

This means that ***you will not be identified in any way in our reports***.

The research team that has access to your information has an obligation to keep your information private. We will use a participant number (not your name) in our written and computerized records so that the information you provide is not associated with your name or organization. All your identifying information will be kept in a separate file, in a secure place. All electronic records will be kept secure in a password-protected, encrypted file on a USB device. If the interview is audio-recorded, the recording will be stored on an encrypted USB and destroyed immediately after transcription. All raw data from interviews and questionnaires will be retained for a maximum duration equivalent to the publication of the researcher's PhD thesis (estimated August 2021).

If You Decide to Stop Participating

You are free to leave the study at any time, until October 31, 2020. If you decide to stop participating at any point in the study, you may decide whether you want the information you have contributed to be removed or if you will allow the use of that information. After October 31, 2020, it will become impossible for us to remove your responses since they will have been analyzed.

How to Obtain Results

We will provide you with a summary report of group results when the study is complete. This summary may also be made publicly available through the Ocean Frontier Institute Module M website – Social Licence and Planning in Coastal Communities (https://coastalfutures.ca). The results of this study will also be published as part of a PhD doctoral thesis which will be made available through Dalhousie's online catalogue.

Questions

We would be happy to answer any questions or concerns you may have about your participation in this research. Please contact Jenny Weitzman (902-209-2935, jenny.weitzman@dal.ca) at any time. We will contact you if any new information emerges which could affect your decision to participate.

This research study has been reviewed and approved by the Research Ethics Board at Dalhousie University. If you have any ethical concerns regarding your participation in this research or in the research study, you may contact Research Ethics, Dalhousie University at (902) 494-1462, or e-mail: ethics@dal.ca (and reference REB file # 2020-5071).

Informed Consent Form

Project Title:
Understanding stakeholder perceptions of salmon farming : A cross-case comparison in Nova Scotia

Lead Researcher:
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Dr. Jon Grant [supervisor]
Department of Oceanography, Dalhousie University, Halifax, Nova Scotia

Print name

I, ____________________________ have read the Summary Document that outlines the explanation and purpose of this research study, including how my information will be used and protected. I have been given the opportunity to discuss the study and my questions have been answered to my satisfaction. I understand that I have been asked to take part in an interview and questionnaire. I understand that by signing below, I am agreeing to take part in this study. I understand that my responses will be kept anonymous and my information confidential. I understand that my participation is voluntary and that I am free to withdraw at any point in the study, until October 31, 2020.

________________________________ ___________
Signature *Date (dd/mm/yy)*

I agree that my interview may be audio-recorded. ☐Yes ☐No

I agree that direct quotes from my interview may be used without identifying me. ☐Yes ☐No

________________________________ ___________
Signature *Date (dd/mm/yy)*

D.4 Questionnaire

This questionnaire is divided in four sections. Please answer all the questions to the best of your ability. If you have any questions, the interviewer is free to provide any clarifications about the question. When you are finished, the interviewer will ask a few follow-up questions on your answers.

Section 1 – Priorities and interests

1. Please rank the importance of the following **ocean and coastal benefits**, relative to your area.

	Not important	Somewhat important	Moderately important	Very important
Providing food	☐	☐	☐	☐
Supporting jobs and economic development	☐	☐	☐	☐
Long-term productivity of marine resources (fish, natural resources)	☐	☐	☐	☐
Supporting biodiversity	☐	☐	☐	☐
Habitat for important plant and animal species	☐	☐	☐	☐
Visual quality of the ocean (sight, smells, feel)	☐	☐	☐	☐
Supporting spiritual and cultural experiences	☐	☐	☐	☐
Providing recreation and community activities	☐	☐	☐	☐

2. From the list below, please select the **top 5 issues** you believe are *currently* the most important in planning for the community's future related to marine/ocean development, with 1 being the most important, and 5 being the least important.

____ Increase business opportunities
____ Diversify economy
____ Job and income generation
____ Encourage sustainable development
____ Protect natural resources
____ Preserve biological diversity
____ Promote mixed-use development
____ Preserve and protect viewsheds
____ Protect private property rights
____ Other (describe)
__

3. Please rate the amount of influence each of the following marine-related sectors currently have on **your day-to-day life** (based on how much interaction you have with these sectors either at work or in your personal life).

	No influence	Minor influence	Considerable influence	Major influence
Fisheries	☐	☐	☐	☐
Aquaculture	☐	☐	☐	☐
Oil and gas	☐	☐	☐	☐
Marine shipping	☐	☐	☐	☐
Navy or Coast Guard	☐	☐	☐	☐
Coastal Tourism	☐	☐	☐	☐
Ocean and/or coastal recreation	☐	☐	☐	☐
Coastal housing development	☐	☐	☐	☐
Marine research	☐	☐	☐	☐
Coastal and/or marine conservation	☐	☐	☐	☐
Other (Please identify) :	☐	☐	☐	☐

4. Please rate the amount of influence each of the following marine-related sectors currently have for **this community**.

	No influence	Minor influence	Considerable influence	Major influence
Fisheries	☐	☐	☐	☐
Aquaculture	☐	☐	☐	☐
Oil and gas	☐	☐	☐	☐
Marine shipping	☐	☐	☐	☐
Navy or Coast Guard	☐	☐	☐	☐
Coastal Tourism	☐	☐	☐	☐
Ocean and/or coastal recreation	☐	☐	☐	☐
Coastal housing development	☐	☐	☐	☐
Marine research	☐	☐	☐	☐
Coastal and/or marine conservation	☐	☐	☐	☐
Other (Please identify) :	☐	☐	☐	☐

Section 2 – Experiences with aquaculture

5. Overall, how would you rate your <u>interaction</u> experiences with salmon aquaculture in this area?

☐Very dissatisfied ☐Dissatisfied ☐Neither dissatisfied nor satisfied ☐Satisfied ☐Very satisfied

6. In what ways have you interacted with the industry? Please select all that apply.
   ☐Site visit
   ☐Direct communication with industry personnel
   ☐Indirect communication through industry associations or government
   ☐Through community meetings or events (e.g. open houses, town halls)
   ☐None of the above
   ☐Other (describe) : _____________

7. Please rate the extent to which you agree or disagree with the following statements about how the salmon farming industry engages with your stakeholder group.

	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
We as stakeholders have the opportunity to participate in the decisions about aquaculture	☐	☐	☐	☐	☐
We as stakeholders have the opportunity to voice their concerns about aquaculture	☐	☐	☐	☐	☐
The aquaculture industry listens and respects our opinions	☐	☐	☐	☐	☐
The aquaculture industry is prepared to change its practices in response to our sentiments	☐	☐	☐	☐	☐

8. Please rate the extent to which you trust the provincial and/or federal **government**'s commitment to the following aspects of aquaculture management/development.

	Not at all	Not very much	Somewhat	A moderate amount	A great deal
Transparency of information	☐	☐	☐	☐	☐
Communication/ engagement	☐	☐	☐	☐	☐
Monitoring and enforcement of industry	☐	☐	☐	☐	☐
Meeting expectations and realizing promises	☐	☐	☐	☐	☐

9. Please rate the extent to which you trust the **salmon farming industry's** commitment to the following aspects of aquaculture management/development.

	Not at all	Not very much	Somewhat	A moderate amount	A great deal
Transparency of information	☐	☐	☐	☐	☐
Communication/ engagement	☐	☐	☐	☐	☐

Monitoring and enforcement of industry	☐	☐	☐	☐	☐
Meeting expectations and realizing promises	☐	☐	☐	☐	☐

10. Please rate on a scale of 1 to 5 how **knowledgeable** you are about salmon farming in general.

Very limited knowledge			Very knowledgeable	
1	2	3	4	5
☐	☐	☐	☐	☐

11. Please rate on a scale of 1 to 5 how **informed** you feel you are about salmon farming in this area.

Not informed at all			Very well informed	
1	2	3	4	5
☐	☐	☐	☐	☐

12. Are you interested in knowing more about salmon farming

☐Yes ☐No

13. Which of the following sources do you get your information about salmon farming from? <u>Select all that apply.</u>

☐Government
☐Aquaculture industry
☐Science institutions or scientists
☐Environmental NGOs
☐Friends and/or family
☐News (TV, radio, online)
☐Social media and websites
☐Experience and observations
☐Other (describe): ________________

14. Please rate the extent to which you **trust** of the following sources to provide <u>credible information</u> about the salmon farming practices in this area.

	Not at all	Not very much	Somewhat	A moderate amount	A great deal
Government	☐	☐	☐	☐	☐
Aquaculture industry	☐	☐	☐	☐	☐
Science institutions or scientists	☐	☐	☐	☐	☐
Environmental NGOs	☐	☐	☐	☐	☐
Friends and/or family	☐	☐	☐	☐	☐
News (TV, radio, online)	☐	☐	☐	☐	☐

Social media and/or websites	☐	☐	☐	☐	☐

Section 3 – Opinion of salmon aquaculture

15. How would you rate your **general** opinion towards salmon farming in this area? Please select the option that best reflects how you feel.

☐Very negative ☐Somewhat negative ☐Neutral ☐Somewhat positive ☐Very positive

16. Please rate how important you feel the following factors are in influencing or forming your opinion about salmon farming in your area.

		Not important	Somewhat important	Moderately important	Very important
A	Provision of socio-economic benefits	☐	☐	☐	☐
B	Distribution of benefits	☐	☐	☐	☐
C	Creation of local employment	☐	☐	☐	☐
D	Transparency of information about farming practices	☐	☐	☐	☐
E	Communication with stakeholders and public	☐	☐	☐	☐
F	Visual impact of farms on watershed	☐	☐	☐	☐
G	Results from environmental impact assessment	☐	☐	☐	☐
H	Location of farms within the bay	☐	☐	☐	☐
I	The number and size of cages	☐	☐	☐	☐
J	Ownership of the industry	☐	☐	☐	☐

17. Of the above, please select the top **three** factors (letters A through J) that you consider to be the most important

    1 - Click or tap here to enter text.
    2 - Click or tap here to enter text.
    3 - Click or tap here to enter text.

18. Relative to this area, please rate what you feel the salmon farming industry's **impacts** are on:

		Very negative	Moderately negative	Somewhat negative	Neutral	Somewhat positive	Moderately positive	Very positive
A	Employment	☐	☐	☐	☐	☐	☐	☐
B	Youth job retention	☐	☐	☐	☐	☐	☐	☐
C	Support for supply-chain businesses	☐	☐	☐	☐	☐	☐	☐
D	Wage and income	☐	☐	☐	☐	☐	☐	☐
E	Sponsorship of community events or facilities	☐	☐	☐	☐	☐	☐	☐
F	Regional/Canadian economy	☐	☐	☐	☐	☐	☐	☐
G	Visual character of ocean/coast	☐	☐	☐	☐	☐	☐	☐
H	Access for recreation	☐	☐	☐	☐	☐	☐	☐
I	Marine tourism	☐	☐	☐	☐	☐	☐	☐
J	Commercial fisheries	☐	☐	☐	☐	☐	☐	☐
K	Community identity and culture	☐	☐	☐	☐	☐	☐	☐
L	Animal welfare	☐	☐	☐	☐	☐	☐	☐
M	Marine pollution, including rubbish or debris	☐	☐	☐	☐	☐	☐	☐
N	Noise and/or light pollution	☐	☐	☐	☐	☐	☐	☐
O	Disease and pests (sea lice)	☐	☐	☐	☐	☐	☐	☐
P	Marine habitat beneath cages	☐	☐	☐	☐	☐	☐	☐
Q	Protected or sensitive marine species in the area	☐	☐	☐	☐	☐	☐	☐

19. Of the above, please select the top **three positive** impacts (letters A through Q) that you consider to be the most important relative to salmon farming in this area

1 - _________ 2 - _________ 3 - ___________

20. Of the above, please select the top **three negative** impacts (letters A through Q) that you consider to be the most important relative to salmon farming in this area

1 - _________2 - _________ 3 - ___________

Section 4 – Development options and strategies

21. Ideally, how would you like to see the development of salmon farming in this area? Please select one of the eight scenarios below that best reflects your opinion.

Increase	Maintain	Decrease
☐Increase production by expanding or adding sites	☐Maintain current farming operations, but improve oversight and/or reduce risks	☐Decrease intensity of salmon farming by reducing the number of fish in cages
☐Increase production by expanding current sites, but no additional farms	☐Maintain farms and practices as they are	☐Decrease intensity of salmon farming by reducing the number of cages
☐Increase production, but improve oversight and/or reduce risks		☐Remove all salmon farms from the marine environment

22. Please indicate how much change you think is needed in the following areas related to how salmon farming is conducted and managed.

		None	Minor changes	Major changes	Extensive changes
A	Policy and decision-making process	☐	☐	☐	☐
B	Community engagement	☐	☐	☐	☐
C	Stakeholder engagement	☐	☐	☐	☐
D	Education about aquaculture	☐	☐	☐	☐
E	Regulations for aquaculture	☐	☐	☐	☐
F	Planning and siting of farms	☐	☐	☐	☐
G	Assessments of environmental impacts	☐	☐	☐	☐
H	Transparency of practices and decisions	☐	☐	☐	☐
I	Communication of practices and decisions	☐	☐	☐	☐
J	Science and knowledge about aquaculture	☐	☐	☐	☐

23. Of the above, please select the top **three** areas for change (letters A through J) that you consider to be the most important, relative to this area.

1 - _________ 2 - _________ 3 - ___________

Thank you for completing this questionnaire. Please make sure all questions have been answered. When you are satisfied with your responses, please save and return this e-mail to jenny.weitzman@dal.ca

D.5 Interview guide

Thank you for agreeing to speak with me today about your experiences and thoughts on salmon farming in this area. Before we begin, did you have any questions about this research, or the specific questions you filled out in the questionnaire?

The goal of this interview is to give you the opportunity to expand on any of the aspects covered by the questionnaire, and provide any reasoning, or details to explain your thoughts and experiences about salmon farming in this area. What I will be doing is going section by section building off the questionnaire with some broad overarching questions, that you can respond to with reference to your responses. Before we jump into the specific questions, would you tell me a little bit about yourself, and your level of familiarity with this area?

Section 1 – Priorities and interests

1. In what ways are the ocean and coast in this area important to you?
2. As it relates to development in this area, what issues or sectors do you think should be the priority? Explain your answer.

Section 2 – Experiences with aquaculture

3. Why have you been satisfied or dissatisfied with salmon aquaculture in your area?
4. How do you think stakeholders and/or community should be engaged within decisions related to aquaculture in this area?
5. Overall, do you trust the industry, or the decision-making process for the industry? Why or why not?
6. Is there anything else you would like to say about how or what information/knowledge about salmon farming is communicated to you or your group?

Section 3 – Opinions of aquaculture

7. Can you explain your reasons why you answered the way you did in **questions 15**?
8. Are there any other benefits or impacts that salmon farming creates in this in this area, that you think are important but were not listed?

Section 4 – Development and future outlook

9. Why do you feel your selected scenario is the best option for this area?
10. What specific types of improvements do you think need to be made?

D.6 Coding of history and experience dimensions

Table D.1 Topics relevant to themes regarding the history and experiences expressed by participants in forming their perceptions and opinions to aquaculture.

Theme	Topic	Examples
Aquaculture experiences	Direct interactions	"I've never had any issues with any of the aquaculture people. They're always open to questions. They showed us everything" (2873)
	Industry attitudes and culture	"It's not like they don't have the resources to clean the shore up… they can go over to the store on any fine day and clean their garbage out. But they have no interest in doing that." (3675)
Aquaculture history	Local operations	"Years ago, when they promised to build a plant here and didn't, they promised that wouldn't use antibiotics and they do." (9033)
	Operations elsewhere	"And then obviously there's a lot of bad press as well…that mess in Port Mouton and on the west coast where they had a big release of fish…" (8655)
	Industry changes	"The industry is doing much better now [about reaching out and communicating to other stakeholder groups and community]… I think they have learned a lot in the last couple of years on how they should be interacting with the community." (4285)
Political history	Regulatory changes	"There was a time, a number of years ago, when aquaculture was not actually controlled or monitored or policed…to the level it should have been. And things happened that shouldn't have, and the province was not as involved as they are today." (1685)
	Governance of other industries	"You can pick up the paper almost every day and there are decisions being made by the government that do not include at the point in time they should input from the community. You can talk about clear cutting, golf club, forestry..." (7199)
	Local relations with the government	"It's difficult to maintain trust there because of a lot of past incidents where, um, you know, people felt like the government has essentially lied to them or they feel like they're acting in bad faith as a regulator." (7931)
Environmental changes	Changes in habitat and species	"We have to protect what we got first, because what we got already is a tenuous situation as it is with the lobster, they have been migrating up the coast of the US for decades" (3009)
	Changing oceanography	"We are increasingly having these bad wind storms that just rip up the salmon cages…" (3985)
Socio-economic changes	Changing economic structure	"We have a debt load that will take a generation to pay back - whats our alternative? We don't have a rail track no more, we dont have a ferry to the US…We got scallops but our codfish quota is nothing…" (2667)
	Changing community values	"Here in Queens county, I see that more and more we're becoming self-sufficient we're not relying on anywhere else to get our food. There's, you know, many people garden and raise their own animals." (9936)

D.7 Coding of values dimensions

Table D.2 Topics relevant to themes regarding the values expressed by participants in forming their perceptions and opinions of aquaculture.

Theme	Topic	Examples
Environmental Values	Conservation and protection	"If you compromise the nursery, you compromise the entire system. That is the biggest mistake that we can make, by not recognizing that those small creatures that play such an important role." (2011)
	Bequest for future	"What we're, uh, preparing to do for our children and our children's children is make sure that they can live on this planet. And that's, that's just an element of it." (1349)
Governance	Community empowerment	"I think the, that the community... we have a voice, you know, it's, the government does have, shouldn't be allowed to make decisions for a community that clearly does not want open pen fish farms." (4448)
	Serving people	"But they [government] have lied, they are implicated, they are propagandists rather than serving the people that they have been sworn in to serve." (5128)
	Effective use of resources	"I just feel that we have to be fair and protect the environment, but utilize it for everything for all its potential." (4567)
	Use of ocean space (property rights)	"So I think we have a right, and we were here long before the fish farm." (4448)
	Well-being and quality of life	"That isn't the goal - the goal is happiness, quality of life and standard of living." (5138)
	Self-sufficiency	"Our world is going to more natural, you know, grow your own produce for yourself. Here in Queens county, I see that more and more we're becoming self-sufficient we're not relying on anywhere else to get our food." (9936)
Sustainability	Long-term productivity	"people in our area that are concerned because if everything is used, there is nothing left for the future, nothing left for the grandchildren or anyone" (1165)
	Balance of ecological, social and economic goals	"But it's getting that happy medium in there and that, yes, yes, there are crooks, but they're not the end-all. And, um, but are communities out the end-all either because the community eventually will die if we don't have what we need here as so, and we'll need to be moving forward." (9033)
	Earth-centered	"let's do it in, uh, uh, ecological way in a more sustainable way. Um, so we're saving the environment for the natural fish and wild fish that are out there, and let's create an environment somewhere for our farmed fish." (8655)

D.8 Coding of relationship dimensions

Table D.3 Topic and themes regarding relationships with place by participants

Theme	Topic	Examples
Priorities for development in area	Economic development/growth	"So talking about Liverpool Harbor, it could be vibrant, alive, active on many fronts. So the increased business opportunities, job and income generation would help, uh, encourage sustainable development" (4567)
	Local population growth	"We're a province, that's declining. So it's important for us to grow our population here. And one of the things we have to offer is, you know, come and live next to the ocean. So the aesthetics of our county is huge." (9936)
	Economic diversification	"we want to be able to attract a variety of industry and job opportunities that is obvious - we don't want to be totally dependent on fishery. We want to be able to attract small business to the area to provide a more diversified employment opportunity for people living here but we can't really separate most of that from our proximity to the ocean." (7199)
	Priorities for change	"We've relied on those traditional industries for a very long time. We need to change…We have been a community that has not had priorities on change or on education, although that's changing now…" (4285)
	Protect existing livelihoods	"We have to protect what we got first, because what we got already is a tenuous situation as it is with the lobster It's wise to focus on what we already have." (3009)
	Small-scale industries	"My number is to promote and support small scale industry with regards to marine and ocean development. When you start to focus on small, smaller models, and scale, its easier to see the implications of what you are doing and do the adjustments" (5128)
	Conserve environment	"Well, I think it's much the same as, uh, you know, our whole coast. Uh, we need to look after our coastal areas." (6877)
Meanings of place	Livelihoods	Well, people spend about 10-20 times as much time in a boat than they do in a car might be a first step. The local economy is almost entirely fishing and what's left over is people to enjoy the natural environment. Everything is very important, we are an ocean community (3009)
	Personal identities	"I am the water…The marine life is traditional, it is cultural, it is in the fibre of the people who live here and in everything we do, our language and what we eat, and what we think…" (5128)
	Social fabric of communities	"I guess my community means a lot to me. You know, when something happens, everybody kind of pitches in and helps someone another. So it's, you know, it's pretty close knit community around here. And a lot of there's a lot of small businesses and stuff like that. Everybody tries to help one another." (3675)
	'Natural'	"It's a beautiful place. There are a lot of people who visit here and then ended up moving here because of the attractive, nature of living in a seaside environment and I think it's a relatively unspoiled environment." (6048)
	Ocean as 'playground'	"The coast was also our playground…It was the place where everyone went instead of the school yard or whatever to play together." (5058)
	Habitat	"It's a nursery for everything that lives in the ocean. If you compromise the nursery, you compromise the entire system." (3009)

D.9 Additional insights from case studies

Detailed history of case study areas

Given journal paper restrictions, additional contexts that were used to build case study contexts and histories for each area are provided below, including secondary data sources to build a rich historical context within each case study area.

Digby

The Digby area is located in western Nova Scotia, and includes the historic Town of Digby, and the rural communities within the Municipality of the District of Digby. The Town of Digby is governed by a Town Council consisting of a mayor and four councillors. Numerous federal and provincial services for the County are located within the Town of Digby. The rural communities that make up the Municipality of the District of Digby are governed by an elected council made up of five district councillors, one of whom is selected to take a lead role as a warden. Within the Municipality of the District of Digby, two of five Electoral Districts (District 3 and District 4) are relevant to the case study area and include a 35 km narrow peninsula encompassing the regions known as Digby Neck, Long Island and Brier Island that are nestled between the Bay of Fundy and St. Mary's Bay.

The Town of Digby was semi-settled by New England immigrants in the 1760s, but only formally settled in 1783 by United Empire Loyalists. Since that time, the Digby area has relied on traditional industries including fishing and forestry. By the end of the 19th century, Digby area had been established as tourist destinations. Today, St. Mary's Bay is situated within Canada's most lucrative lobster fishing zones., landing 20,907 tonnes of lobster worth $361 million for the 2019-2020 season (Comeau, 2021). The inshore lobster fishery is the primary employer and economic driver in the area, also supporting economic spinoffs related to the industry (e.g., boatbuilding, suppliers, trucking). Yet, the rural population has faced consistent population declines since the 1940s.

The geographical area of Digby is the most active area for salmon farming in the province, which have been active since the mid 1990s, with clusters both in the Annapolis Basin adjacent the town of Digby (Figure D.1) and St. Mary's Bay near to the communities of Westport and Lockport. In 1996, six sites were operational throughout the area. In the early 2000s, New Brunswick company Cooke Aquaculture began operations in Nova Scotia, taking ownership of many of the leases in the Digby area. In 2011, two new sites were established in St. Mary's Bay, each the largest in the area at around 42 hectares. In 2019, Norwegian conglomerate Cermaq was granted the option to explore expanding their operations into Nova Scotia and began pursuing lease options in four areas in the province, including St. Mary's Bay. However, in April 2020, Cermaq announced that they were unable to find the necessary 15-20 sites across the province and decided not to move forward with the expansion. In Digby, opposition has formed among several rural communities (Figure D.3B), including an organized group of citizens have formed the advocacy group St. Mary's Bay Protectors (https://protectourbay.ca/). This group regularly holds community meetings regarding salmon farming activity and proposals in the area.

Figure D.3 Photos of Digby case study area, showing A) fishing community on Long Island, B) visual anti-farm sentiments of residents, and C) view of a fish farm from the road (Town of Digby). Photos taken by ©Kyla Smith, 2022

<u>Shelburne</u>

Shelburne Harbour is located along Nova Scotia's South Shore, including the Town of Shelburne and the Municipality of the District of Shelburne, located in Shelburne County, Nova Scotia. The Town of Shelburne is governed locally by an elected council consisting of a mayor, deputy mayor and three town councillors. The Municipality of the District of Shelburne is governed by an elected council of seven district councillors (Districts 2 and 3 encompassing the study area), and one selected lead as warden.

The Town of Shelburne is a historic area, with many buildings dating back to when Loyalist settlers arrived in 1783 at the end of the American Revolution (Figure D.2A). Once the most extensive settlement for near to 16,000 loyalists, the population dwindled throughout the 1800s as they settled across the province, although many descendants of the original Loyalists still live in the area today. The numerous historic places along the Shelburne harbourfront (Figure D.2B) have been used as the site for film productions over the years. Historically, shipbuilding has also been a significant industry, hosting a newly renovated shipbuilding facility in Shelburne in 2011. Fishing remains the primary employer in the area, with approximately 9.5 million pounds of fish passing through the port annually. Other economic activities include tourism, aquaculture, fish processing, and the manufacture of barrels, granite monuments, and marine supplies. The Town of Shelburne and surrounding areas are also active coastal housing development, attracting many seasonal and retired homeowners from across Canada.

Figure D.4 Photos of Shelburne case study area, showing A) loyalist influences on Shelburne harbourfront, B) the picturesque viewscape of historic Town of Shelburne, and C) view of fish farm from town. Photos taken by © Kyla Smith, 2022

Shelburne has been a centre of aquaculture presence in rural Nova Scotia. One of the main regional offices for the Nova Scotia Department of Fisheries and Aquaculture operate out of Shelburne. In addition, the Shelburne Campus of the Nova Scotia Community College has training programs for aquaculture. Salmon farming began in Shelburne Harbour in the 1990s, with three small sites operating near the Town of Shelburne by 2000 (Figure D.2C). In the mid-2000s, Cooke Aquaculture acquired all sites in the area. In 2008, a fourth larger site was established on the eastern edge of McNutt's Island on the outer edge of Shelburne Harbour. In 2012, Cooke announced plans to build a processing plant in Shelburne, expecting to bring up to 300 jobs to the area. After multiple delays, Cooke was not able to get leases and announced in 2016 it will not be going through with the plan. Yet, in 2019 as part of a larger expansion plan, Cooke announced it is refloating its proposal to build the plant in Shelburne. Relative the Shelburne area, the Twin Bays Coalition (https://www.twinbays.ca/) was formed following 2018 exploration option by Cermaq across Nova Scotia. This organization represents citizens from all along the South Shore, and hosts public engagement sessions, disseminates information to citizens, and lobbies against government proposals for aquaculture along the South Shore.

Liverpool

Liverpool Bay is located on Nova Scotia's South Shore, including the Liverpool community and surrounding rural towns in the Region of Queens Municipality in Queens County, Nova Scotia. Incorporated as a town in 1897, Liverpool and Queens Municipal District voluntarily amalgamated in 1996 to form the Region of Queens Municipality. Liverpool remains the municipality's administrative centre. The Municipality is governed by an elected council consisting of one councillor for each of its seven districts (Districts 2, 3 and 4 encompassing the study area), and an at-large mayor.

Following historic declines of a once flourishing shipbuilding industry in the 18th century, the area's prosperity resurged with the establishment of the Bowater Mersey Paper Company in 1929, which remained the area's largest employer until it closed in 2012. In recent years, the area's most important economic drivers include tourism, wild fisheries, fish processing, forestry-related manufacturing, and retail. In addition, the natural landscape has become important economic drivers with a rebranding of the Municipality to the "Queen's coast". The Liverpool area has several important ecological habitats such as beaches (Figure D.3A) and wetlands. At the mouth of the bay lies nature reserve Coffin Island, a nesting ground for several bird species including the endangered Harlequin Duck.

Figure D.5 Photos of Liverpool case study area, showing A) Popular recreation destination Beach Meadows Beach, and B) view of the fish farm from Beach Meadows Beach. Photos taken © Jenny Weitzman, 2022

Salmon farming in Liverpool Bay consists of one small salmon farm that has been in operation since 2000 and is currently undergoing an application for expansion (Figure D.5B). The site is located on the western side of Coffin Island, at the outer edge of Liverpool Bay, around 6 kilometres from the mouth of the Mersey River. In 2012, the site was acquired by Cooke Aquaculture. In 2019, Cooke announced major expansion plans beginning with the expansion of their current site in Liverpool Bay from 4 hectares (14 cages) to 40 hectares (20 cages). In addition, two additional 40-hectare sites at the mouth of the bay are currently under review. This plan would include the first new open-pen salmon farm since the moratorium in 2013. In 2018, anti-salmon farming group Protect Liverpool Bay (https://www.protectliverpoolbay.org/) was formed representing a group of citizens primarily calling on the government to withdraw the Cooke expansion proposal. This group has been vocal against open-net pen salmon farming in the province at community events and in the media and has led organized salmon farm protests and petitions.

D.10 Key points from questionnaire responses

Probing questionnaires were administered to familiarize participants with interview topics and provide a structure for interviews. In addition, questionnaire responses provided context to interpret interviews. The first section of the questionnaire asked participants about their relationship with their local marine areas, and asked them to rate the top priorities for ocean and coastal planning and development in their areas. Three priorities consistently emerged as most important among participants, including: economic growth, sustainability, and safeguarding the environment for resources. However, the order of these priorities varied across case study locations (Table D.4).

Table D.4 Participant responses to questionnaires regarding relationship with the area, experiences with salmon farming, and perception of the industry across case study areas.

		Digby	**Liverpool**	**Shelburne**
Priorities for the area				
	First choice	Economic growth	Sustainability	Safeguard environment for resources
	Second choice	Safeguard the environment for resources	Safeguard environment for resources	Sustainability
	Third choice	Sustainability	Economic growth	Economic growth
Knowledge and awareness of aquaculture				
Types of interactions				
Direct	Site visit	Majority	Minority	Very few
	Industry personnel	All participants	All participants	Minority
Indirect	Community meetings	Majority	Majority	Majority
Knowledge	(median)	4	4	2
Most popular information sources (reported by over 80% of participants)				
		Government	Aquaculture industry	Friends or family
		Aquaculture industry Experience and observations	Government Experience and observations Social media NGOs	News
Perceptions of benefits and risks of aquaculture				
Top benefits				
	First choice	Employment	Employment	Employment
	Second choice	Support for supply-chain businesses	Youth retention	Wage and income
	Third choice		Commercial fisheries	Regional economic development
Top risks				
	First choice	Marine pollution	Marine pollution	Disease and pests
	Second choice	Protected or sensitive species	Commercial fisheries	Marine habitat
	Third choice	Disease and pests	Protected or sensitive species	Marine pollution

The second section of the questionnaire asked participants about their experiences, knowledge and awareness of salmon aquaculture. Most respondents had indirect interactions with the industry, although varying degrees of direct interactions (i.e., with industry personnel or visiting sites) (Table D.4). Most participants in Digby had direct interactions with the industry, while less than half of participants in Shelburne had any form of direct interactions. Comparatively, all participants in Liverpool reported direct interactions with industry personnel, but very few had previously visited a site. Participants also expressed different self-reported knowledge levels, with participants in Shelburne reporting low knowledge about aquaculture (median = 2 based on a 5-point Likert scale from very limited to very knowledgeable), deriving their information primarily from news or family and friends. In comparison, both Digby and Liverpool felt they were considerably knowledgeable (median = 4), with the most frequent information source being from government, industry, and personal observations. Across case study areas, most participants reported receiving information about aquaculture from the government, the aquaculture industry, and personal experiences and observations (83% of participants).

This section also asked participants about their perceived trust, or confidence, in various actors in aquaculture, including the government, aquaculture industry, and information sources. Across participants, ratings of trust were generally low for both government and industry (Figure D.6). Regarding different sources of information, scientific institutions or scientists, as well as environmental NGOs were the most well-trusted sources of information about aquaculture (Figure D.7). The aquaculture industry was the least well-trusted source of information across participants. The participant's ratings of trust in government as a source of information were inconsistent, including a range of different perceptions of trust. Grouping trust ratings based on assigned perspectives (Chapter 6), trust was strongly linked to more positive perceptions, as the 'moving forward' perspective (i.e., supporters of aquaculture) was the only one to have high trust in aquaculture (Figure D.8).

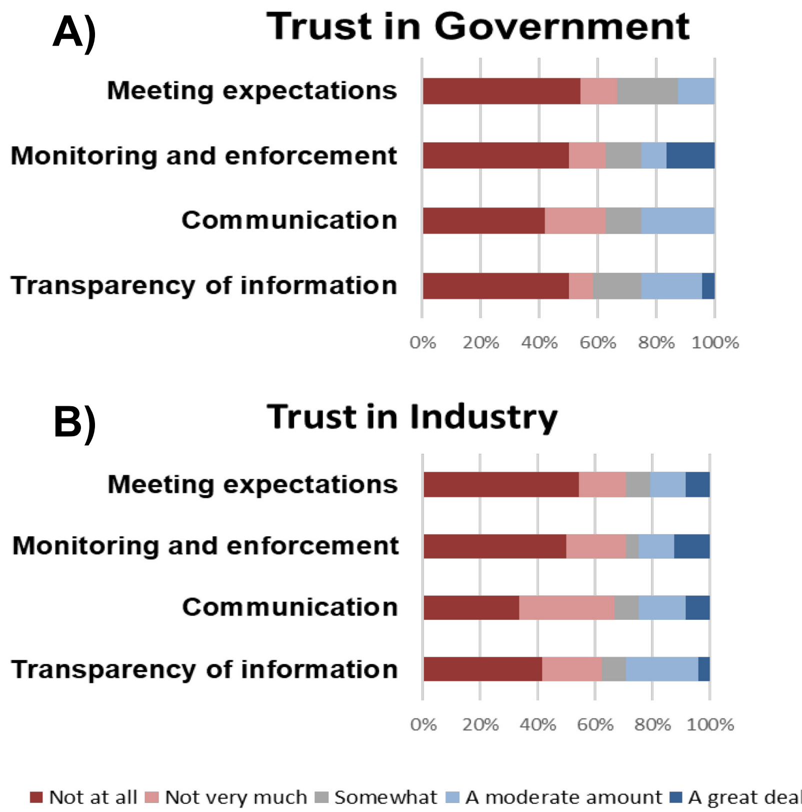

Figure D.6. Participants rating of trust in A) Government and B) Aquaculture industry's commitment to various aspects of salmon aquaculture management in Nova Scotia

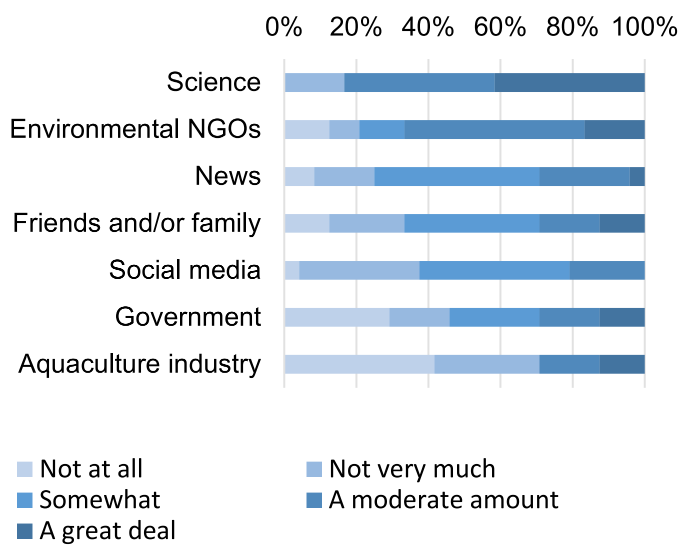

Figure D.7 Participants rating of trust towards various sources of aquaculture information

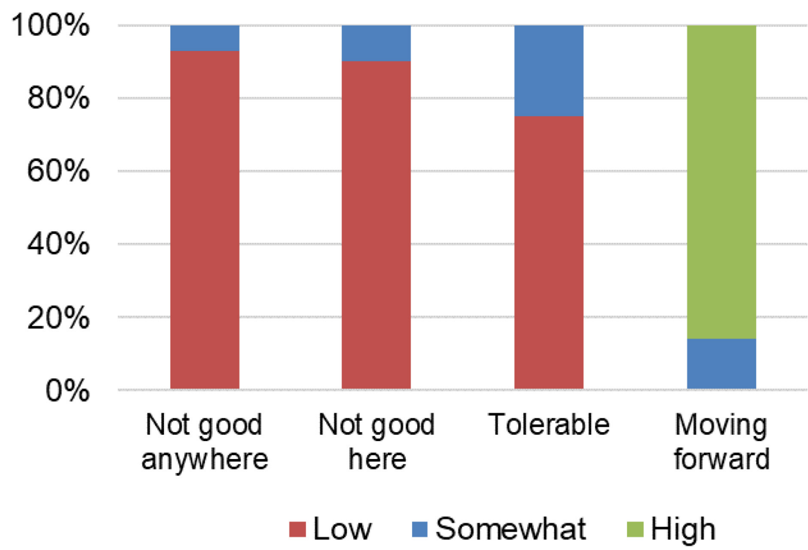

Figure D.8. Percentage of participant's within each perspective group with different ratings of overall trust (combined industry and government). Ratings based on merged categories where Low = not at all + not very much, Somewhat = somewhat, and High = moderate + a great deal.

The third section of the questionnaire asked participants to rate their opinion on salmon aquaculture and their attitude of various potential positive or negative impacts across environmental, economic, and social considerations. Participants reflected primarily negative attitudes towards aquaculture, with overall opinion ratings being negative, despite different perspectives (Figure D.9). Notably, those with a "tolerable" perspective which recognizes both negative and positive impacts and considers themselves unaligned in their support or opposition for the industry reported that their overall opinion was somewhat negative. When asked about specific positive or negative impacts, employment was most recognized as the top benefit of salmon aquaculture across all case study areas (Table D.4). Yet, across different areas, different benefits were considered most important across case study areas. All three case study areas recognized the importance of marine pollution as a top risk from aquaculture. Furthermore, issues around disease and impacts on sensitive species were important.

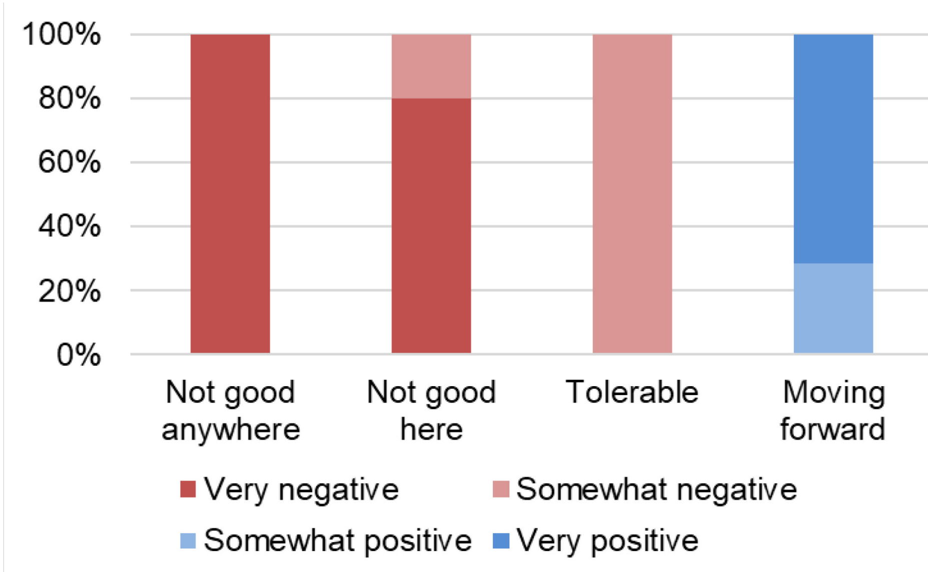

Figure D.9. Percentage of participants within each perspective group with different overall ratings to the question: How would you rate your general opinion towards salmon farming in this area?

The final section of the questionnaire asked participants on their perceptions regarding future of the salmon farming industry in Nova Scotia. First, participants were asked to select their optimal scenario for the industry from options that included eight potential scenarios ranging from increasing, maintaining, or decreasing the scale of the industry. Of the scenarios, five scenarios were selected, although the majority of participants advocated for a removal of the industry from the ocean (Figure D.10), and a shift towards land-based (Chapter 6). While several participants advocated that the salmon industry should continue to grow, many thought that additional oversight was still required for the industry. Likewise, majority of participants (over 75%) highlighted the need for major changes in several aspects of aquaculture governance in Nova Scotia. Among a list of potential changes, participants were asked to rate the top areas they considered required the most improvements/changes (Figure D.11). Among those, participants reported environmental impact assessments, transparency, communications, and regulations as some of the most important changes required.

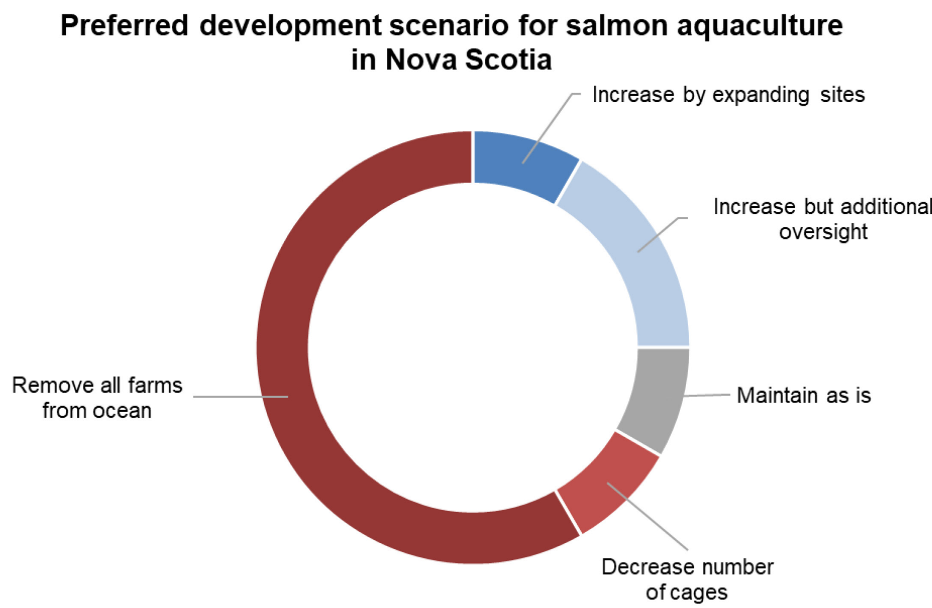

Figure D.10 Pie chart of participant responses to their preferred development scenario for the salmon farming industry in Nova Scotia.

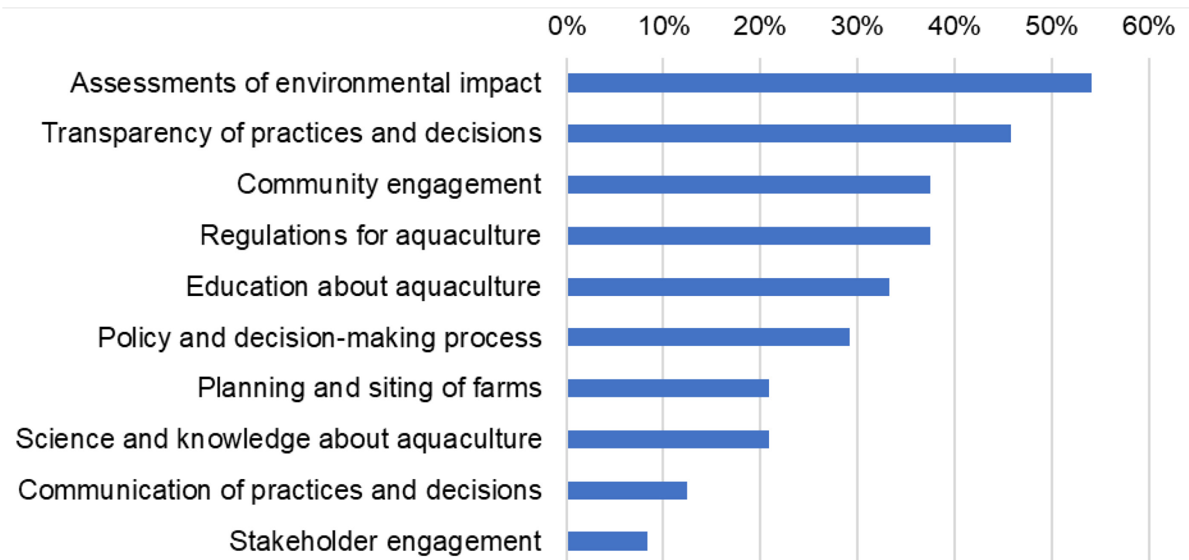

Figure D.11. Frequency of participants rating different changes for aquaculture that are needed within their top three most important changes.

D.11 Final codebook (Chapter 6).

Table D.5 Final codebook describing themes and topics across interviews.

Theme	Topic	Description of when applied
Input legitimacy		Perceptions around the adequacy of procedures and processes related to aquaculture policy, planning, and management
Evidence behind decisions		Regarding to how governments collect and use evidence to guide decisions around aquaculture siting, planning, and management
	Local knowledge	Perceptions around how decisions use knowledge and evidence of local experts
	Science collection	Regarding the adequacy and extent of scientific research being collected, and by whom
	How science is mobilized	In reference to perceptions of decisions being informed by evidence available
Who makes decisions		Regarding the influence of different aquaculture actors, interests, and expertise in decision-making processes
	Influence of industry	Perceptions over the power of industry to influence aquaculture policy and planning
	Political influences	Referring to the influence of politicians in aquaculture siting and planning decisions
	Inclusion of stakeholders	In reference to how, when, and which stakeholders are involved in consultation
	Expertise of decision-makers	Referring to the background and knowledge of those in decision-making power
	Decentralization	In reference to bottom-up vs top-down governance (e.g., community empowerment)
Priorities and motivations		Regarding what motivates decisions made by industry and government, including mindsets, priorities, and organizational mandates
	Government mandates	In reference to official mandates, such as promoting and/or regulating industry
	Government priorities	In reference to how decisions are influenced by different government priorities
	Personal motivations	In reference to personal motivators influencing decision-making (e.g., career growth...)
	Corporate priorities	In reference to industry priorities, including aspects of CSR and profits
Industry oversight		Regarding how governments oversee the industry to protect the environment and public interest
	Regulations	In reference to the content of laws and policies in place to govern the industry
	Monitoring	In reference to the processes to monitor industry's impacts and regulatory compliance
	Enforcement of regulations	In reference to government ability to enforce regulations
	Following rules	In reference to industry compliance with regulations
Throughput legitimacy		Perceptions around how individuals are made aware of aquaculture procedures and risks, and how they are engaged within decision-making
Transparency and availability		Regarding the quality of information about aquaculture available to individuals
	Accessibility	In reference to the ability of individuals to find, and retrieve relevant information
	Clear language	In reference to the clarity of information that is understandable
	Awareness	In reference to perceived knowledge about aquaculture
	Education	In reference to processes of education about aquaculture
Reliability of information		Regarding the degree to which information can be depended on to be accurate
	Misinformation	In reference to false or inaccurate information about aquaculture
	Media	In reference to how and what is communicated by media (news and/or social media)
	Independent sources	In reference to provision of information by sources other than government or industry

Engagement	Regarding the how individuals are given opportunity to voice opinions and concerns during engagement and consultation processes
Openness	In reference to attitudes of government or industry that are available for listening
Early engagement	In reference to opportunities to engage early in decision-making process
Representation during consultation	In reference to the ways, and extent that stakeholders (public, fishermen etc. are engaged, involved, and communicate to
Quality of engagement	Regarding perceptions of how individuals are treated during engagements (describing attitudes of government or industry – e.g., respect, contempt…
Output legitimacy	Perceptions around the consequences and outcomes of aquaculture planning and policy decisions, including the risks and benefits of aquaculture operations
Environmental impacts	In reference to descriptions of how salmon farming interacts with the marine environment, including assessments of impacts on the environment
Species impacts	In reference to impacts on wild animal species (e.g., wild salmon, lobster)
Disease	In reference to spread of disease and/or parasites
Escapes	In reference to impacts from the escape of farmed fish into the marine environment
Habitat impacts	In reference to impacts on marine habitat, including seafloor, from feces, wastes, etc.
Ecosystem impacts	In reference to far-field impacts, and/or on the functioning of the ecosystem
Feed impacts	In reference to impacts from feed creation and usage
Material well-being	Regarding practical welfare and standards of living, including economic and physical health
Employment	In reference to number and quality of jobs provided by salmon farming operations
Economic spinoffs	In reference to potential secondary effects of aquaculture developments on other economic industries that support the industry
Regional economy	In reference to regional economic impacts of province or country (e.g., GDP)
Sponsorships	In reference to industry sponsoring of events, scholarships, programs etc. within community or province
Youth retention	In reference to how aquaculture contributes to attracting, and/or retaining youth
Impact to other livelihoods	In reference to the impact of aquaculture on how individuals and/or communities support their livelihoods (e.g., reflecting financial impacts to other industries)
Food security	In reference to aquaculture contribution to food security, globally or locally
Food safety and health	In reference to health and safety aspects of farmed salmon (a consumer perspective)
Subjective well-being	Regarding impacts to on experiences and values, reflecting spiritual, emotional, and mental well-being
Aspirations	In reference to personal and/or community desires and/or hopes for aquaculture, community development, or individual
Visual aesthetics	In reference to impacts on the beauty or pleasing appearance of the environment
Quality of living environment	In reference to descriptions of social impacts of salmon farming reliant on the quality of the environment that participants use for enjoyment, recreation, or livelihoods
Emotions	In reference to emotional health related to aquaculture, including aspects such as fear, anger, hatred, hope, disappointment, uncertainty, etc.
Animal welfare	In reference to welfare and well-being of farmed salmon
Relational well-being	Regarding impacts of aquaculture on the ability and quality of relationships and communications with others
Social tension	In reference to tensions and conflicts amongst individuals within a community
Community split	In reference to division within communities due to differing values and opinions
Fighting	In reference to action of conflict and/or fighting between individuals, neighbours, etc.

Institutional impacts	In reference to altered confidence and relations with government
Distribution	Regarding the distribution of social and environmental risks and benefits among different groups in society
Distribution of benefits	In reference to where, and to whom, potential aquaculture benefits are distributed
Who pays for risks	In reference to where risks are felt, and who is responsible for costs
Trust	Perceptions of trust towards aquaculture
In government (Gov)	In reference to trust of government (federal and/or provincial)
Trust in Gov - personnel	In reference to trust in individuals working for government
Trust in Gov - Institutions	In reference to trust in government organizations and/or institutions
Trust - beyond aquaculture	In reference to trust of government (not related to aquaculture)
In industry (Ind)	In reference to trust of aquaculture industry
Trust in Ind - personnel	In reference to trust in individuals working for aquaculture industry
Trust in Ind - company	In reference to trust in aquaculture companies
Trust in corporations	In reference to trust of large corporations (may include, but not necessarily, aquaculture)
In science	In reference to trust of scientists, academic, and/or research institutions studying aquaculture
In information	In reference to trust of information communicated from various aquaculture actors (e.g., government, industry, scientists, NGOs, media, etc.)
Social responses	Reflecting judgements towards aquaculture, or an aspect of aquaculture
Attitude	Reflecting negative or positive evaluations of an issue or topic concerned with aquaculture
Positive	In reference to positive comments about aquaculture
Negative	In reference to negative comments about aquaculture
Advocacy	Reflecting direct statements of defense towards a position around aquaculture
Support	In reference to support, or approval of aquaculture
Opposition	In reference to disapproval, or argument against aquaculture
Unaligned	In reference to being uncertain about their advocacy, or expressing a neutral position about aquaculture
Preference	Reflecting statements about individual's personal preference for the future of the aquaculture industry
Increase	In reference to supporting expansion, or increase in aquaculture presence locally, regionally, and/or globally
Maintain	In reference to maintaining current operations as is
Decrease	In reference to decreasing the presence of aquaculture
Land-based	In reference to removal of salmon farms from the marine environment, specifically expressing a preference towards moving to land-based aquaculture operations

D.12 Perceptions across perceptual factors and perspectives

Table D.6 Summary of perceptions related to legitimacy and trust for aquaculture, expressed by participants within each perspective.

	Not good anywhere	**Not good here**	**Tolerable**	**Moving forward**
Input legitimacy - Policies and procedures	• Governance is corporate-led • Experts not consulted • Industry is only profit driven • Underregulated and mismanaged	• Ill-informed management and siting • Government motivated by growth over community • Mismanaged due to poor industry oversight	• Little understanding of policy processes and decisions • Need to consider future cost in policy • Concerns over corporate motivations	• Continuous process of improving regulations • Government keeps industry accountable • Need to emphasize communication processes
Throughput legitimacy – Engagement and interactions	• Knowledge from media and operations elsewhere • Industry and government information is "propaganda" • Manipulation of engagement processes	• Critical information is hard to find • Consultation is "publicity" • Greater community engagement	• Uncertainty and lack of information • Little direct interactions with industry • Emphasize transparency and communication	• Positive dialogue and relations with industry • Actors perceived as forthcoming and open • Information available (but not always accessible) • Critics guided by misinformation
Output legitimacy – Risks and benefits	• Industry problematic everywhere • Disease and animal welfare concerns • Risks on natural populations • Not a food security solution	• Distribution of benefits and risks locally • Community impacts on social relations • Risks to local livelihoods	• Way forward for global protein needs • Benefits not currently realized • Need to put into community • Uncertainty around risks and benefits	• Farms well sited and limited negative impacts • Economic development to revitalize communities
Trust	• Distrust in government and Corporations (beyond aquaculture)	• Poor trust in information • Distrust in government and industry	• Uncertain trust	• Interpersonal trust • Confidence in institutions