Spring 5-20-2021

The Human Dimensions of Aquaculture Development in Maine Including a Governance Perspective

Molly Frances Miller
molly.miller@maine.edu

THE HUMAN DIMENSIONS OF AQUACULTURE DEVELOPMENT IN MAINE INCLUDING A GOVERNANCE PERSPECTIVE

By

Molly Frances Miller

B.A. Vassar College, 2010

M.S. University of Hawai‘i at Mānoa, 2014

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

Ecology and Environmental Science

The Graduate School

The University of Maine

May 2021

Advisory Committee:

Teresa Johnson, Associate Professor of Marine Policy, School of Marine Sciences, Advisor

Brian Beal, Professor of Marine Ecology, University of Maine at Machias

Keith Evans, Associate Professor of Marine Resource Economics, School of Economics

Samuel Hanes, Associate Professor of Anthropology, Department of Anthropology

Sandra De Urioste-Stone, Associate Professor of Nature-based Tourism, School of Forestry

THE HUMAN DIMENSIONS OF AQUACULTURE DEVELOPMENT IN MAINE INCLUDING A GOVERNANCE PERSPECTIVE

By Molly F. Miller

Dissertation Advisor: Dr. Teresa Johnson

An Abstract of the Dissertation Presented
in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy
Ecology and Environmental Science
May 2021

Aquaculture is the fastest growing food production system in the world. Aquaculture growth is heavily influenced by the governance system that establishes property rights and determines the rules by which individuals and communities must follow. This dissertation focuses on the social and ecological factors that influence development of marine aquaculture, as they exist within the governance system, in Maine, USA. In Maine, the marine aquaculture industry is experiencing a period of intense growth necessitating further understanding of the factors shaping its development.

Chapter 2 analyzes semi-structured key informant interviews to identify challenges and opportunities to inform sustainable industry growth. Research participants identified regulatory, environmental, technological, socio-cultural, and economic challenges and opportunities. The leasing system, climate change, infrastructure, public perceptions, and access to capital were major challenges identified. Opportunities include favorable environmental conditions, farm innovation, skilled workforce, strong product demand, and the research and development capacity in Maine.

Chapter 3 identifies factors influencing development of intertidal soft-shell clam (*Mya arenaria*) aquaculture in Maine and how it would intersect with the wild fishery. Intertidal clam aquaculture has the potential to diversify and sustain a declining wild fishery that is important to the economies and

cultures of coastal communities. This qualitative study utilized semi-structured interviews with wild clam harvesters, state regulators and other key stakeholders. Participants identified predation, environmental change, and failing state management efforts as leading causes for the overall decline in wild clam populations. Maine's intertidal property rights system, loss of access to the intertidal, and community preferences regarding privatization of this resource are primary challenges for development of intertidal clam aquaculture.

Chapter 4 examines why non-governmental organizations (NGOs) are becoming involved in aquaculture in Maine and how they are shaping its development. NGOs have played instrumental roles in development and management of a variety of natural resources. In aquaculture, NGOs have historically organized in opposition to development, but this is changing. Semi-structured interviews with Maine NGOs involved in the aquaculture sector indicate they are playing critical roles in development processes including research, economic development, training, education and outreach. Findings suggest most NGOs have become involved in aquaculture in response to rapid industry growth and new funding opportunities.

The research conducted in this dissertation used a qualitative research approach to help identify factors influencing development of aquaculture in Maine. The social and ecological context of a place are unique so while global trends may inform development, site specific data is needed in order to approach development of the sector in a sustainable fashion. Particular attention is given to the governance system, a major component of social-ecological systems, which has enormous influence over the use and management of natural resources. The findings of these chapters indicate a need for marine planning which could reduce user conflicts as competition for coastal waters intensifies.

DEDICATION

I'd like to dedicate this dissertation to my grandmothers who passed away in the early stages of my doctorate as well as my mentor, Dr. George Kidder, who passed away as the final edits were underway. Their strength, wisdom, and unending support have undoubtedly helped and inspired me to reach this milestone. I'd also like to dedicate it to my Goddaughter, Malina and my niece, Charlotte in hopes that they know, if they don't already, they can do anything they set their minds to.

ACKNOWLEDGEMENTS

The expression “it takes a village” has never held more truth for me than it has over the past five and a half years while working towards my doctorate.

I would like to thank my advisor and dissertation committee for their continual support and guidance. Each of them provided a unique skillset and perspective that has made me a better researcher and writer. I would like to thank the Johnson lab for their encouragement and feedback on numerous research guides and presentations, the SEANET and Human Dimensions team for their support, the Margaret Chase Smith Policy Center for providing my office space, and my research participants without whom this dissertation would not have been possible. This activity was supported by National Science Foundation award #IIA-1355457 to Maine EPSCoR at the University of Maine and the University of Maine Graduate Student Government.

My family has been my absolute rock and I am quite certain that I would not have made it through this process without them. They have been constant (daily) voices of encouragement, have mailed me care packages, read chapter drafts, made me laugh and supported me in every possible way. My partner and his family on Vinalhaven have been my home away from home throughout this process and have served as my (literal) shoulder to cry on, provided me with plenty of chances to laugh throughout the day, a full fridge with coffee only a pour away, and acceptance of however I showed up that day. My friends near and far have been sources of inspiration, encouragement, laughter, tough love, outdoor adventures, and trips to OBC. Finally, my counselor has been an outstanding place for me to share my sadness, anxiety, and fear with understanding and grace.

Thank you all for the love and support you have given me. We did it!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1. Researcher as Instrument Statement

As a human-dimensions scholar I believe it is important to situate myself as a researcher (Ely et al., 1997). My research interests are applied social and natural sciences that can help solve real-world problems. I have always been drawn to the marine environment and I feel passionately about sustaining marine resources. Through my work I have found myself restoring eelgrass (*Zostera marina*) in Upper Frenchman Bay, working with fishermen to understand their concerns with cooperative research, and finally understanding the social and ecological factors influencing the development of sustainable ecological aquaculture in Maine. My interest in marine conservation and restoration is what now draws me to research regarding marine resource management. I hope that my research can help coastal communities understand their specific social-ecological context and work towards sustainable outcomes. Because I am drawn to applied research, I find that my worldviews align most with the paradigm of pragmatism (Teddie & Tashakkori, 2010; Creswell & Clark, 2017). This means that I find myself moving between paradigms based on the research question at hand. I hope that my research questions can help solve real-world problems and believe that there exist a wide variety of ways to do so (Ivankova, 2015).

1.2. Aquaculture Development Trends

Aquaculture is the fastest growing food production system in the world and now accounts for more than half of the world's seafood production (FAO, 2018). While fish production from capture fisheries has long since plateaued, marine aquaculture continues to expand and diversify all over the world (FAO, 2018). As such, many countries have begun to grow their aquaculture industries to feed both domestic and international markets with 39 countries across the world producing more aquatic animals from farming than fishing in 2018 (FAO, 2018). The United States imports more than 90 percent

of its seafood and more than half of the seafood imported is farm raised (Knapp & Rubino, 2016; FAO, 2018). This strong demand for aquaculture products necessitates ecologically sustainable and socially acceptable aquaculture development moving forward to maintain a viable industry (Costa-Pierce, 2010).

Currently marine aquaculture in the United States is a relatively small industry far below its potential (Knapp & Rubino, 2016; Lester et al., 2018). Some of the constraining factors include the fact that marine waters are a public resource, the industry is seen as an unknown, negative public perception, and a faltering governance system (Knapp & Rubino, 2016; Murray et al., 2017; Lester et al., 2018). The United States' growth potential for marine aquaculture stems from its amount of coastline, water quality, strict environmental regulations, and large continental shelf (Kapetsky et al., 2013; Knapp & Rubino, 2016). Maine is one of the leading producers of marine aquaculture products within the United States and continues to experience steady growth (Johnson et al., 2019; Bricknell et al., 2020). Maine's aquaculture sector produces Atlantic salmon (*Salmo salar*), American/Eastern oysters (*Crassostrea virginica*), and blue mussels (*Mytilus edulis*), as well as marine algae (*Alaria esculenta*, *Saccharina latissima, Saccharina angustissima)*, Atlantic sea scallops (*Placopecten magellanicus*) and clams (*Mya arenaria* and *Mercenaria mercenaria*). The total annual harvest value is more than $88 million USD (MDMR, 2019). Furthermore, Maine's governor recently approved a 10-year strategic economic development plan that calls for the further development of the aquaculture industry. The potential for growth as well as the additional resources being applied to this sector make this an ideal time to further examine this industry.

1.3. Social Ecological Systems

Marine aquaculture production occurs in the context of a classic coupled social-ecological system (Johnson et al., 2019). Social-ecological systems are "nested, multi-level systems that provide essential services to society such as supply of food, fiber, energy, and drinking water" (Berkes & Folke, 1998, 185). The concept of social-ecological systems (SES) reflects the notion that humans and the

environment are heavily intertwined with one another and cannot be seen as separate entities (Berkes & Folke, 1998). Social and natural systems are dynamic and constantly in flux. Complex environmental problems can no longer be addressed with simple solutions, but rather need to be tackled through an interdisciplinary approach that combines multiple ways of knowing and expertise from the social and natural sciences (Ostrom, 2009). It is essential to understand the complex nature of each individual system as well as their interactions and feedbacks (Ostrom, 2009).

In recognizing the complexity of the environmental problems that humans face, it is necessary to find an approach that combines the knowledge of natural sciences, social sciences and other disciplines in order to achieve sustainable solutions (Ban et al., 2013). Social-ecological systems approaches recognize the diversity of knowledge types and provide a foundation for collaboration and integration of these diverse sets of information that can be used to understand and regulate use of natural resources. One of the most important reasons for adopting an SES approach for finding solutions to complex environmental problems is that "the SES view emphasizes the unpredictable, dynamic, and evolved nature of linked social and ecological systems" (Ban et al., 2013, 196). By using an SES research perspective, scholars are more readily able to respond to this dynamism in its full complexity.

Due to the realization that an SES perspective leads to more holistic understanding, there have been many frameworks developed to answer complex SES research questions (Binder et al., 2013). The varying ontological perspectives of disciplines have resulted in a diversity of frameworks in terms of their research goals, underlying assumptions, and consideration of natural and social systems (Binder et al., 2013). Because of this, the choice of which framework one adopts has immediate implications of the research. While SES frameworks provide a common language for multiple disciplines to collaborate, the theoretical underpinnings of a framework can be represented in the language used, thereby influencing is applicability and ability to integrate diverse perspectives (Hertz & Schluter, 2015).

This dissertation was conducted as part of the Sustainable Ecological Aquaculture Network (SEANET), an interdisciplinary team of researchers and graduate students across more than nine disciplines aimed at improving and further informing the development of aquaculture in Maine (Johnson et al., 2019). The project adopted Elinor Ostrom's SES framework (SESF) to organize it's interdisciplinary efforts (Johnson et al., 2019). The SES Framework:

> enables researchers from diverse disciplinary backgrounds working on different resource sectors in disparate geographic areas, biophysical conditions, and temporal domains to share a common vocabulary for the construction and testing of alternative theories and models that determine which influences on processes and outcomes are especially critical in specific empirical settings. (McGinnis & Ostrom, 2014, 30)

The primary variables involved in the SESF are the resource system, resource units, governance system, actors, and their interactions within the broader social, economic, and political setting (Ostrom, 2009). The SESF's utility as a diagnostic tool enabled the SEANET project to assess the state of Maine's coastal environment and the communities in which aquaculture is embedded to understand what variables may be important to development of the industry. The application of the SESF to aquaculture development as detailed in Johnson et al. (2019) is a novel concept that deserves further exploration.

My dissertation research was heavily informed by Ostrom's SESF and contributes further knowledge regarding the governance system to the broader field of social-ecological systems research. As a human dimensions scholar, my work focuses primarily on the social system and its interactions with the natural system. This dissertation focuses specifically on how characteristics of the governance system, including institutions, influence the development of sustainable ecological aquaculture in Maine. The governance system influences how actors interact with the resource system and resource units (Ostrom, 2009). The governance system is characterized by multiple variables including government and non-government organizations, network structures, property-rights systems, operational-choice rules, collective-choice rules, constitutional-choice rules, and monitoring and sanctioning rules (McGinnis & Ostrom, 2014). The findings from this dissertation contribute additional

knowledge about the variables within the governance system and how they interact with the larger social-ecological system in the context of aquaculture development.

1.4. Research Chapter Summaries

1.4.1 Research Chapter 2 Summary

Chapter two is an exploratory study to understand both the current state of the Maine aquaculture industry as well as potential for future growth. Researchers used a snowball sampling method to target a vast array of participants involved in in Maine's aquaculture industry (Miles et al., 2014). Participants included aquaculture farmers, state agency and non-governmental organization staff, as well as researchers. Each of the 52 research participants was interviewed once to obtain the breadth of information desired. Semi-structured interviews allowed for some flexibility within the interview guide while using major themes of interest identified through the SEANET project as a way to allow for comparisons across interviews (Bernard, 2011). Interviews were transcribed by the transcription service Verbal Ink and analyzed in NVivo 11 Pro software to identify major themes. Results indicate that there are five major themes: regulatory, environmental, technology, socio-cultural, and economic in which there exist both challenges and opportunities for development of aquaculture in Maine.

1.4.2 Research Chapter 3 Summary

Chapter three examines the social and ecological factors influencing development of intertidal clam (*Mya arenaria*) aquaculture and how it would intersect with the wild clam fishery in Maine. As soft-shell clam landings continue to decline in Maine, clam aquaculture can potentially off-set some of the negative social impacts to coastal communities by providing alternative livelihoods to wild harvesters, thereby potentially making these communities more resilient to environmental change. However, there remain many institutional and social challenges associated with intertidal aquaculture development.

The soft-shell clam fishery in Maine has existed for over 200 years (Hanna, 2000). Throughout this time clam landings have declined significantly, which has left many speculating about the vulnerability of the fishery and the clam harvesters who depend on it. The co-management regime for the clam fishery in Maine has allowed for cooperation among clammers and the state while maintaining a sense of independence for clam harvesters and an equal opportunity fishery (Hanna, 2000). Nonetheless, the continued decline in landings brings into question whether intertidal aquaculture could offset some of the decline in clam populations. Currently, town shellfish committees are beginning to adopt aquaculture practices in areas of the flats that are then harvested by clammers in a joint effort. These practices include seeding an area with wild or hatchery seed and then using netting or boxes for predator exclusion (Beal& Kraus, 2002).

This study used semi-structured interviews with municipal shellfish committee members and other key informants in the clam fishery to understand their perception of the factors shaping development of clam aquaculture and how it may intersect with the wild fishery. A total of 23 semi-structured interviews were conducted and recorded. Interviews were transcribed by the transcription service Verbal Ink and were analyzed in NVivo 11 Pro software. Major findings indicate that privatization of this common-property resource is the largest barrier to the development of intertidal aquaculture. The idea of privatizing a common property resource in coastal communities with strong “moral economies” could pose a challenge (Pinkerton, 2015, 411). The riparian property rights system in Maine also reduces the likelihood of clam harvesters’ willingness to go through the leasing process as well as challenges their access to the mudflats for the wild fishery. Despite these challenges, municipalities continue to use aquaculture practices for conservation as a communal effort and interest in these practices continues to rise. While not the traditional owner/operator form of aquaculture, this type of community aquaculture effort bypasses the challenges with property rights and maintains the equal

opportunity mindset of clam harvesters. This unique form of aquaculture continues to gain traction and will likely be the form of intertidal clam aquaculture that persists in the foreseeable future.

1.4.3 Research Chapter 4 Summary

Chapter 4 examines why non-governmental organizations (NGOs) become involved in aquaculture and what roles they play in the development process. As one component of the governance system, NGOs can play a significant role in facilitating sustainable use and management of common-pool resources (McGinnis & Ostrom, 2014). The role of NGOs in aquaculture is not well-documented and much of the current literature on NGOs in aquaculture focuses on environmental NGOs that view aquaculture as a threat to environmental sustainability (Bostick, 2008). In contrast, the role of NGOs in other natural resource sectors and other common pool resource systems is well documented, particularly in forestry and forest management. In these natural resource sectors, NGOs have been shown to play an important role in sustainable development by providing a variety of services including funding, education and training, public outreach, technical assistance, and conservation (Wright & Andersson, 2012; Deighan & Jenkins, 2014; Cook et al., 2017).

In Maine, a variety of NGOs have recently developed aquaculture portfolios as the sector has drastically expanded over the past five years. The purpose of this study was, therefore, to understand why NGOs are becoming involved in Maine's aquaculture industry and what roles they serve. This study utilized semi-structured interviews with a total of nine NGOs in Maine that actively participate in the aquaculture development process. Interviews were recorded and then transcribed by Verbal Ink and TranscribeMe! Transcripts were analyzed in NVivo 11 Pro software to identify major themes discussed by organization participants. All but one of these organizations views aquaculture as a positive contribution to Maine's coastal communities and aims to help its sustainable development. The remaining organization is an environmental NGO that is not against all aquaculture but is opposed to the current siting process and feels it is leading to unsustainable development. The majority of NGOs are

playing similar roles to those in other natural resource sectors including funding, training and education, public outreach, technical assistance, and lobbying. These organizations also feel that the size, species, and intensity of aquaculture will need to vary by community. Most of these NGOs are in part dependent upon grant funding, and while those opportunities are readily available in aquaculture currently, there is concern as to whether or not these organizations will remain committed to aquaculture development once funding is less available.

This qualitative study in Maine contributes a more complex perspective of the role of NGOs in aquaculture development and thereby important information regarding institutional roles in SES research. Because little research has been done globally on the role of NGOs in aquaculture development, the findings of this study could provide guidance for other places trying to further develop a sustainable aquaculture industry.

1.5. Significance

Overall, this dissertation builds upon Johnson et al. (2019) and thus, McGinnis & Ostrom (2014), by contributing new understanding regarding the governance system as it pertains to aquaculture growth. While identifying challenges and opportunities for development of aquaculture broadly, there is also a need to understand these variables with specific regard to intertidal aquaculture. All of these social and ecological variables exist within the context of the governance system, which enables and constrains users and their interface with marine resources. For that reason, understanding particular aspects of institutions and how they play a role in managing common pool resources, especially with regard to aquaculture, is increasingly important. Non-governmental organizations are one such type of institution that has played significant roles in managing other natural resources around the world, yet their role in aquaculture remains unknown. As development of the marine coastal zone increases, the role of the governance system in managing marine aquaculture must be understood and documented in

order to ensure ecological and social sustainability in the coastal communities shaping, and being shaped by, these changes.

CHAPTER 2

CHALLENGES AND OPPORTUNITIES IN MAINE'S AQUACULTURE INDUSTRY

2.1. Introduction

As seafood production from global capture fisheries declines and human population increases, aquaculture has great potential for feeding communities. Aquaculture is the fastest growing food production system in the world, and now accounts for half of the world's seafood supply (FAO, 2018). On the global scale, the industry is incredibly diverse in terms of species farmed and the size and intensity of operations, ranging from small artisanal farms to large multi-national operations (FAO, 2018). Total production amount per country also varies incredibly with China accounting for more than 60 percent of the global supply (FAO, 2018). As such, many countries have begun to grow their aquaculture industries in order to feed domestic and international markets.

The United States has been identified as one of the countries with significant potential for aquaculture growth (Knapp & Rubino, 2016). Currently, the channel catfish (*Ictalurus punctatus*) represents the highest biomass of any species cultured in the United States, though, the marine aquaculture sector is steadily growing. Maine is one of the leading producers of marine aquaculture products within the United States and continues to experience steady growth (Johnson et al., 2019; Bricknell et al., 2020). Maine's aquaculture sector produces Atlantic salmon (*Salmo salar*), American/Eastern oysters (*Crassostrea virginica*), and blue mussels (*Mytilus edulis*), as well as marine algae (*Alaria esculenta*, *Saccharina latissima, Saccharina angustissima)*, Atlantic sea scallops (*Placopecten magellanicus*) and clams (*Mya arenaria* and *Mercenaria mercenaria*). The total annual harvest value is more than $88 million USD (MDMR, 2019). In 2020, Maine's governor announced a 10-year strategic economic development plan that targets the aquaculture industry for further expansion, signifying additional resources amidst a period of already intensive growth making this an excellent time to study the industry here (Maine Department of Economic & Community Development, 2020). While

many opportunities exist for growth in this industry, marine aquaculture also faces many development challenges both in the United States and elsewhere. Both challenges and opportunities are unique to the social-ecological context of place, and must be researched at multiple scales, including the local level (Johnson et al., 2019).

While this study focuses on the specific social and ecological factors influencing development of aquaculture in Maine, it is important to also understand global trends. The contrasting sociopolitical, economic, and ecological factors of differing scales affecting development of aquaculture can lead to the improvement of governance at the local and global scale (Bennet & Howlett, 1992; Young et al., 2019). Furthermore, identifying social, ecological, and economic carrying capacities as well as their interactions helps to predict the overall carrying capacity and thus, sustainability of the aquaculture industry in a place (Gibbs, 2009). This necessitates identifying: 1. environmental; 2. social; 3. technological; and, 4. economic factors of aquaculture development, which are often influx (Gibbs, 2009).

2.2. Literature Review: Global Aquaculture Challenges

2.2.1. Social Challenges

Overcoming social concerns is one of the most notable challenges for aquaculture development globally. Social opposition to aquaculture has been identified as one of the primary barriers to its growth (Knapp & Rubino, 2016). Others have identified social carrying capacity, or the "biomass/water space of culture that the community is willing to allow" (Inglis et al., 2000, 31), as the limiting factor for aquaculture development in industrialized countries (Gibbs, 2009). Challenges related to social carrying capacity include negative public perceptions, interactions with other industries, and consolidation (Osmundsen & Olsen, 2017; Young et al., 2019; Hoerterer et al., 2020). Much negative public perception of aquaculture development has stemmed from the negative impacts of intensive production on the environment including concerns over the build-up of waste products, genetic mixing, depletion of wild

fish stocks, and pathogen and disease spread (Diana, 2009; á Norði et al., 2015; Forseth et al., 2017; Osmundsen & Olsen, 2017).

Competition for space in the marine coastal zone is another common social challenge affecting growth of aquaculture development on the global scale. Marine aquaculture vies for space with numerous other industries such as fishing, tourism, recreation, and shipping (Knapp & Rubino, 2016; Evans et al., 2017; Dalton & Jin, 2018). In the United States and Canada, significant concern exists over aquaculture infringing on commercial fishing grounds, particularly with the lobster fishery (Osmundsen & Olsen, 2017; Young et al., 2019). The tourism industry's dependence upon the perceived "pristine" nature of coastal spaces can also compete with aquaculture development (Dempster & Sanchez-Jerez, 2008; Young et al., 2019). Tourism and travel contributed 10.3 percent of the global GDP or $8.9 trillion USD in 2019 and serves as a more significant economic force than aquaculture in many countries (WTTC, 2020). As a result, tourism can significantly influence the development of coastal spaces (Dempster & Sanchez-Jerez, 2008; Gibbs, 2009). In the United States tourism contributed approximately 2.9 percent of the GDP as of 2018 (UNWTO, 2020). Acquiring sites for aquaculture farms is therefore becoming more challenging as diverse interests compete for space (Duarte et al., 2009; Young et al., 2019). A lack of marine planning in many countries leaves room for uncertainty around aquaculture siting, that can increase conflicts with other stakeholders, and has led to threats of litigation by opposition groups (Ricketts & Hildebrand, 2011; Young et al., 2019).

2.2.2. Ecological Challenges

Changing environmental conditions prove to be another challenge facing the future of the aquaculture industry (Cheney et al., 2010; Spillman et al., 2015). Warming ocean temperatures have drastic impacts on marine organisms, including farmed species (Spillman et al., 2015; Bricknell et al., 2020). Increases in disease spread in fish and shellfish, availability of food for filter feeders, increased predation, and increased ocean acidification are some of the documented concerns for the aquaculture

industry (Spillman et al., 2015; Young et al., 2019). In addition, sea level rise and increased frequency in storm events threaten the coastal infrastructure necessary to the industry. Furthermore, a growing human population is expected to cause increased sedimentation and pollution of coastal waters where aquaculture farms are situated (Diana, 2009; Cheney et al., 2010; Coast-Pierce, 2010).

2.2.3. Technological Challenges

As aquaculture continues to grow on a global scale in both wealthy and developing countries, the need for innovations in technology has become a significant challenge to further industry expansion. Improvements in equipment, feed technology and operational efficiency are challenges the industry will need to overcome to be successful on a larger scale (Kumar & Engle, 2016; Fairbanks, 2016; Kumar et al., 2018). The fierce competition for space in the marine coastal zone has led to the exploration of offshore and integrated multi-trophic aquaculture (IMTA). Offshore IMTA operations remain few in number, however (Buck et al., 2018). Overall, the "technology and system design" have yet to be translated to offshore settings with more extreme environments (Buck et al., 2018). Another challenge requiring technological advances made readily available is biofouling, as it can significantly impact both cultured organisms and farm gear (Sen et al., 2020).

2.2.4. Economic Challenges

Economic challenges facing the aquaculture industry include prohibitive start-up costs, access to capital, and competition with amenity values. Aquaculture operations in many countries such as the United States are still small-scale operations (FAO, 2018). The relatively small size of the aquaculture sector in the United States is a challenge because aquaculture farms cannot achieve economies of scale "in production, processing, transportation, and marketing" (Knapp & Rubino, 2016, 215). As small businesses, the expenses required for standard operation such as equipment, staff, and cultured organisms can be prohibitive. While the aquaculture industry can produce vital revenue for communities, competition for space provides an economic comparison with other industries such as

tourism which often generate significant income for communities (Krause et al., 2020). This leads communities to prioritize the industries with greater income generation that often view aquaculture development as mutually exclusive (Gibbs, 2009; Knapp & Rubino, 2016).

2.3. Global Aquaculture Opportunities

2.3.1. Social Opportunities

Despite the gamut of social challenges in aquaculture development globally, there are enormous possibilities in this sector as well. One pathway to build social acceptance of the aquaculture industry is to provide educational opportunities to the general public through school curriculum, hosting events, and offering farm tours (Bricknell et al., 2020). Opposition to industry development is, in part, attributed to a lack of understanding and awareness of aquaculture (Thomas et al., 2017). Bricknell and Langston (2013), for example, have called on the industry to improve communication with a variety of stakeholders including the general public, press, and regulators. Because aquaculture in many places is a young industry compared to other marine sectors situated in the same area, such as fishing and tourism, the onus is on the industry to educate others and demonstrate their importance as well as stewardship of the environment in which they farm. Community-led initiatives and partnerships, such as marine conservation projects, are helping to build trust between different stakeholder groups and the aquaculture industry (Gibbs, 2009). The local food movement is also benefiting farmers while demonstrating the demand and importance of aquaculture at the community level (Stabiner, 2014). There are many opportunities to raise awareness about the advantages of aquaculture in ways that might increase understanding and acceptance of the industry (Bricknell & Langston, 2013).

2.3.2. Ecological Opportunities

Opportunities for aquaculture development and expansion also include a variety of environmental and biological factors, such as bioremediation, conservation, and disease treatments (Petersen et al., 2014; Spillman et al., 2015; Kowalska et al., 2020). Aquaculture for conservation is a

common practice that has been used to help preserve a variety of species including Atlantic and Pacific salmon and soft-shell clams (Beal et al., 2016; Bricknell et al., 2020). Shellfish and seaweed aquaculture also has the ability to improve water quality and has been used as such a tool in many places including the Chesapeake Bay in Maryland, United States (Parker & Bricker, 2020). Due to the prevalence or diseases and subsequent damage to farmed species, biological treatments such as the use of bacteriophages are gaining in popularity and have great potential to diminish disease spread and reduce the need for antibiotics (Kowalska et al., 2020).

2.3.3. Technological Opportunities

Research and development efforts in aquaculture are constantly underway to improve farm efficiency, which has made it one of the largest opportunities for growth of the industry. Advancing technological developments in aquaculture production could improve feed efficiency on fish farms, close production cycles on farms, enable greater offshore production, and help ensure dependable supplies of protein in a changing climate (Duarte et al., 2009; Jones et al., 2015). Improvements in environmental forecasting would allow farmers to optimize the growing season, thereby production, as well as prevent losses due to inclement conditions (Spillman et al., 2015). Establishing mechanisms for early disease detection will also help increase production and farmers' financial security (Ferreira et al., 2014). Advances in offshore and open ocean aquaculture research and technology can open a huge bottleneck that would greatly increase global food production (Morse & Rice, 2010; Langan, 2013). Some countries, such as China, have already advanced farm technology that has been implemented as far as eight miles offshore (Marra, 2005). Two additional innovative aquaculture production methods include land-based recirculating systems and integrated multi-trophic aquaculture (IMTA) (Barrington et al., 2009; Costa-Pierce, 2010). Land-based recirculating systems are gaining traction as a production method particularly in areas with limited coastal space, which reduces user conflict in the coastal zone. Integrated multi-trophic aquaculture also addresses sustainability issues through innovative growing techniques that will

include shellfish and macroalgae production alongside finfish farming to filter excess nutrients out of the water column (Barrington et al., 2009; Bostock et al., 2010).

2.3.4. Economic Opportunities

With the global population estimated to reach over nine billion by 2050 (FAO, 2018), arable land, fresh-water resources, and capture fisheries will be unable to meet food demand. However, aquaculture has potential to grow across most of the world's oceans. The industry's growth also provides economic diversification in coastal communities that are vulnerable to environmental change (Grebe et al., 2019). In rural areas, especially areas susceptible to drought, aquaculture expansion could serve as a primary source of generating income for households (Shava & Gunhidzirai, 2017). Growth of the aquaculture industry also includes innovations in business management, marketing, and increased efficiency along the supply chain (Bostock et al., 2010; Brugère et al., 2019). Placing greater emphasis on the role of "post-harvest stakeholders," (Brugère et al., 2019) including consumers, includes further development of markets and infrastructure necessary to reach those markets (Bostock et al., 2010). Rural communities are often dependent on a natural resource-based economy and development of the aquaculture sector and related infrastructure could have significant benefits to these communities (Obiero et al., 2019; Clough et al., 2020).

2.4. Research Objective

The objective of this study was to use key informant interviews to identify the social and ecological challenges and opportunities involved in the development of Maine's aquaculture industry, which have thus far not been documented at such a scale, qualitatively. Social and ecological factors are site specific thus, while there is a plethora of knowledge regarding aquaculture development on the global scale, it is important to identify the most relevant factors affecting Maine. By identifying the specific factors relevant for Maine's aquaculture industry, the results of this study can better focus

efforts on overcoming the key challenges to the industry and capitalizing on the opportunities specific to the state.

2.5. Study Site

This study is situated in the state of Maine, USA. Maine has approximately 5,600 kilometers of rocky coastline. There is a strong maritime tradition in the state with many people working in marine-related sectors. Historically most working waterfront jobs have been in capture fisheries. In the face of a changing climate there is speculation of the fate of the lobster fishery and Maine's coastal economy. The Gulf of Maine is rapidly warming which, could cause a myriad of adverse impacts to marine related sectors (Pershing et al., 2015). The growing aquaculture industry has the potential to diversify the landscape of the working waterfront and revenue streams for coastal communities. Maine's aquaculture industry has existed since the 1970s, with more intensive development of the sector occurring in the last 10 years (MDMR, 2019).

Maine's heterogeneous coastline is well suited for a diversity of aquaculture species. The commonly farmed species include Atlantic salmon, mussels, oysters and seaweeds, with the majority of farms growing oysters. The northern, mid-coast, and southern regions of the state are experiencing aquaculture growth at different rates with the Damariscotta River in the mid-coast region having the longest standing history of aquaculture farms. These regions also have diverse ecological conditions that enable specific types of aquaculture to prosper with salmon farms occurring in the colder waters in the eastern region of the state, and shellfish and seaweed farms occurring primarily in the mid-coast and southern waters. Not only does the coastal ecology differ between regions, but the composition of the coastal communities in which these farms are situated is also extremely diverse. During summer months, seasonal residents and tourists contribute significantly to the composition of coastal communities. The state's subtidal waters are a public resource with a multitude of uses including fishing, shipping, recreation, and tourism. This combination of social and ecological factors combined with the

state's intent to grow the aquaculture industry makes Maine an ideal location to study the challenges and opportunities for the industry.

2.6 Methods

This exploratory study (Graziano & Raulin, 2012) used semi-structured interviews with key informants in Maine's aquaculture industry. Semi-structured interviews allow for some flexibility within the interview guide while using consistent themes of interest that allow for comparisons across interviews (Bernard, 2011). Questions explored the history of Maine's aquaculture industry, the scale and types of aquaculture, the challenges and opportunities for growth, community interactions and conflicts, the role of science in informing development, and leaders of industry development. Researchers used a snowball sampling method to target individuals involved in Maine's aquaculture industry including as farmers, state agency staff involved in the aquaculture sector, members of non-governmental organizations (NGOs) and academic institutions involved in the sector, and state legislators. In total, 18 farmers, 4 state legislators, and 30 individuals from state government, NGO, and academic institutions participated in this study. Each of the 52 research participants was interviewed once to obtain the breadth of information desired. While the interview guide focused on the range of topics mentioned above, this particular study focuses on sections pertaining to the challenges and opportunities for aquaculture growth in Maine.

Interviews ranged from thirty minutes to three and a half hours. Four graduate students within the research team conducted interviews. Interviews were audio-recorded with permission and were later transcribed verbatim by the transcription service Verbal Ink. The transcripts were analyzed using NVivo 11 Pro software. During First Cycle coding, the researcher adopted an inductive coding approach to allow major themes to emerge organically (Miles et al., 2014). During Second Cycle coding, the researcher used pattern coding to refine the number of emergent themes. Pattern coding groups and refines codes from the initial coding process into fewer themes or constructs to establish more

meaningful units of analysis that are explanatory in nature (Miles et al., 2014). This Second-Cycle coding strategy allowed the researcher to refine codes so that major and minor themes are easily understood (Miles et al., 2014).

2.7. Results

Challenges and opportunities pertaining to the development of Maine's aquaculture industry are presented in the context of five major themes that arose during the interview process. These included: 1. regulatory; 2. environmental; 3. technologic; 4. socio-cultural; and, 5. economic factors related to aquaculture development (Table 2.1 & Table 2.2).

2.7.1 Regulatory Challenges and Opportunities

Research participants identified a variety of regulatory challenges including: 1. the speed and complexity of the leasing process; 2. environmental and food safety regulations; 3. lack of DMR capacity; and, 4. a lack of marine planning. More than half of research participants identified regulatory challenges and of those responses, three quarters of participants identified the leasing process as the largest challenge for sector growth. While some interview participants found the process to be overly complex and intimidating, the largest issue identified by research participants was the length of time before a lease is granted.

> The other hurdle is the lease process. Without a doubt, the lease process is – I mean the lease process itself is not broken, as in the regulations maybe need some tweaks, but it's a thoughtful process that has got a long history to why it is the way it is, but it's broken because it's taken years – taken years for farmers to get a lease. (Agency Staff)

Participants discussed the length of time taken for an individual's lease application to be approved, which has taken up to two years. This is thought to be, in large part, due to the size of the aquaculture department at the Maine Department of Marine Resources (MDMR). Individuals suggested that increasing numbers of positions within the aquaculture department would reduce lease application time

and provide capacity for proactive and innovative thinking regarding industry growth. Participants explained that the lengthy process makes it incredibly challenging for a farmer to start a business. Waiting so long prior to a decision regarding the status of a lease application, means that farmers cannot be certain whether they will be able to begin or grow their aquaculture operation, which further delays revenue. Research participants also noted that the process for obtaining a lease can be both intimidating and lengthy, which has deterred interested individuals from applying.

Another common issue mentioned by participants is that individuals have taken advantage of Limited Purpose Aquaculture License (LPA) rules. LPAs are 400 ft^2 and require no lease hearings. Individuals can lease up to four LPAs annually and some individuals combine leases with other family members or friends to create a much larger lease site without the public input process, thus creating conflicts in communities. The MDMR has since attempted to address this problem by creating a minimum age requirement for leases and limiting the number of LPAs for which an individual can be an assistant (MDMR, 2019). The process continues to evolve but the regulatory process, otherwise remains burdensome.

While few regulatory opportunities exist that were noted by participants, they identified: 1. the use of LPAs for site testing; 2. LPAs as a source of individual food production; 3. LPAs as a mechanism for reducing entry time for new farmers; and, 4. growing the MDMR aquaculture department. Participants noted that LPAs were a valuable resource for novice and experienced farmers alike. Novice farmers are able to obtain up to four LPAs to try their hand at aquaculture and decide if it is something they want to pursue on a commercial scale. Seasoned farmers can benefit from LPAs as a mechanism for site testing before they invest resources into a new lease site on a larger scale. In each case, LPAs have the shortest review process and greatly reduce the barrier to entry time.

2.7.2. Environmental Challenges and Opportunities

Within the context of environmental challenges, research participants identified a variety of factors including: 1. disease; 2. climate change; 3. ocean acidification; 4. predation; 5. storm damage; 6. lack of wild seed; 7. water quality; and, 8. siting conditions. Of approximately two thirds of participants who identified environmental constraints, half identified disease as one of the most pressing environmental challenges. Several types of diseases impact farmed species in Maine, particularly shellfish, including paralytic shellfish poisoning (PSP), *Vibrio*, and multinucleated sphere unknown MSX (*Haplosporidium nelson)*. The first two diseases cause consumption of shellfish to be harmful with potentially life-threatening consequences.

> A couple years ago, there was an outbreak of an oyster disease that took out a lot of the oyster industry… Especially with something where you're working in the open water and within one ecosystem, something somebody else does can have a drastic effect on you… (Agency Staff)

As indicated by several interviews, MSX spread rampantly among oyster farms in 2010 when it shut down most of the industry. Oyster aquaculture farms are the most common farm type in Maine and are situated along much of the coast, so threats such as MSX can have disastrous consequences for the industry as a whole.

Impacts of climate change were also frequently discussed by interview participants as a major threat to the industry. Warming waters and ocean acidification were openly discussed as well as indirect effects such as increases in harmful algal blooms and invasive species. As such, farmers are increasingly concerned with the fate of their crops. Ocean acidification is of particular concern to shellfish farmers as juvenile shellfish have difficulty accumulating shell as pH levels decrease. One of two oyster hatcheries in the state buffers its seawater because it is already too acidic for spat growth and survival. These concerns have grown as climate projections predict increasing temperatures and levels of carbon dioxide.

Despite these concerns, Maine's environment was cited by respondents as one of the most notable opportunities for the growth of aquaculture in Maine. Respondents discussed excellent water quality, proper water temperatures and salinity, and ample amounts of phytoplankton to feed shellfish as reasons why Maine's industry has the capacity to continue expanding.

> (in Scotland) It takes four years to get to market from spat. We're 18 months. And we have similar water temperature, similar tides in terms of current and the difference is the amount of nutrient in the water. It takes 36 months in Newfoundland. So, it's the Gulf of Maine, it's the place that helps us be successful, whether it's oysters, whether it's seaweed and now finfish. It's the amazing quality of the water. (Farmer)

Respondents identify the Gulf of Maine as an ideal locale for aquaculture due to a breadth of biological factors and diversity of coastal habitat that can support a variety of farmed species. In addition, Maine's coastal waters have a reputation for cleanliness which participants feel is a growing concern among consumers. As such, Maine's products stand out as both clean and environmentally friendly.

2.7.3. Technology Challenges and Opportunities

Approximately one third of interview participants identified technology challenges on aquaculture farms including: 1. need for infrastructure and innovation; 2. general availability and access to equipment; and, 3. the need for tech transfer with other countries and among farmers. Of the issues identified, more than two thirds of the respondents discussed infrastructure and innovation as the largest barriers including the need for processing equipment, weather-resistant gear, technology to prevent biofouling, and recirculating aquaculture systems (RAS) and integrated multi-trophic aquaculture systems (IMTA). Processing and production capabilities, particularly for seaweed aquaculture, were discussed as one of the major bottlenecks of a burgeoning industry in Maine.

> We always have major challenges. For seaweed, it's a whole new industry… we're taking this idea that we have, and we're trying to translate it into a whole new industry. So, you need to build every piece along the way, which is kind of a daunting task, really. (Farmer)

Environmental conditions for seaweed aquaculture are perceived as extremely favorable along Maine's coast. However, delivering fresh product to markets is challenging in remote settings and the technology to dry and process seaweed is unavailable for most farmers. Standard drying methods in the industry in other parts of the world normally entail allowing the seaweed to air dry on lines. Maine does not have enough warmth and sun exposure for long periods of time to take advantage of this basic technique. Instead, farmers must resort to more advanced methods of drying that are not fully developed or readily available due to cost.

Because the buildup of unwanted organisms on equipment (biofouling) is a common challenge for farmers, the need for biofouling technology was discussed pertaining to a range of species including oysters, mussels, and kelp. Advances in biofouling would help reduce labor efforts, and therefore costs, required to maintain farm gear. When sea water temperatures reach the freezing point during winter months in Maine, ice build-up, especially in coastal settings, can cause damage to farm gear. Technology to break apart or prevent ice buildup on farm sites would be greatly beneficial to reduce gear damage and product loss during winter or severe storm conditions. Another interesting aspect of the small owner-operator aquaculture farms that dot Maine's coast is that many technological innovations occur at the farm level. Having streamlined technology available across the state would help ensure success of small farms that may not have the funds or capacity for innovation.

Despite current limitations to aquaculture development in Maine, participants identified several technological opportunities including: 1. species innovation; 2. land-based recirculating tanks; 3. processing; 4. IMTA; 5. feed innovations; and, 6. broader research and development. One of the most promising areas of research and development revolves around marine algae. Currently only a few

species (*S. angustissima*, *S. latissima*, *A. esculenta*) are grown commercially in Maine but participants identified many product innovations to be developed.

> And there are just a lot of different species to grow and a lot of different uses – a ton of different uses – so it's not like selling something that goes from the farm to the plate: this could go from the farm to the cosmetic's industry, the fertilizer industry, the prepared food industry, the frozen food industry – even the fresh food industry. (Agency Staff)

Seaweed aquaculture in Maine still comprises only a small portion of farms in the state but the potential for this industry is perceived to be enormous. Maine's environmental conditions are highly conducive to growing a variety of macroalgae species which provide valuable ecosystem services and could be used for a wide range of value-added products. Research into value-added products is an avenue that could lead to buy-in by more farmers and advances in food science and technology in Maine are making this possible.

The growing interest in integrated multi-trophic aquaculture (IMTA) and land-based recirculating aquaculture systems (RAS) was also mentioned by many interview participants. Although it was widely acknowledged that the technology and capacity to implement IMTA is not currently accessible to most farms, the interest and research capacity in the state are believed to be sufficient to realize this type of farming. Interview participants who discussed this potential opportunity felt that this production method could help companies diversify in the face of changing climate conditions and reach new markets for greater economic gains. Land-based recirculating tanks were discussed by some research participants as a mechanism for reducing environmental impact and community conflict of finfish farms. Currently, two companies are investing in development of these systems by converting old paper mills into salmon farming operations. This was discussed as an innovative way to repurpose infrastructure and revitalize communities in need of economic opportunities.

2.7.4. Socio-cultural Challenges and Opportunities

The primary socio-cultural challenges identified by participants include: 1. public perception and education; 2. user conflicts; 3. disappearance of the working waterfront; and, 4. consolidation of the industry by large foreign companies. While two thirds of participants identified socio-cultural challenges, three quarters of those identified public perception, often stemming from lack of education around aquaculture, as the primary challenge.

> Does the good outweigh the bad? To me, in most cases, it does when it comes to farmed fish, but again, public perception is that you'll eat cattle that are farmed—you'll eat pigs that are factory farmed, but people won't eat fish. And I just—I don't get it. (Agency Staff)

Participants discussed the general lack of education about aquaculture as a major contributing factor to negative perceptions. Consumers, regulators, as well as residents in communities with aquaculture were identified as lacking the necessary knowledge to understand the positive contribution of aquaculture to the economy and communities.

Aquaculture operations in Maine are, for the most part, owned by local community members wanting to make a year-round living on the waterfront. Communities along the coast of Maine are steadily increasing in the number of seasonal property owners, many of whom own shorefront properties. Respondents attributed negative perceptions of aquaculture to seasonal residents who did not want aquaculture to be a part of their viewshed. Interviews indicate a disconnect between seasonal landowners and the history of Maine's working waterfront.

> As people come into an area who don't have those traditions and have forgotten those traditions… they are looking for a suburban existence but it's green lawns and fertilizer and everything that they brought from New Jersey, for God's sakes, they're trying to bring here. And they don't like it when people are trying to make a living. (Agency Staff)

The divide in communities between those year-round residents who acknowledge the importance of fisheries and aquaculture to local economies and residents who are perceived as wealthier and lack awareness of local community needs emphasizes an issue that continues to grow as the number of seasonal properties continue to increase.

The most frequently discussed socio-cultural opportunity was the growth and maintenance of the working waterfront in Maine including the transition of fishermen to farmers who are believed to already possess many of the skills necessary for aquaculture operations.

> You know guys are out on the water anyway hauling traps or whatever they may be doing, scallop diving or whatever, so for them it's just kind of a natural transition in the way they do their day-to-day work and it's a fairly cheap thing to get into. The gear can be sometimes made in your backyard using readily available material. (Agency Staff)

Maine is fortunate to have coastal infrastructure already in place from past or current fisheries that allows aquaculture farmers easier access to their farm sites. Furthermore, fishermen interested in diversifying their revenue streams often have much of the needed materials as well as the savvy necessary for working on the water. Providing educational training programs to those interested in adoption of aquaculture is currently underway as well as curriculum in schools that also was identified as an important aspect of social sustainability for aquaculture growth in Maine.

The local food movement that also has gained traction in the state has made communities more aware of sourcing their food locally. While farmers markets occur across the state, interview participants felt the popularity of the small, local farmer has not yet transferred to aquaculture. Participants felt this attitudinal shift can be capitalized through awareness of aquaculture products available to consumers. Such awareness has already begun in the form of festivals and aquaculture farm tours that not only encourage a locavore mindset, but interview participants also believe it can reduce community conflict around aquaculture development.

> All these different festivals are opportunities for engaging with the communities. And they're not measurable, but they increase the visibility all the time. And that can't necessarily be a bad thing. (Agency Staff)

Many efforts have been made to engage coastal communities and the broader public in aquaculture education, as well as social events that build a stronger sense of community. Research participants felt that opportunities for events and outreach that provide visibility to the industry in a positive way will increase social acceptance and social sustainability of the growing industry in Maine.

2.7.5. Economic Challenges and Opportunities

Finally, approximately half of interview participants identified several economic challenges that pose major obstacles to the growth of the aquaculture industry including: 1. access to capital; 2. the high costs of entry; 3. lack of marketing; 4. lack of government investment; and, 5. market competition. Of these, nearly 90 percent of participants identified access to capital that included access to bank loans and outside investment into the industry as the most pressing economic challenge facing Maine's industry. Most aquaculture farms in Maine are small and operated by local farmers who often do not have access to large amounts of capital. The amount of funds necessary to begin an operation and purchase necessary supplies, like seed, gear, and processing equipment, can be prohibitive to farmers. Unfortunately, most farmers are unable to secure bank loans, and investment firms are uninterested in small companies that will not generate revenue for the first few years of the business.

> So, we have within Maine a whole ream of small-to-medium-sized businesses in this industry. There's only one or two really big players. Investors are interested, traditionally, in big investments with big and quick return. (Agency Staff)

The small size of the majority of aquaculture farms in Maine is viewed as a less attractive business proposition to the banks providing loans; however, most of these small farms are not interested in scaling up their operations to such a degree.

The leasing process also plays into the investment of farms. Obtaining a lease can take up to two years, and farmers will not make any profits within the first year of operations, as explained in the quote by the following interviewee.

> So, investors don't want to invest in something that it's gonna take 18 months just to learn whether they have zero or whether they can move forward and then at least another 18 months before they start to see a dime of revenue. Tracking investment to something like that is incredibly difficult. (Farmer)

Investment firms are unlikely to wait three years before receiving a return on their investment. The other major limitation for farmers is the high start-up costs associated with a farm. Without the willingness of companies to invest in small aquaculture farms, individual farmers must have the economic stability to survive multiple years before turning a profit. These economic challenges must be overcome for the aquaculture industry to continue to grow in Maine.

Fortunately, many economic opportunities exist for the industry as well. Currently, the market for Maine's aquaculture products is strong, and due to the local food movement, consumers in the northeast United States want to buy locally sourced seafood products from Maine. Within this context, interview participants discussed the opportunity to develop marketing based around the "Maine brand."

> I think the seafood coming off the farms has helped the brand for the coast of Maine. I mean, people come to Damariscotta 'cause of the oysters. And the aquaculture oysters and mussels and now kelp – is a draw to the coast of Maine… And the whole local food movement has played into it, where a lotta growers are doing farm to table operations. (Farmer)

The clean, cold waters of Maine are not only ideal for aquaculture, but that is the exact environment from which consumers want to source their seafood. By developing marketing schemes that can represent the whole of Maine's aquaculture industry, participants felt that Maine's seafood products "speak for themselves" and can create new markets from this credibility and consistency.

Additional economic opportunities identified included: 1. the creation of working waterfront jobs; 2. the development of cooperatives; and, 3. value-added/product innovations. As changes in the environment and capture fisheries have occurred, fewer opportunities exist for jobs working on the water. The developing aquaculture industry is credited with providing many new job opportunities to coastal communities that may be lacking these year-round positions. Some participants identified the creation of aquaculture cooperatives that pool resources and share knowledge to further their operations. This is an innovative strategy to share costs for supplies, such as processing equipment, and makes entry into the industry more affordable. Farmers are also finding new uses for their products including makeup, fertilizer, and biofuel as well as many value-added food products. Research participants felt that this market has, thus far, been incredibly underutilized and has the potential for huge growth. These products are thought to maximize the return on their efforts and investment as well as benefit rural farmers who have difficulty getting fresh product to market. With such business and marketing innovations, participants feel the aquaculture industry has enormous potential to increase profits to farmers as well as benefiting other stakeholders in other sectors, such as restaurants and tourism.

Table 2.1. Challenges in Maine's Aquaculture Industry

Theme	Sub-themes
Regulatory	Environmental regulations, food safety, lack of marine spatial planning, leasing process
Environmental	Climate change, disease, ocean acidification, predation, siting, storm damage, water quality
Technologic	Infrastructure, RAS technology, access to technology, innovation, tech transfer
Socio-cultural	Consolidation, public perception & education, user conflicts, working waterfront disappearance
Economic	Access to capital, competition, entry costs, marketing, profit margins

Table 2.1. Major and minor themes identified by research participants regarding the challenges facing Maine's aquaculture industry.

Table 2.2. Opportunities in Maine's Aquaculture Industry

Theme	Sub-themes
Regulatory	LPAs for site testing, LPAs for individual food production, LPAs for reducing entry time, growing MDMR aquaculture dept.
Environmental	Location, water quality, ideal water temps and salinity, ample phytoplankton, Ecosystem services from AQ
Technologic	R&D for: species innovation, land-based recirculating tanks, processing, IMTA, feed innovations
Socio-cultural	Growth and maintenance of the working waterfront, education and outreach, tourism,
Economic	Develop "Maine brand," strong demand, job creation, AQ cooperatives, value-added/product innovations

Table 2.1. Major and minor themes identified by research participants regarding the opportunities facing Maine's aquaculture industry.

2.8. Discussion

While many similarities exist with other parts of the world experiencing aquaculture growth, challenges and opportunities are specific to the social and ecological context in which they are situated. This is to say that ecological and biophysical factors such as currents, water quality, salinity, pH, food availability, etc. as well as the culture, traditions, job availability, gentrification, governance system etc.

that affect the ability to farm in coastal waters is unique to a particular place. Therefore, understanding these factors for Maine's aquaculture industry can illuminate the way forward to grow the sector in an ecologically and socially sustainable manner. At the same time, the case of aquaculture development in Maine may help provide insight to other states and countries regarding their own challenges and opportunities. Participants overwhelmingly feel that Maine's location and unique climate have situated the aquaculture industry for enormous growth potential. Maine is fortunate to have clean waters with an abundant food source making it an ideal candidate for aquaculture development. The ecological carrying capacity, or amount of aquaculture production that can be supported based on the resources available without causing "unacceptable ecological impacts" (Inglis et al., 2000), for aquaculture in Maine will likely not be a limitation for growth of the industry.

Maine's future in a changing climate remains a point of concern. The Gulf of Maine is rapidly warming and altering those exact conditions that enable such incredible growth of farmed species (Pershing et al., 2015; Bricknell et al., 2020). Climate change has been identified globally as a major threat to the aquaculture industry. Adverse impacts to the Gulf of Maine include warming water temperatures, sea-level rise, ocean acidification, and increased incidence of disease (Gubbins et al., 2013; Bricknell et al., 2020). These factors likely will affect the survival of cultured organisms in the Gulf of Maine, potentially threatening the future of the aquaculture industry (Bricknell et al., 2020). Environmental forecasting and technological innovations, such as the current techniques in Maine used to buffer seawater in shellfish hatcheries, can mitigate adverse impacts of climate change. Each individual body of water may be affected differently; thus, research must be performed at the local level to understand how aquaculture impacts the ecosystem, and vice-versa.

The social-environmental conditions in Maine also are changing, and the state likely will reach social carrying capacity well before it reaches ecological carrying capacity (Johnson and Hanes 2018). The relatively rapid growth of the industry has become more visible to coastal communities that are

experiencing increased development of the marine coastal zone. As a result, user conflicts, negative public perceptions, and lack of education around aquaculture prove to be challenges for the industry to overcome in Maine as has occurred elsewhere in the world (Young et al., 2019; Hoerterer et al., 2020). Within the United States specifically, the public's general understanding and education surrounding issues pertaining to aquaculture is limited (Murray et al., 2017). Johnson & Hanes (2018) and Thompson et al. (2016) consider the role of increasing levels of gentrification and amenity migration on Maine's coastal communities and traditional uses. Johnson & Hanes (2018) found that while amenity migration has led to increased conflicts around aquaculture development in some areas, other factors such as scale and type pf aquaculture as well as levels of trust in the community need to be considered. This finding supports the perceived increase in seasonal residents and shorefront property owners in this study whom participants identify as often opposing development due to negative perceptions and user conflicts. In Maine, efforts to increase education and public awareness of aquaculture are underway through school curriculum, festivals, and other public outreach endeavors (Interview Data). As mentioned by Stabiner (2014) and Knapp & Rubino (2016) the small farm and local food movements can also be capitalized on to demonstrate the positive contributions of the aquaculture community.

Public discontent with aquaculture development frequently comes into play during the regulatory process (Hanes et al., 2018). The creation of Limited Purpose Aquaculture licenses was intended to allow new entrants the ability to try aquaculture on a very small scale or allow a farmer to test a potential site without going through the cumbersome leasing process. Some individuals, however, have managed to take advantage of LPAs by obtaining the maximum of four LPAs for several family members and stringing them together in one location, thus creating a standard size lease without the due process. Such actions have caused a continued evolution in the LPA process that garners feedback from industry members and other stakeholders to further inform the amendments to policies regarding development. Despite the conflicts that have arisen since the creation of the LPA, interview participants

agreed that this was one of the most impactful ways to reduce the lease application approval time. The Department of Marine Resources has limited capacity to review applications, hold hearings, and visit potential farm sites especially given the rate of growth the aquaculture industry is experiencing in Maine. This rapid growth can be seen in the number of LPAs active in the state, which has risen from 191 in 2014 to 676 in 2019 (MDMR, 2019). This unique leasing structure has significantly reduced the barrier of entry to new aquaculture farmers. While this particular leasing system is unique to Maine, LPAs could be used as a model in other areas of the world looking to grow aquaculture with small, local farms. The concept of the LPA is one with great potential while other states and countries can benefit from Maine's mistakes with this process.

The lack of capacity at the state level has resulted in reactive policy decisions rather than a proactive approach to aquaculture development. As a result, aquaculture development continues to evolve in a patchwork of farms along the coast with varying degrees of community acceptance. While criteria exist from which stakeholders may voice objections to an aquaculture lease in the hearing setting, these criteria do not allow for objections based on subjective criteria such as viewshed. Because an individual could not obtain a lease for something such as conservation to hold a space from being developed, aquaculture farmers and the state are essentially deciding how the marine coastal zone develops in Maine's coastal communities. One potentially useful tool for Maine's coastal communities is marine spatial planning which has been shown to be effective in many circumstances involving conflicting uses of coastal waters (Douvere & Ehler, 2009; Lester et al., 2018). By participating in such an activity, communities would be able to decide for themselves what they want the marine coastal zone to look like in their municipality. This process could create spaces for multiple uses such as aquaculture, fishing, recreation, tourism, etc. that meets the community's needs while still allowing businesses such as aquaculture farms to succeed. As the demographics of coastal communities shift and the coast becomes more densely populated, user conflicts will only increase. Because of the state's lack of

capacity, its reactive policies could cause conflicts to intensify without some sort of future planning mechanism for communities.

Research and development efforts to create aquaculture infrastructure, improve technological efficiency, and understand impacts of climate change are vital contributions to the industry in Maine and elsewhere. Rural areas, in particular, often lack the infrastructure and technology necessary for large scale operations (Shava & Gunhidzirai, 2017). As a rural state with approximately 5,600 kilometers of coastline, access to infrastructure such as processing equipment and transportation services stymies the growth of the industry in many areas. The high cost of entry is also a challenge that can be felt world-wide (Shava & Gunhidzirai, 2017). In Maine, the dominant cultured species is the American oyster. While the gear required is less expensive than for finfish, farmers must be able to afford the start-up and operation costs until a profit can be generated from their farm, which often takes as many as two years after lease approval. Furthermore, farmers are unable to obtain loans from banks because of the uncertainty of success. Contrary to countries such as Canada, where the government subsidizes aquaculture production, farmers in Maine do not have financial support from the government. Farmers in Maine must compete directly with Canadian aquaculture products such as mussels in the market which can be sold for lesser value due to their subsidies. These economic challenges leave Maine farmers at a disadvantage that must be overcome to successfully grow the industry and help to maintain the small, local farm reputation that has been established.

Although Maine is a rural state, much of the coast has an existing working waterfront with skilled workers and fishing infrastructure that could be advantageous to the aquaculture sector. The lobster fishery is an essential component of coastal communities but, in the face of climate change, fisher diversification is an important strategy for resilience of coastal communities and aquaculture has been proposed as a likely alternative (Cleaver et al., 2018). Aquaculture cannot only offer an alternative source of income but can piggyback off existing fisheries infrastructure in most coastal communities. As

Bricknell et al. (2020) postulate, “The social resiliency of aquaculture is dependent upon the industry’s (adaptive) capacity to leverage networks, institutions and discourses to cope with existing changes and adapt to new ones” (p. 2). Maine is fortunate to have existing infrastructure, a skilled workforce, and research and development capacity to allow the aquaculture industry flexibility and stability in the face of shifting ecological and social dynamics. Without this support system, development of aquaculture in a socially and ecologically sustainable manner would be exceedingly difficult.

2.9. Conclusion

The results of this exploratory study have a variety of implications for aquaculture development both in Maine and elsewhere. As a state with a rapidly expanding aquaculture industry, it is unsurprising that the sector is experiencing growing pains. While a variety of challenges and barriers exist to overcome for the aquaculture industry in Maine, many hurdles have also been identified by research participants as areas of opportunity to further grow and advance the industry. Research and development was widely identified as an advantage in the state with a variety of university and research organizations that have established aquaculture portfolios. Therefore, the challenges and opportunities identified by research participants represent areas of inquiry for further investigation by relevant institutions. Areas of growth such as value-added products and marketing schemes, education, and ecological assessments represent areas of collaboration for industry, academia, and other organizations to further guide socially and ecologically sustainable aquaculture. This research has been conducted with the aim of identifying barriers to the development of a sustainable aquaculture industry in Maine. The unique social-ecological context of a place yields unique place-based solutions to a sustainable industry and thus, local level studies can contribute a more nuanced understanding of factors affecting aquaculture growth globally. Continued research should target the five primary topics identified here by research participants: regulatory, socio-cultural, economic, ecological, and technology challenges and

opportunities to both break down barriers to development and ensure that aquaculture continues to grow in a way that acknowledges the ecological and social limitations.

CHAPTER 3

SOCIAL AND ECOLOGICAL FACTORS INFLUENCING SUSTAINABILITY OF INTERTIDAL SOFT-SHELL CLAM AQUACULTURE IN MAINE

3.1. Introduction

The soft-shell clam (*Mya arenaria*) fishery in Maine has existed for over 200 years (Hanna, 1998) and is the third largest fishery in the state by value, contributing more than $18 million USD in 2019. Clam landings have declined significantly, from a maximum harvest in the late 1970s of approximately 40 million pounds to present day landings of approximately 10 million pounds (MDMR, 2018) (Figure 1). Several ecological studies have examined the decline in clam landings with much of the loss attributed to the impacts of climate change, especially predation (Beal & Kraus, 2002; Beal, 2006; Beal, 2006; Congleton et al., 2006; McClenechan et al., 2015; Beal et al., 2016, Beal et al., 2018). Threats to the fishery are expected to increase as seawater temperatures in the Gulf of Maine continue to rise (Beal et al., 2016; Bricknell et al., 2020). The significant decline in landings and climate change trends have left many speculating about the vulnerability of the fishery and the coastal communities who depend upon the vital source of income (McClenechan et al., 2015; Beal et al., 2016).

Predation by the green grab (*Carcinus maenus*) has been shown to cause detrimental impacts to soft-shell clams in Maine and is flourishing as water temperatures increase (Beal, 2006). Decreases in ocean pH also pose challenges for the growth of soft-shell clams, especially juveniles, due to the amount of calcium carbonate necessary to build their shells. As with other shellfish, the life cycle of the soft-shell clam is highly dependent upon the environment, including water temperature, pH, and food availability. In Maine, soft-shell clams typically spawn once each year and grow between the months of April and November, which is temperature dependent (Beal et al., 2001). Juvenile clams are highly susceptible to predators and experience the highest mortality at this time in their life stage (Beal & Kraus, 2002).

Not only have studies shown that recruitment has declined in parts of the state (Congleton et al., 2006), but post-settlement mortality is especially high (Beal et al., 2018). Additionally, increased run-off from coastal development and other sources of pollution result in recurring harmful algal blooms (Evans et al., 2016; Mizuta & Wikfors, 2020). These blooms result in closures that lead to significant economic losses, impacting clam harvesters and their families as well as restaurants, seafood buyers, and processors (Evans et al., 2016; Anderson & Plummer, 2017).

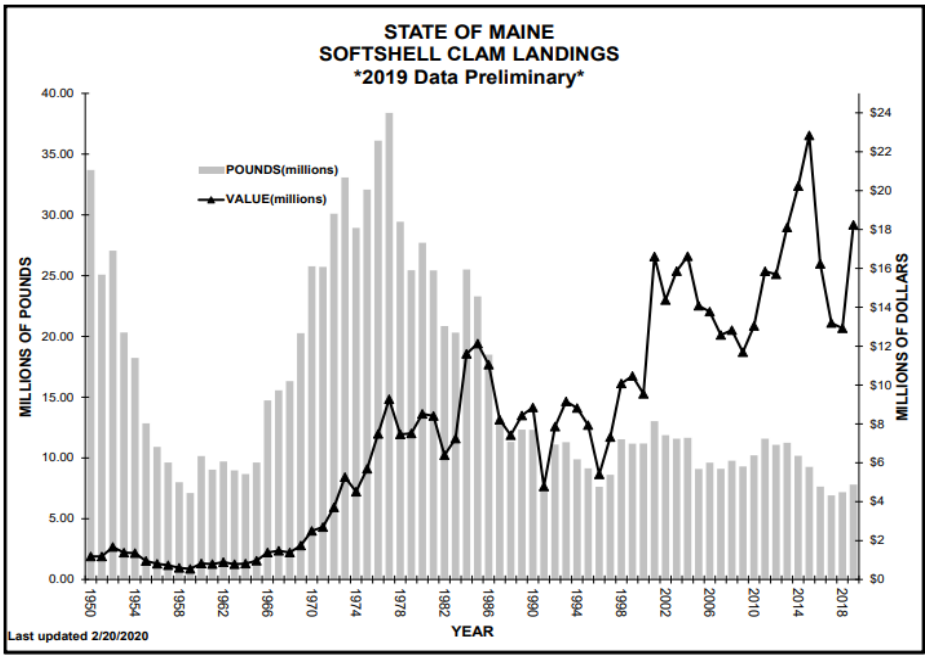

Figure 3.1. Maine soft-shell clam landings from 1950 to 2019 (MDMR, 2020).

Management of the soft-shell clam fishery has been a collaborative process known as co-management that gives resource users at the community level affected by management decisions rights and responsibilities in the decision-making and enforcement process (Jentoft et al., 1998; Berkes, 2009). Co-management has been touted as an inclusive solution to common-pool resource management that can generate the buy-in of diverse stakeholders that will lead to sustainable use of a resource, minimizing exploitation and maximizing cooperation (Jentoft, 2000; Berkes, 2009). Taking into account

local level ecological knowledge and system dynamics can make regulations more suitable for the scale of the ecological system and can allow decision-makers to react swiftly and more precisely to localized changes in social and environmental conditions (Agrawal, 2003; Berkes, 2009; Cinner & Huchery, 2014). Unfortunately, despite such a co-management system in place in Maine, soft-shell clam populations continue to decline which increases vulnerability of the coastal communities who depend on this resource.

Aquaculture has the potential to diversify and sustain a declining wild fishery by augmenting current wild populations as well as protecting clams from predation. Aquaculture would allow for a harvester to control access and fishing/management activities for some portion of mudflats. Possessing exclusive rights to an area of mudflats provides an individual harvester with more incentive to protect that area from threats of pollution, predation, etc. By assigning property rights to individuals, a stronger incentive for stewardship as well as production of that area tend to emerge (Anderson, 2002). However, this emerging strategy for intertidal species raises new questions regarding ownership, management authority, and access to the resource, as well as the role of communities in moving this sector forward (Underwood, 1996; Galappaththi & Berkes, 2014).

In Maine, intertidal clam aquaculture would intersect with an existing fisheries co-management structure. Currently in Maine, towns have the option to obtain shellfish ordinances from the Maine Department of Marine Resources (MDMR), which allows for a degree of local level control of shellfish. The state maintains control of size limitations and intertidal closures due to public-health concerns while the municipality can control access to the resource itself and assumes conservation and management responsibilities (Hanna, 1998). By controlling access laws to the resources, municipal and state institutions become “cornerstones of resilience” (Gelcich et al., 2006, 953). Municipalities generally control access through resident and non-resident licenses that often require conservation hours to maintain license status (Hanna, 1998). The state of Maine authorizes towns to lease up to 25 percent of

the intertidal for private aquaculture ventures (Hanna, 1998). Despite this law, intertidal clam aquaculture remains an unrealized concept in Maine aside from research and town conservation efforts. There are no commercial soft-shell clam farms but there are experimental farms as well as restoration and supplementation efforts. Little scholarly work has been done to explore the development of intertidal clam aquaculture in Maine and the interactions with both the wild fishery and the coupled human and natural system in which it is embedded.

The purpose of this qualitative study was to understand the social-ecological variables important to the development of intertidal clam aquaculture. Intertidal clam aquaculture has the potential to address some of the devastating impacts of climate change on the wild clam fishery by using predator exclusion techniques and providing additional spawning stock to the environment. This opportunity would also help coastal communities dependent upon the soft-shell clam resource as vital income. While some towns are using conservation efforts that mimic aquaculture, they do not consider it to be the same and there are no traditional aquaculture efforts underway. Although ecological factors for intertidal clam aquaculture have been well studied, little attention has been paid to the social factors influencing development of this new type of aquaculture in Maine. Research efforts investigating the motivations and attitudes that municipal shellfish committees have towards conservation efforts and developing intertidal aquaculture are, therefore, an important step towards addressing the decline in clam landings and increasing the resilience of coastal communities in the face of climate change.

3.2. Background

Intertidal clam aquaculture in Maine would occur in the context of the co-management system that has been in place since the early 1960's (McClenechan et al., 2015). The state maintains control of size limitations and intertidal closures due to public-health concerns while the municipality can control access to the resource itself and assumes conservation and management responsibilities (Hanna, 1998). Municipalities generally control access through resident and non-resident licenses and many offer

conservation activities to reduce license cost. A total of 72 towns participate via 58 municipal shellfish ordinances, as some towns choose to cooperatively manage their resource with other municipalities. Towns vary greatly in terms of number of commercial clam harvesters and acres of mudflats available for clamming. In this study, the number of harvesters per municipality ranged from four to 135 with mudflat acreage ranging from 18 to over 4,000 acres. Although some of these towns have abundant acreage, the amount of suitable clam habitat as well as the amount of habitat that can be accessed by harvesters is highly diverse. Another factor that adds to the complexity of developing intertidal aquaculture is an ordinance developed in 1641, where riparian landowners, unless stated otherwise in a property deed, maintain ownership down to the mean low water mark or 100 rods (Hanna, 1998). While the public can access this area for fishing, fowling and navigation, aquaculture is not included in the definition of fishing. This means that individuals wanting to farm in the intertidal would first need to receive permission from a landowner to lease an area of the intertidal, followed by permission from the municipal shellfish committee.

Intertidal clam aquaculture would occur in the intertidal zone which is the area covered by water at mean high tide and exposed during mean low tide. The intertidal zone can also be ideal for farming due to the ease of access to farm sites. Based upon experimental efforts there is an established farming protocol to help ensure a successful venture (Beal & Kraus, 2002). Clam seed should be planted in late spring to maximize shell accretion in the first growing season which will make the juvenile clams less vulnerable to predators (Beal & Kraus, 2002). The farm site requires nets with apertures less than the size of the spat, typically 4.2 or 6.4 mm (Beal & Kraus, 2002). Any visible predators should be removed at this time, otherwise enclosure can have a concentrated detrimental effect (Beal, 2006). Nets must be secured in the sediment on all sides and buried into the sediment to ensure they stay in place during tidal fluxes. Floats must be attached to the underside of the nets to ensure that they lift during tidal inundation and allow the clams to feed. Experiments have used 9 styrofoam floats attached to the

underside with success (Beal & Kraus, 2002). If nets do not lift they can create anoxic conditions underneath them, potentially killing the clams (Beal et al., 2016). As predation slows in late fall, with cooling water temperatures, the nets should be removed to prevent lost or destruction of nets during winter storm events (Beal & Kraus, 2002). Nets can be placed into the sediment again in early spring and should be tended to every few weeks to remove any biofouling (Beal & Kraus, 2002). Clams may be harvested depending on location and environmental conditions in as soon as 3 years (Beal et al., 2006). As with other bivalves, farming of soft-shell clams can have many ecological benefits to an area. Biofiltration removes considerable amount of nutrients from the water column. Clam farms also have the potential to protect wild recruits from predation. Experimental techniques have shown the potential success of commercially farming soft-shell clams as well as the beneficial impacts these farms can have on wild populations and overall environmental conditions (Beal & Kraus, 2002).

3.3. Methods

To identify perceptions of social and ecological factors influencing the clam fishery and intertidal clam aquaculture, this project draws on the qualitative research methods of semi-structured interviews and document analysis. A total of 23 semi-structured interviews were conducted in two rounds. Four semi-structured interviews with key informants from the clam fishery, research institutions, and non-governmental organizations were conducted in summer 2017 to learn about the history of intertidal aquaculture efforts in Maine, how aquaculture would interact with the wild fishery, and the perceived opportunities and challenges in the development process. The information provided from these interviews informed the development of a semi-structured interview guide that targeted municipal shellfish committee members and other key stakeholders in the clam fishery for 19 additional interviews. Those interviews were conducted from February to December of 2019.

Document analysis also was used to examine the annual reviews of the municipal shellfish committees in the state from 2015 to 2017 which were provided by the MDMR. Over the three years,

the number of municipal shellfish ordinances ranged from 57 to 62, including three regional shellfish committees composed of several towns. Thus, three reports were analyzed per each shellfish ordinance totaling approximately 180 documents. The annual reviews consist of an array of committee efforts for the year, including goals for shellfish management, conservation credit hours, warden activity, conservation closures, and budget. For this study, the researcher focused on the conservation activities of the committees, which include predator protection, reseeding, clam density surveys, brushing, and establishing conservation areas for flat rotation. Two of these activities are the same practices and procedures used for intertidal clam aquaculture: predator exclusion and reseeding, which entails adding clam seed from a hatchery or the wild to enhance the clam populations. Additional areas of interest include the license activity and limitations on licenses in each town, which help determine the number of people in these coastal communities that depend on the clam resource. This review allowed the researcher to observe which towns were and were not using aquaculture-related conservation activities, which informed the sampling frame.

Document analysis of the annual reviews was summarized in Microsoft excel. The data was initially analyzed using the number of harvester licenses per municipality and each conservation activity in which a municipality participated from 2015 to 2017. Data was then refined to focus on the conservation activities of predator-exclusion and reseeding, and the number of harvester licenses each year as well as the acreage of mudflats per shellfish ordinance. Towns were separated into five categories: those who utilized predator exclusion structures for conservation but not reseeding, those that used reseeding but not predator exclusion, those that used both methods (i.e. aquaculture practices), those that used neither method, and those that used both at some point over the three years. Municipalities were contacted from each of these groups with variation in numbers of harvesters and acreage of mudflats as well. This helped to ensure that interviews represented a diversity of views on conservation and intertidal aquaculture more generally.

For the semi-structured interviews, questions for municipal shellfish committee members focused on understanding the importance of the clam fishery to the community, the threats to the fishery, reasons for undertaking particular conservation activities, perceptions of aquaculture and intertidal clam aquaculture, and challenges and opportunities for developing intertidal aquaculture. Communities targeted for interviews were based on purposive sampling methods, as mentioned above, to get a broad representation of opinions. Towns were targeted across Maine's coast using the number of licenses, the number of acres of mudflats, as well as the type of conservation efforts practiced as they pertain to aquaculture (i.e. reseeding and predator exclusion). Interviews were conducted until theoretical saturation was achieved, for a total of 19 interviews.

During interviews the researcher took notes as well as audio-recorded each interview if permission was granted. Interviews were transcribed verbatim using the transcription services TranscribeME! and Verbal Ink. Transcripts were analyzed for common themes and insights using NVivo 11 Pro software. A code book was initially developed to facilitate the coding process, reflecting the major fields of inquiry from the interview protocol. During First Cycle coding, the researcher adopted a provisional coding approach, which allowed the researcher to select interview material that followed within major themes identified by the interview protocol (Miles et al., 2014). Provisional coding is a type of exploratory coding technique in which the researcher assigns preliminary codes to the data based on "preparatory investigation" (Saldaña, 2015). The researcher then used an inductive strategy to add additional codes to the codebook based on the interview participants' responses. During Second Cycle coding, which is done to further refine initially discovered themes, the researcher used focused coding. This method of Second Cycle coding aims to identify the most frequent and significant codes based on "thematic similarity" (Saldaña, 2015).

3.4. Results

3.4.1 Current Status of Clam Populations

While clam populations were frequently discussed as a cycle of highs and lows, approximately two-thirds of interview participants discussed an overall decline in clam populations that ranged across the state. Although the state's landings data indicates a drastic decline in clam landings in the last few decades, there are also fewer harvesters which also contributes to declines in landings. Nonetheless, participants from municipalities coast-wide indicated that they have observed a negative change in the resource. Participants from the easternmost part of the state felt that clam populations were less in decline in part due to the comparatively mild impacts of environmental change, especially predation of green crabs. A small number of participants perceived an increase in clam populations, which they largely attributed to conservation efforts.

3.4.2. Threats to Clam Populations

3.4.2.1 Predation

Interview participants unanimously agreed that predation is the most pressing challenge for the clam fishery. Municipalities located further east on Maine's coastline feel that their predation issues are less devastating than in towns further west and attributed this to the colder winters and water temperatures. While the majority of municipalities identified green crabs as the most pressing issue, select towns in various coastal regions identified milky ribbon worms (*Cerebratulus lacteus*) and moon snails (*Euspira heros*) as the larger concern. Nonetheless, green crabs are the dominant predation threat and can drastically alter the clam populations in a municipality.

> That's become problematic now because with green crabs, we basically don't have any beaches that are immune to green crabs. So we're getting hammered. We don't have a lot of resource… So we're talking 98 percent – 99 percent mortality to whatever, and we think it's crabs. We get

some milky ribbon worms, nothing like they get in the southern part of the state. (Shellfish Committee Member)

Towns feel that predation is the primary reason that towns are seeing a decline in clam populations especially juvenile clams because they are not as deep in the mud. For this reason, many harvesters are not seeing very much recruitment when they are on the mudflats. While practices such as predator exclusion netting may be effective for green crabs, they are not effective at keeping out these infaunal predators (Beal et al., 2016).

3.4.2.2. Environmental Change

The second most commonly identified threat to soft-shell clams and the fishery is environmental change. Participants discussed threats including water quality from point and non-point source pollution, ocean acidification, warming water temperature, and anoxic sediment or "dead mud." Many interview participants discussed the threats of climate change as secondary to predation but they often did not identify specific environmental threats.

> The environmental stuff, who knows. We've got so much stuff being thrown at us… I feel like we don't have a lot of control over it. The acidity thing I worry about because I feel like the water quality is not great. You know, even something we weren't thinking about years ago but it's in the news now and the more I think about it the more I think, yeah, it could be bad. (Harvester)

While participants were aware of the changing environment, they felt that this was an unknown entity out of their control. As juvenile soft-shell clams are already extremely susceptible to predation, adverse environmental conditions could further reduce survival rates of juveniles and adversely impact the fishery; however, some participants feel these threats are more difficult to address and thus, remain a looming problem as far as many harvesters are concerned.

3.4.2.3. Aging of the Industry

Another challenge for both the future of the clam fishery and intertidal aquaculture, identified by approximately half of participants, is the view that clam harvesters are an aging population across the state of Maine, what has been referred to as “graying of the fleet” in other fisheries (Johnson & Mazur, 2018). As older fishermen retire there will be fewer people harvesting or potentially farming, adding an additional threat to future of the wild fishery and intertidal aquaculture.

> There isn't a lot of fisheries in Maine in particular, and clams are not a closed fishery but yet, the population or the pattern of the harvesters is they're aging and there's not really a lot of young people coming in to replace them, and so just as a fishery it's kind of – it's almost archaic and there's not a lot of young blood in it. (Shellfish Committee Member)

This phenomenon of fishermen aging without new, younger entrants to the fishery also has been identified as problematic in other Maine fisheries such as the lobster industry (Henry & Johnson, 2015; Johnson et al., 2015; Johnson & Mazur, 2018). There are very few young entrants into the fishery while many harvesters are approaching retirement age. Harvesters, in particular, feel that the declines in clam populations and the outmigration of young people from rural coastal communities are contributing to this loss of young harvesters in the fishery. Without younger entrants, some participants even speculate that the future clam populations and even intertidal aquaculture may be irrelevant because there will be no one left harvesting.

3.4.3. Property Rights/Access

Three-quarters of participants identified the current property rights structure as an impediment to both development of intertidal aquaculture and the wild clam fishery. Approximately half of participants identified, specifically, the loss of access to the intertidal as a primary challenge for intertidal aquaculture development as well as the future of the wild fishery. The intertidal is often accessed by land across both public and privately owned properties. Participants perceived that local

residents have moved away from the coast due to increases in property taxes while summer residents and retirees from “away” have moved into these coastal homes. Interview participants discussed the lack of understanding many coastal property owners have regarding the cultural and economic importance of the clam fishery.

> The landowners. That would be – you know, getting them on board with something if you were trying to do it. Absolutely would be a problem. They seem to be able to hire lawyers and just spend a lot of money. (Harvester)

Participants view the shift in community structure as the cause of losing access points once used to easily come and go from desirable clam flats. As coastal property increases in value, interview participants only expect this trend to increase. Many harvesters have boats that they launch from public landings, but others who cannot afford to do so are at higher risk of losing income.

3.4.4. Privatization

Privatization of the intertidal zone for individual use was unanimously identified as an issue that would hamper the development of intertidal aquaculture. The intertidal has historically been used as a common property resource in which any harvester with a license can access the mudflats. Harvesters are uncomfortable with the notion that an individual would have sole access and harvesting rights to an area of mudflats.

> Say I get a lease in town. But I still have a town license. Well, guys can't dig where I lease but I can go dig where they dig. That's not right. (Harvester)

Harvesters view ownership of the intertidal for aquaculture leases as unjust because it prevents access of a particular area of mudflats to other harvesters while the farmer would be able to cultivate the lease area as well as harvest anywhere else within the municipality. While leases could potentially be granted for areas of mudflats that are sub productive, many interview participants objected to that notion on the basis that those areas could become productive in the coming years and wild harvesters would want

the option to dig there as well. Although the Maine Legislature approved up to 25 percent of a town's mudflats for aquaculture dating back to 1917, the perception of the intertidal as a common property resource has been so thoroughly ingrained in the culture of the clam fishery over hundreds of years that the idea of privatization for individual gain is seen as unacceptable.

3.4.5. Community Conservation

In many municipalities with a shellfish ordinance, harvesters participate in conservation activities to reduce the cost of license fees. Using the annual reviews of municipalities from 2015 to 2017 the researcher examined reseeding and predator exclusion, as these activities mimic those of intertidal aquaculture. Thirty-four towns participated in reseeding, 26 participated in predator exclusion, and 18 participated in both at once over the course of the three years. However, other popular activities included beach cleanups, brushing or roughing the mudflats to increase settlement of spat, and rolling conservation closures to allow clam populations to rebound over a designated period of time. Reseeding and predator exclusion efforts in combination equate to the current soft-shell clam aquaculture practices. The difference is that these conservation efforts are being done by the municipal shellfish committee as one entity for conservation as opposed to an individual performing these activities on a farm.

> This might be something we should do as a group, like take a cove and say, 'Okay, this area's going to be strictly for seeding, wild and store-bought seed, and leave it alone, and then three years from now we'll see what happens.' That would be interesting. Maybe we'll try that. (Harvester)

As a town, these efforts are done in a conservation closure and once the closure is lifted, all municipal license holders are able to harvest clams as compared to private aquaculture ventures in which only the individual who has obtained a lease is allowed to harvest the designated area. While towns are largely opposed to individuals having sole access to areas of the intertidal, community led conservation,

including aquaculture activities is commonly practiced and is considered stock enhancement. Due to the rise in predation from green crabs, this type of aquaculture at the town level is seen as a useful tool for protecting clam populations as well as supplementing the wild clam populations that are in decline.

3.4.6 Market

Approximately half of interview participants identified challenges with the market for soft-shell clams as an impediment to both intertidal aquaculture and the success of the wild fishery. Participants who perceived challenges with the market identified the limited number of buyers and their ability to fix the price for harvesters, the need for better marketing campaigns, and the fear of intertidal aquaculture flooding the market.

> Aquaculture would outcompete. You can bring a larger quantity faster to market. You got clam diggers that can only bring in two to four bushel apiece. That's them bent over for four to five hours, pulling every clam up one by one. (Harvester)

Some interview participants expressed concern that aquaculture might produce quantities of clams that could potentially flood the market and drive down the price of clams statewide. The control over the clams would allow farmers to harvest and sell their product during the peak season when prices are at a premium. However, this extensive supply is feared to hurt wild harvesters who lack this kind of control. Despite fear of downstream competition, approximately one quarter of respondents feel the market is working well and discuss the notion that there is plenty of space in the market for additional clams provided from aquaculture. These respondents feel that intertidal clam aquaculture has the potential to extend and open new markets for clam harvesters because they can assure a steady supply of clams.

3.4.7 Government Interactions

Approximately two-thirds of interview participants reported negative interactions with the state pertaining to the management of soft-shell clams. Many of these respondents feel that the state

government does not care about the wild fishery and that it mismanages the resource to the detriment of harvesters, thus fostering negative relationships with municipalities.

> I think if clammers don't figure out a way to work together, then they're going to continue to come out behind, as far as the amount of money that's invested in fishery research by the state, the number of staff members that are assigned to deal with the fishery; all that stuff– it's just going to keep getting whittled away at because it's not perceived as that important. And I think that's a shame for the amount of impact that it really has on these coastal communities. (Key Informant).

Many towns are now extremely skeptical of the state because they feel that the state has not done their due diligence in a variety of ways that have led to dysfunction in the co-management system. For instance, participants voice concerns over insufficient and incorrect water quality sampling techniques that have led to widespread closures of the intertidal, barring harvesters from a vital source of income. Respondents feel the state tries to provide a generic management template that does not account for the social and ecological differences across the state's coastal communities. Despite the overall negative perception of the state's management of the fishery, there were several positive comments regarding the state's shellfish biologists. The three shellfish biologists who offer support to towns are perceived to be doing a fantastic job working with communities and serving as a valuable resource.

3.5. Discussion

Despite a lack of widespread interest in individual aquaculture operations amongst clammers, there is interest and ongoing efforts in aquaculture as a municipal conservation effort. Currently, town shellfish committees are beginning to adopt aquaculture practices for conservation in areas of the flats that are then harvested by clammers in a joint effort. Furthermore, there may be interest in intertidal aquaculture in a more traditional sense from other individuals outside of the current clamming community. As mentioned by several interview participants, there is a fundamental difference in the

nature of the soft-shell clam fishery as it currently operates compared to that of soft-shell clam aquaculture. Clam harvesters currently have a very low entrance fee into the fishery because the only equipment necessary is a clam hoe and hod as well as a state and municipal license. Anderson (2002) points out that as property rights are strengthened, a longer-term perspective is reached regarding the resource and resource system. The role of an aquaculture farmer requires a great deal of forethought that includes the preparation of the farm site, acquiring or buying the clam seed and necessary materials for the farm, maintaining the gear, harvesting, marketing, and selling their product. This mentality is in stark contrast to many wild capture fisheries and, compared to the clam fishery, requires more upfront investment into the business.

There are other members of coastal communities that have expressed interest in intertidal clam farms. Interestingly, these individuals are not currently clam harvesters that could indicate a different type of mentality about privatizing the intertidal, less rooted in tradition, is necessary for aquaculture to develop. As current clam harvesters continue to age, it is possible that new, younger entrants into the fishery may approach the topic with a different perspective where aquaculture has a place at the table. It is also important to note that some municipal shellfish committees were open to the idea of individual intertidal aquaculture farms if the fishery continued to decline. In communities where the clam landings have decreased and environmental pressures such as predation have increased, there may be a shift in mentality on the part of harvesters who will be more open to diverse options to keep the mudflats productive and continue to earn a living as clam harvesters. Social and ecological vulnerability are inextricably linked (Adger, 2000; Folke et al., 2010) thus, as threats to the clam fishery intensify, so too does the vulnerability of the communities who depend upon this failing resource. Resisting introduction of clam aquaculture in the face of greater environmental change could increase vulnerability of these communities. Clam harvesters, therefore, may need to accept aquaculture as an alternative livelihood strategy to reduce risks brought on by climate change and increase their own personal resilience.

Even with municipal shellfish committee support for individual intertidal leases, the property rights structure will continue to be a barrier. The ownership of the intertidal by riparian landowners is an antiquated law dating back to the 17th century. Riparian landowners do not pay property taxes on the intertidal despite having control over activities in this area outside of fishing, fowling, and navigation. For aquaculture to develop in the traditional sense where individuals or companies possess a lease in the intertidal, this property rights structure would need to be amended. As current legislation stands, an individual would need permission by the landowner and the state to have an intertidal lease. Unfortunately, the risks of property changing hands, potential conflicts with landowners, etc. remain too high for potential farmers to be willing to invest in the new venture. Additionally, as mentioned in the results, the concept of privatizing the intertidal proves to be an even greater barrier to establishing intertidal clam aquaculture farms.

Since the practices of reseeding and predator exclusion are fairly common, the willingness to conduct such efforts indicates that the notion of aquaculture is not necessarily opposed but that it is the privatization aspect of traditionally conceptualized owner/operator aquaculture farms. The "strong ethic of equal opportunity" posited by Pinkerton (2015) with regard to resource dependent coastal communities holds true for Maine's clam fishery as well. By having areas of a town's intertidal zone that are only accessible to certain individuals, the sense of equal opportunity could be eroded as clam farmers have access to "their" clams as well as those in the rest of the municipality. While working to enhance clam flats at the municipal level reduces an individual's income potential, the perceived equal distribution of profits satisfies the deep-rooted belief of equal opportunity. Intertidal aquaculture has the potential to improve the environmental quality of clam flats and reduce economic losses due to closures, but the long-standing traditions of equal opportunity and self-sufficiency could provide significant barriers to this form of clam harvesting. Perhaps in a small town, with harvester consensus, the committee could proceed with a conservation closure but allot each harvester a space to seed,

protect, and harvest. This would bypass the need for riparian landowner approval since it is a municipal conservation effort as well as overcome the barriers in ideology around the commons as each harvester could have an area within the closure. However, the likelihood of consensus among all harvesters in a town seems unlikely. Aquaculture could, therefore, continue to grow as a community effort and not on the individual level in order to combat decline in clam populations.

One of the more concerning findings of this study that merits further discussion is the indication by municipalities that there is a breakdown in the overall management of the soft-shell clam fishery on the part of the state. Effective co-management cannot be realized without a well-functioning "government administrative structure" (Pomeroy & Berkes, 1997). Agrawal (2003) states that "as the ultimate guarantor of property rights arrangements, the role of the state and overarching governance structures is central to the functioning of common property institutions" (p. 250). The Maine DMR ultimately controls much of the management decisions surrounding the clam fishery, particularly area closures. The lack of trust, exclusion of harvesters in decision-making, and overall mismatch in management practices over diverse social-ecological settings indicates a failure in the co-management system. Co-management will not be effective towards sustainable outcomes if the level of management does not match the biological conditions (Johnson et al., 2012). The inaccurate water sampling techniques previously mentioned in the results harken back to previous mismatches in scale and fisheries management regulations in North America as discussed as well as the marginalization of small-scale fisheries and their socio-economic importance (Pinkerton, 2015).

McEvoy (1987) discusses the flaws in the political process for state-owned property as being mirrored in overall health and management of the resource itself, which appears to be taking place in the soft-shell clam fishery in Maine. In some instances, research participants also felt that the state gave preferential treatment to coastal landowners in both accessing the intertidal and in harvesting clams, which is their right as municipal license holders. In one instance conservation efforts, similar to

aquaculture, were denied because an extremely wealthy landowner did not want those efforts within their view-scape and threatened a lawsuit. Feeny et al. (1990) describe the breakdowns in resource management when the state is particularly responsive to the interest of the elite as opposed to the other stakeholders who depend upon the resource for their livelihoods. This appears to be the case in such instances as the one described above that not only have interrupted municipal conservation efforts but have also intimidated and thwarted potential intertidal aquaculture farmers from entering into the leasing process.

Despite the disconnect between the state and the needs of municipalities, participants raved about the quality of the three state biologists that provide guidance and assistance to municipalities within their region. These individuals seem to be serving the vital role of boundary spanners between the state and municipal shellfish committees that has allowed the co-management system to remain intact and will likely play an important role in possible development of intertidal aquaculture as they know the stock status of clams in each town as well as the harvesters' interests in conservation and development.

Lastly while the adverse impacts of climate change have been thoroughly discussed, the proverbial elephant in the room seems to be that the aforementioned issues such as warming waters, increased predation, increased acidification, etc., will likely only intensify as we move forward. While climatic changes such as warming waters and increased predation have drawn light on many weaknesses and frustrations in the co-management system, clam populations and the number of clam harvesters, continue to decline. As the resource continues to decline, the resentment towards the state's inaction could increase (Feeny et al., 1990). The opposition to privatizing the intertidal, current property rights structures, and the adverse impacts of climate change raise grave concern regarding the future of the clam fishery and Maine's coastal communities who rely on this important resource for income as well as cultural identity. Many rural communities heavily dependent upon a natural resource-

based economy have few other opportunities and could be disproportionately vulnerable to threats of climate change.

From her analysis of the soft-shell clam fishery over 20 years ago, Hanna (1998) stated, “Signs of strain such as falling clam harvests and rising management costs have signaled a need for management to continue to adapt to its changing environment” (p. 190). The need to adapt to changing social and environmental conditions is once again upon us. Although many towns expressed opposition to private aquaculture operations in the intertidal, the decline in clam populations and failure of the co-management system suggest that aquaculture at least for the sake of conservation should not be dismissed lightly.

CHAPTER 4

THE ROLE OF NON-GOVERNMENTAL ORGANIZATIONS IN THE DEVELOPMENT OF MAINE'S AQUACULTURE INDUSTRY

4.1. Introduction

Marine aquaculture development takes place within the context of coastal communities that utilize the marine coastal zone in a variety of ways including fishing, shipping, tourism, and recreation. As coastal communities continue to develop the marine coastal zone, these uses can conflict with one another. Governmental institutions are commonly responsible for establishing the rules that govern use of this space as well as enforcement of those rules. In addition, non-governmental organizations (NGOs) can play a significant role in facilitating sustainable use and development of common-pool resources and strengthening "durable collective action" surrounding their management (McGinnis & Ostrom, 2014; Barnes & van Laerhoven, 2015). These organizations can play a much different role in communities than state and federal organizations. Many non-governmental organizations are situated in communities and are active participants of community activities and decision-making.

Currently there exists limited research on the roles of NGOs in natural resource management with regards to aquaculture development. Most of the current literature references environmental NGOs who frequently oppose aquaculture development for fear of environmental degradation (Vormedal, 2017; Lindland et al., 2019; Hernandez et al., 2019). The negative publicity, media campaigns, consumer boycotts and lobbying on the part of environmental NGOs has led to more stringent regulations on imported aquaculture products to countries such as the United States (Vormedal, 2017; Hernandez, 2018). In Norway, NGOs have called for more thorough regulation of the aquaculture industry after observing the disappearance of shrimp and cod as well as the ethicality of a few people becoming rich at the expense of the marine environment (Lindland et al., 2019). The literature suggests that the other primary method of involvement of NGOs is through environmental

certifications, or ecolabeling, that have proliferated in recent years (Vogel, 2008; Potts et al., 2014; Schouten et al., 2016; Giuliani et al., 2017; Wijen & Chiroleu-Assouline, 2019). Typically, certifications are through third parties such as World Wildlife Fund (WWF) whose certification can fetch higher prices from consumers and thus benefit fishermen and farmers as well (Potts & Haward, 2007; Bleakley, 2019). In the absence of strong government regulations and supply chains that span many countries, these labeling schemes can provide accountability and lead to improvements in the production process that improve overall ocean health (Bartley, 2007; Ward & Phillips, 2008; Baron & Lyon, 2012; Bush et al., 2013; Wijen & Chiroleu-Assouline, 2019; Tlusty et al., 2019).

NGOs also have become involved in aquaculture as a mechanism for conservation. Poret (2019) provides examples of NGOs partnering with aquaculturists to aid coral reef conservation and management. The partnerships created by these NGOs involve not only the industry but also local communities, universities, and government to sustainably manage coral reefs (Poret, 2019). Veettil et al. (2019) also discuss the role of NGOs in restoring mangroves lost to shrimp farming by creating a hybrid model of mangrove and shrimp cultivation. In Bangladesh, a local NGO developed a model for community floodplain aquaculture that has been met with success (Bayazid, 2016). While they exist, examples of NGO involvement in promoting aquaculture development are in the minority.

Despite their scarcity in aquaculture literature, the role of NGOs in other natural resource sectors and other common pool resource systems is well documented, particularly in forestry and forest management (Raberg & Rudel, 2007; Cook et al., 2017). From an institutional perspective, the roles that NGOs play in resource management are largely dependent on the mission and vision of the organization (Raberg & Rudel, 2007; Cook et al., 2017). In forest resource management, many NGOs have either an environmental or developmental mission that is highly significant in the activities and the functions of the organization in a local context (Cook et al., 2017). While there are a wide variety of roles and functions that NGOs can serve, common supporting roles include: providing funding (Raberg & Rudel,

2007; Espinosa-Romero et al., 2014), education and expertise (Deighan & Jenkins, 2015; Ashmawy, 2018), technical support (Pretty & Ward, 2001; Espinosa-Romero et al., 2014; Ashmawy, 2018), developing community networks (Deighan & Jenkins, 2015), building local capacity (Espinosa-Romero et al., 2014), lobbying for government support (Ashmawy, 2018), training and facilitation (Espinosa-Romero et al., 2014; Deighan & Jenkins, 2015), policy implementation (Ariti et al., 2018), empowerment and inclusion (Espinosa-Romero et al., 2014), and conservation and environmental monitoring (Asquith et al., 2008; Wright & Andersson, 2013).

Due to their independent role in communities, NGOs can help facilitate use and management of common pool resources as well as find solutions that encompass social-ecological interests (Calado et al., 2012). Because of the many uses of this marine space, there are also many stakeholders with vested interest in the development of this coastal zone (Knapp & Rubino, 2016). Conflicts can arise when user groups have conflicting interests regarding the appropriate use of the space (Whitmarsh & Palmieri, 2008; Ferreira et al., 2011; Knapp & Rubino, 2016; Hanes, 2018). Aquaculture farms may conflict with historical fishing grounds or areas with high recreational use (Whitmarsh & Palmieri, 2008; Knapp & Rubino, 2016; Lindland et al., 2019). Within the context of marine planning, NGOs serve as important facilitators by providing a platform for government agencies, vested stakeholders, and the general public to work together in an inclusive manner (Calado et al., 2012; Espinosa-Romero et al., 2014). Aquaculture is but one of the many uses of the marine coastal zone and NGOs could potentially have a significant impact in informing the development of this zone. These organizations are often located in the communities in which they work so the relationships developed between the organizations and community members can help foster successful collaborations.

Many factors influence an organization's decisions to become involved in natural resource management. Ariti et al. (2018) details the importance of donor interest, project agreement, community interest, organizational strategy, and government policy in shaping an NGO's actions as well. The

dissatisfaction of environmental NGOs (eNGOs) in aquaculture development is cited as a common issue in countries around the world (Bostick, 2008). There is also a need to understand the challenges or barriers that may prevent NGO involvement in the aquaculture industry. Ariti et al. (2018) has identified a variety of barriers for NGO involvement in natural resource management in Ethiopia including administrative, capacity, poor cooperation among NGOs, lack of information, and lack of a clear role in policy issues. An organization's capacity has also been identified by Balboa (2014) and Pieck (2020) as one of the primary determinants for success. Organizations with greater capacity are shown to demonstrate greater power and may, therefore, be more influential in development and management activities (Balboa, 2014; Pieck, 2020).

The United States has been identified as one of the countries with the highest growth potential for aquaculture farms (Knapp and Rubino, 2016) and the state of Maine is no exception. The number of aquaculture farms in the state has increased dramatically over the last decade (MDMR, 2020). Maine's marine coastal zone continues to develop with fishing, aquaculture, tourism, and recreation interests all vying for space. Many of the NGOs participating in aquaculture development are local to the state and, for the most part, are situated in communities along the coast. NGOs have the potential to play significant roles in the sustainable use and development of the marine coastal zone in Maine. Although the number of NGOs involved in aquaculture has increased significantly, there is no known research to date examining what roles they are playing. The objective of this research was, therefore, to understand why NGOs become involved in the aquaculture sector and how NGOs are shaping the development and management of marine aquaculture in Maine. This research contributes more broadly to common-pool resource management as well as social-ecological systems research. This is because subtidal aquaculture in Maine exists within the waters held by the state in the public trust. Therefore, formal property rights are being assigned to an area that is a public resource for all Maine residents. Because NGOs play a significant role in the governance system that manages sustainable use of common-pool resources

(McGinnis & Ostrom, 2014), understanding their roles with regards to aquaculture development is a novel contribution to the literature in this field.

4.2. Study Site

This study is situated in the state of Maine, United States. Maine has approximately 5,600 kilometers of rocky coastline. Maine's aquaculture industry has existed since the 1970s with more intensive development of the sector occurring in the last 10 years. Maine's heterogeneous coastline is well suited for an array of aquaculture species. The commonly farmed species include Atlantic salmon, mussels, oysters and seaweeds with oyster farms being the most common in number (MDMR, 2020). There is also a strong maritime tradition in the state with many people working in marine-related sectors.

4.3. Methods

This qualitative study used semi-structured interviews with NGOs active in aquaculture within the state of Maine. Because the marine aquaculture sector is the focal point of the study, the majority of organizations of interest are based in coastal counties. Each organization represented has direct involvement in aquaculture development in Maine in some capacity, including opposition to development. Organizations range in size and focus of involvement from local community to multi-state. The researcher used purposive sampling as the intent of the study relies on understanding the role of organizations already involved in aquaculture development in Maine. The researcher first identified key informants from organizations that have historically been involved with the aquaculture industry as advocates and through providing training programs. From there, the researcher adopted snowball sampling techniques which allows for participants to build upon the already existing sample by providing "information rich" cases (Creswell & Poth, 2016). From these correspondences a total of twelve organizations were identified as playing an active role in aquaculture development. Two of the twelve organizations felt that they were not quite yet active in aquaculture though planned to be soon. As a

result, the sample was reduced to ten possible organizations. One of the 10 organizations did not respond to several attempts to contact them, therefore, a total of nine interviews were completed.

The researcher reached out to NGO staff members directly involved in projects with the aquaculture industry, including those who are actively involved in opposing aquaculture development through lease hearing attendance. Interviews focused on the history and structure of the organization, constituents they aim to serve, the role(s) in aquaculture development they aim to fill, their motivation for being involved, their vision for development in Maine, opportunities and challenges they see, as well as how they generally serve the communities in which they are involved. Questions also examined how the mission of each NGO guides their project decisions and community engagement/community relationships as well as their size (capacity), funding sources, projects, and partnerships.

Interviews ranged from approximately 50 to 90 minutes and were transcribed verbatim using the transcription service TranscribeMe!. Transcripts were analyzed using NVivo 11 Pro software. A code book was developed deductively to reflect the major fields of inquiry from the interview protocol. A provisional coding approach was adopted during First Cycle coding that allowed for selection of interview material that followed within major themes identified by the interview protocol (Miles et al., 2014). An inductive strategy was then used to add additional codes to the codebook based on the interview participants' responses. Next, pattern coding was used to refine the number of emergent themes. Pattern coding is a form of "meta-coding" that groups similarly coded data to generate major themes (Miles et al., 2014; See Results).

4.4. Results

4.4.1.1. Motivation for NGO Involvement in Aquaculture

All but one of the participating organizations view aquaculture in a positive light and want to be involved in moving this sector forward. While geography has played a part in the focus of some organizations, several discuss their motivation for becoming involved in aquaculture as a state-wide

initiative in response to a rapidly growing industry. In addition to the funding opportunities, aquaculture leases, particularly small leases intended for new entrants to the industry, have grown rapidly in the last decade. Organizations feel that this industry will play a significant role in the future of Maine's coastal communities and that it is a logical transition for them. Four organizations interviewed are new to aquaculture in the last five to ten years, some of which have continued to evolve their focus within aquaculture. Three organizations had already been involved in aquaculture but broadened the scope of their work to include new species, research, and organizational capacity as the industry develops. Two of the organizations that have focused primarily on aquaculture for many years reported little change aside from adjusting to a rapidly growing industry. The remaining organization is a local environmental organization that concerns itself with the health of the bay in which it is located and fears that aquaculture development could potentially threaten water quality and wildlife in the area, as well as harm nature-based tourism and industry. While they are not outright opposed to aquaculture development, they oppose the current development process.

4.4.1.2. NGO Mission Statements

An NGO's mission reflects the values of the organization and serves as a guide for the activities with which the organization engages. Three of the nine organizations are focused specifically in aquaculture and, as a result, have been involved in this sector's development since their inception. The remainder of these organizations are largely focused on serving coastal communities and sustainability of marine resources whether that be through education, research, and/or community development. Though aquaculture is not specifically a part of their missions, these organizations all view aquaculture as having an important influence on coastal communities, for better or for worse, and have therefore invested in the aquaculture development process.

The mission of an organization is important in identifying the constituents they aim to serve. The participating organizations aim to serve a number of stakeholder groups with all but one of the

organizations identifying fishermen and aquaculturists as constituents they aim to serve. Two-thirds of participating organizations identified coastal communities and the general public and two or fewer organizations identified the environment, resource users, and students and teachers as groups that they serve.

> The more of the sort of industry partnership sector where we work with forestry and agriculture and fisheries, we're really trying to serve the people that are being most impacted by climate change. So for my work in particular, partnering with fishermen, looking at ways that we can diversify or restore fisheries, resources, to really help fishermen and coastal communities that depend on those resources. (NGO Participant)

Many of the organizations that identified fishermen and coastal communities as constituents discussed the importance of social and economic resilience in coastal communities that is and has been threatened by factors such as climate change and overfishing. Because marine resources are a vital piece of the economy in these communities, many NGOs focus on research, education and outreach that can help businesses and thereby these communities to continue to thrive.

Interview participants were asked if and how their organizations have changed in focus or scope regarding the aquaculture industry to better understand their interests in the sector. Only a handful of these organizations have had long-term involvement in aquaculture development, particularly those focused primarily in aquaculture. Other organizations entered the conversation around aquaculture due to their locations in coastal communities and focus on sustaining Maine's coastline.

4.4.1.3. Workforce and Economic Development

In response to questions regarding the particular motivations for organizations to engage in the aquaculture sector, more than half of participants cited sustainable workforce and economic development as a primary interest.

> Lobsters are going to be less available in the Gulf of Maine… so we could lose a whole generation of fishermen. Which is important economically, but it's also really important culturally. And so that's (aquaculture) a way to diversify. (NGO Participant)

As this quote illustrates, aquaculture is viewed as helping to diversify Maine's coastal economy in ways that will increase resiliency for those communities heavily dependent on the lobster industry. There are also many economically depressed communities, especially in the eastern region of the state, that are heavily dependent on natural resources. NGOs citing workforce and economic development have therefore become involved in these communities to help provide alternatives to capture fisheries and other natural resource industries such as forestry.

Organizations also see aquaculture as helping to sustain coastal communities in the face of a changing climate. Coupled with the potential to feed communities, organizations that view aquaculture in a generally positive light feel that developing the aquaculture sector can increase economic resiliency of communities in the face of growing environmental uncertainty.

> And per capita, there's a ton of NGOs here, but there's also need and there's money. And aquaculture it's not that it's trendy, but it is right now. And when you realize it's going to help sea level rise and climate change, dovetail with that, and those conversations are top of mind in any community at the election level. Aquaculture has potential to feed a large portion of our population. The ocean is underused in that respect, and it's a balance thing. (NGO Participant)

Participants discussed the environmental benefits of shellfish and seaweed aquaculture such as biofiltration and increasing wild stock using hatchery technology as well as aquaculture's ability to feed a growing population. Not only can this sector provide jobs, it can also help to improve food security in the face of climate change.

4.4.1.4. Funding Availability

Another motivating factor for NGO involvement in aquaculture development is the availability of funding. While only one-third of the organizations identified funding availability as motivation for becoming involved in aquaculture, there is a perception that funding drives NGO involvement.

> R&D is research and development, and it's the D part of the equation which we have done very little in over the years with the exception frankly of the work that the association did until about three to four years ago, and then we got a group of other people. And frankly, it boils down to follow the money, right? There was money that was coming into the NGO community specifically targeting aquaculture and, in some cases, aquaculture development, and so those NGOs responded to those funding opportunities. (NGO Participant)

There is a long history of aquaculture research at universities and private institutions in Maine. Seven of the nine organizations identified grants as one of their primary funding sources. Six organizations identified philanthropy while three or fewer organizations identified membership dues, state funds, organizational programs, and university funds as important contributors to their operations. In the interviews, three of the organizational participants specifically identified a large, $20 million National Science Foundation grant opportunity as a catalyst for further developing their aquaculture portfolios.[1]

4.4.1.5. Conservation

The final motivating factor as discussed by two of the organizations is conservation. One organization identified aquaculture as playing an important role in marine conservation and restoration. Aquaculture can be used to restore wild stocks that have been depleted for a variety of reasons including increased effects of climate change. The other organization identified the importance of

[1] In 2014, the University of Maine received a $20 million, 5-year National Science Foundation EPSCoR grant to improve and further inform the development of sustainable, ecological aquaculture. This grant established a network of research institutions and organizations around the state, the Sustainable Ecological Aquaculture Network.

marine conservation as a result of growing aquaculture efforts. That organization indicated that aquaculture could have a detrimental effect on the environment including water quality and wildlife.

> To conserve not only the resources of the bay but also the uses of the bay. So traditional fisheries as well as any recreational uses or whatever somebody might want to use it for. But certainly with the conservation of the traditional fisheries because we saw the salmon farming with the potential of pushing the lobstermen right out of there. (NGO Participant)

This organization's involvement in aquaculture began with the development of salmon aquaculture more than 20 years ago. Discharge from farms was believed to negatively impact the water quality of the bay in which the organization is situated but also threatened to force out traditional wild fisheries such as the lobster fishermen. While both organizations aim to conserve the marine environment, they view aquaculture as playing opposing roles in this process.

4.4.2.1 Organizational Roles

When asked how, specifically, organizations are involved in shaping aquaculture development organizations participated in a variety of activities. Most organizations viewed themselves as playing multiple roles. The most common roles for the participating organizations are research and development, education and training of industry members, economic development, public education and outreach, participation in regulatory processes, and information exchange. Other activities include providing funding, technical assistance, advocacy, and environmental monitoring (Table 4.1).

4.4.2.2. Research and Development

Approximately two-thirds of respondents considered their organizations to be directly involved in aquaculture research and development. For example, one NGO-led research project involves creating new technology within the aquaculture industry that can directly inform farmers of environmental data that is crucial to the success of their farms. Another organization conducts research on a variety of

shellfish species and provides hatchery seed to aquaculture farmers as well as technical expertise to better ensure their success.

4.4.2.3. Economic Development

Economic development of coastal communities is both a motivating factor for organizational involvement in aquaculture as well as one of specific roles they play. Currently the aquaculture industry is mostly composed of small farms and the year-round job opportunities are limited. One participating organization is conducting market and workforce development studies to further advise aquaculture farms on the best options and solutions for growing their businesses.

4.4.2.4. Public Education and Outreach

> Approximately half of the organizations interviewed consider themselves as actively participating in education and outreach to students, teachers, and the broader public.
>
> We have a lot of students that now-- we've been going into schools for the past four or five years, using aquaculture kind of as a central tenant of that curriculum. And students have grown their own kelp, they've grown their own scallops, they've done experiments, things like that. (NGO Participant).

Aquaculture curriculum is becoming more common place as such organizations use this very relevant topic as a tool in science lessons. Other organizations give public presentations about aquaculture and see a need for clarifying misinformation.

4.4.2.5. Information Exchange

One-third of respondents discussed both the need for information exchange and how they aim to fill information gaps. Facilitating the exchange of information among farmers as well as between farmers and the public is a role that NGOs identified as a gap that they can and should fill. This information exchange is believed to yield a stronger more knowledgeable industry as well as reduce conflict between industry and other stakeholders.

> There's definitely a need. We used to run these working groups. And it's kind of fallen by the wayside a bit, but we had a mussel working group. The idea was just to bring mussel farmers all together on a regular basis to share things, come up with problems that they need to have solved, kind of focus groups on different sectors. (NGO Participant)

Organizations have been involved in organizing and facilitating working groups to bring aquaculture farmers together that can help with idea exchange and problem solving. This space for learning and knowledge exchange is a valuable service that could help sustainable growth of the industry.

4.4.2.6. Industry Education and Training

Still other organizations provide workforce training and education programs for farmers and potential farmers with the intention of building a more knowledgeable and capable industry. One such program, Aquaculture in Shared Waters, serves a variety of communities and provides farmers with knowledge about basic shellfish and seaweed biology, state regulations, applying for leases, and business models to name a few.

> I think workforce is really important…having workforce programs that actually teach the right stuff, the foundation of the skills pyramid, that the businesses want, that's accessible, and in a way that's sustainable…And then also keeping up to date with what those skills needs are in the occupational standards, as the industry grows and develops. (NGO Participant)

As the industry continues to develop as well as the research and best farming practices, it will be important for training programs to remain at the forefront of the industry. This particular training course is offered in different locations around the state as to be as accessible to interested individuals as possible.

4.4.2.7. Participation in Governance and Regulatory Process

Organizations also feel that one of their primary roles in aquaculture development is participation in the regulatory process. When asked specifically about these roles, almost all

participating NGOs have provided research and information to state scientists and legislators to inform the aquaculture development process. Attending lease hearings and public meetings as experts, facilitators, and industry representatives have also been common forms of engagement in the aquaculture decision-making and policy process. Additional activities reported by organizations include participation in policy formulation, implementation and evaluation as well as petitioning the legislature both on behalf of and opposing aquaculture development.

> If there's a bill submitted in Congress that comes out of nowhere, and it has implications, if there's a series of newspaper articles that are published which clearly misrepresent the industry, which often happens, that would instantly rise to our priority. (NGO Participant)

This organization advocates for the industry at the legislative level as well as provides assistance to individual farmers when needed, including at lease hearings. While most organizations feel that they should primarily be used as a source of information in policy process, they all have been involved in some way.

Engaging in the governance process has been especially important for NGOs because more than half of participating organizations feel that the current process is not working and/or too slow. Organizations also acknowledged that the process is continuing to evolve as the industry grows. Importantly, almost half of the organizations also acknowledge the extremely limited capacity of the DMR in terms of staff and available time. Interview participants were asked what roles in the governance process NGOs can fill that the state cannot. Currently the government is primarily involved in aquaculture through the leasing process as well as enforcement of rules but lacks capacity in terms of funding and staff to be able to take on other roles. Organizations, therefore, felt that roles in education, training, community planning, economic development, information gathering, lobbying, and research are all roles that NGOs can and should fill.

> I do think that, overall, sort of the community conversations don't seem to be something that government has been able to capture. And I don't know that that's really their role anyway. So, I do think that that's where NGOs have played a really important role just in terms of being able to provide a space for everyone's voice to be heard. (NGO Participant)

Community planning was identified as one of the important roles that the government cannot and should not play but can be taken on by NGOs. The state has a small staff working in the aquaculture department and participants felt they did not have the capacity to facilitate these community conversations. Nonetheless, these conversations could help towns be more proactive in the planning of the marine environment.

4.4.2.8. Strategies for Pursuing Aquaculture Projects

Due to the small number of NGOs involved in this sector, each of the participating organizations reported collaborating with other NGOs on aquaculture-related projects. Many of the participants have served as organizers and/or guest speakers for the Aquaculture in Shared Waters training program for new or interested farmers. The participation of these organizations indicates a willingness to work together to further industry development in a sustainable fashion. These organizations also commonly collaborate with communities on aquaculture-related projects. The participating environmental NGO also indicated collaboration with other small, local NGOs that work to protect and sustain the health of the bay in which they live. In both cases, participants view their roles in collaborations as conveners, organizers, and facilitators of meetings and conferences, serving on related boards, research, and community outreach. Participants discussed complementary skillsets and organizational missions as facilitators to these collaborations while barriers included the building of trust and capacity for organizations to be able to collaborate.

> I think certainly in collaborating with the environmental community, the development of trust was a barrier. It really boiled down to individuals, specific people being willing to sit in a room

> and developed a level of trust, and that took time…. And at times, there are bandwidth constraints. So just the number of entities that are out there and our ability to engage in a lot of different things at the same time, that's certainly been a barrier over the years… (NGO Participant)

As with many collaborations, trust is a significant factor in willingness of individuals to collaborate and influences the outcome of the project. In addition to the issues of trust among organizations that have differing views of aquaculture, the capacity of organizations, once again, plays an important role in projects.

4.4.3 Constraints

Approximately half of participating organizations identified time, number of staff, and funding as constraining their involvement in aquaculture projects. Less than one-third of organizations identified organizational infrastructure and state regulations as constraining factors while two organizations said they did not feel constrained in their participation. The organizations in this study range from one full-time employee to as many as seventy employees with over half of the organizations having less than 10 full-time employees. There is a maximum of four employees who focus specifically on aquaculture in any of these organizations and a minimum of one. Therefore, the time and energy devoted to aquaculture projects is at a premium for most of these organizations.

4.4.4. NGO Concerns about Aquaculture Development

Interview participants also expressed concerns of their own regarding Maine's budding aquaculture sector. Concerns included lack of marine planning, carrying capacity, management, biosecurity, environmental impact, user conflict, and consolidation. Two participants expressed no current concerns regarding growth of the industry (Table 2). While almost all organizations voiced concerns pertaining to aspects of the expansion process of Maine's industry, the most frequently expressed concern surrounded the development of the marine coastal zone.

> "…At the basic level, the waters of Maine are public property, whatever that might mean, but they belong to everybody. So, when you start to privatize it, especially large pieces of it for long periods of time, even though the DMR says, "Oh, it's less than one-tenth of 1%." Well, yeah. Okay. But that's not the argument. It happens to be that one-tenth of 1% that everybody wants to use." (NGO Participant)

Leases have vastly increased in number within the last five years (especially Limited Purpose Aquaculture licenses) and occur all along Maine's coast which has increased the visibility of aquaculture development despite the relatively small area they take up. The above interview participant discussed aquaculture growth occurring close to shore in the area that all stakeholders want access to for a variety of reasons including recreation. The small area taken up by leases is viewed as irrelevant because they occur primarily in the area everyone wants to be able to use. The overall lack of marine planning in Maine was discussed by many participants as something that could be problematic in the future.

4.4.5. Future of Aquaculture in Maine

When asked about what the future of the aquaculture industry should look like, organizations differed in whether small owner/operator farms versus larger commercial farms or some combination would best suit Maine's social, economic, and ecological needs. Those who feel that farms should remain small, owner/operator businesses feel that this will maintain a closeness to the community, stimulate local economies, and maintain a sense of environmental stewardship. Others feel strongly that there should also be larger companies coming into Maine because they will have the means to both employ and feed more people. Overall, however, more than half of non-governmental organizations in this study felt that the scale and type of aquaculture should vary by community.

> I do think that it is very much a community-by-community thing. I believe that some communities are going to be more receptive and it's going to work better for them to have a greater number of farms or a greater diversity of types of farms…What I would ideally like to see

though is that we have this diversification tool so that we can continue to have ways for fishermen to adapt, for communities to adapt to changing climate. (NGO Participant)

Most organizations recognize that each coastal community has different social, ecological, and economic needs. They felt the number and size of farms should, therefore, be based around community wants and needs. Participants felt that sustainable development of the aquaculture industry will be more likely when taken on a community-by-community basis.

4.4.6. Leaders

All nine of the participating organizations referenced other NGOs as the leaders in moving the development of Maine's aquaculture industry forward. Approximately half of participating organizations identified universities and Maine Sea Grant as leaders and one organization referenced private research institutions.

> The industry is growing. Therefore, the policy is changing all the time because it's new, and there's not a rule book already written in Maine for all of this, and the research and the engagement is responding. So yeah, I mean, I think all those organizations, yeah, are stepping up the game and trying to get a piece of the pie. (NGO Participant)

While most participants identified specific organizations, this quote illustrates the fact that many of these organizations are recent entrants into the aquaculture sector and are becoming involved as aquaculture has begun to quickly expand. Organizations see an opportunity to both capitalize on funding opportunities as well as contribute to an important development process for Maine.

	Roles of NGOs in Aquaculture (N = 9 Organizations)					
NGO Roles Filled	Research & Development	Industry Education & Training	Economic Development	Public Education & Outreach	Governance & Regulatory Process	Information Exchange
Number Responses	6	6	4	4	3	3

Table 4.1. Self-identified roles in which NGOs serve in Maine's aquaculture industry.

NGO Concerns for Aquaculture Development (N = 9 Organizations)								
Concern	Lack of Marine Planning	Carrying Capacity	State Management	Biosecurity	Environmental Impacts	User Conflicts	Consolidation	No Concern
Number Responses	5	4	3	2	2	2	1	2

Table 4.2. Concerns of NGOs regarding the development of aquaculture in Maine.

4.5. Discussion

This study shows a diversity of ways in which NGOs are engaging with the aquaculture industry in Maine. The NGOs involved in aquaculture development are largely there to help facilitate sustainable growth of the industry. Much of the work of these organizations is designed to focus on the ecological, social, and economic sustainability of both the industry and coastal communities. The only NGO that is not a proponent of aquaculture growth is a local environmental NGO concerned with impacts of aquaculture on the marine environment and traditional uses of the coast. Environmental NGOs in Maine have hired lawyers to oppose lease applications through the state's formal lease hearing process (Hanes, 2018). In Maine, such environmental NGOs have been small, community-level organizations that take issue with local level aquaculture development that impacts their specific communities. The single environmental NGO that has long been involved in the conversation surrounding aquaculture development in Maine has primarily focused on protecting the marine environment and local businesses dependent on fisheries and recreation. This finding is consistent with previous research in aquaculture citing environmental concerns as the primary cause for an organization's opposition to aquaculture development (Bostick et al., 2008; Lindland et al., 2019; Hernandez et al., 2018; Vormedal, 2017). Some

of these organizations have established informal avenues of communication among themselves to provide guidance through the opposition process. Such involvement is similar to past literature and discourse on NGO involvement in aquaculture development at the global scale. Though in the minority, eNGOs are still participating in Maine's coastal development conversation to slow aquaculture development.

The remainder of these organizations want to see a successful and sustainable aquaculture industry and provide services they feel will help the industry succeed long-term and grow in a sustainable manner that will also fit into communities. This finding reflects the evolving role of NGOs in aquaculture development worldwide. Once synonymous with an environmental movement that aimed to impede development of this sector, NGOs possess a more nuanced role in this sphere. This could be in part, due to the improvements in aquaculture production that have reduced the environmental footprint of farms, particularly finfish farms as well as the role previous environmental NGOs have played in ecolabeling certifications. In Maine, however, the role of NGOs in the aquaculture sector has always primarily been to work towards developing the sector. This is partially due to the fact that the NGOs that have been involved for several decades identify the aquaculture industry as one of, if not the, leading constituent that they aim to serve. Their early investment and support for the aquaculture industry has served as an important resource for growth.

In the last five to ten years, several more organizations have become involved in the growing marine aquaculture sector in Maine. The services that they provide are diverse and depend upon the organization's mission to guide their involvement. While aquaculture is fairly new to these organizations, many of them have missions that revolve around sustaining Maine's coastal communities both ecologically and socially. The industry-based organizations focus on advocacy and legislation to protect and assist industry development as well as research and development that will overcome current industry barriers in technology, farm set-up, etc. Other organizations focus on research, training,

education, funding, and community outreach. These services have all been found incredibly important to sustainable management and development in other resource sectors, which bodes well for the future of Maine's aquaculture industry (Sultana & Abeyasekera, 2008; Wright & Andersson, 2013; Espinosa-Romero et al., 2014; Deighan & Jenkins, 2015; Cook et al., 2017; Ashmawy, 2018; Ariti et al., 2019). While Maine's aquaculture industry is relatively small, operations are spread across the entire coastline. This has allowed smaller NGOs to focus efforts on their local communities with project collaborations that create a large impact at a small scale. Findings suggest that the services these organizations provide are the primary sources of assistance for aquaculture farmers and those interested in becoming farmers. All participating organizations referenced other NGOs as the leaders in moving the development of Maine's aquaculture industry forward.

The unanimous agreement on leaders in aquaculture development speaks volumes to the vital roles NGOs play in the sector and could have implications in other areas of the world looking to further develop aquaculture and engage stakeholders. Interestingly, while many believed that the current management process on behalf of the Maine Department of Marine Resources is lacking, they did not feel that the state should have any other roles in development of the industry and that it should, indeed, be the responsibility of NGOs. This contrasts to other countries, such as Canada, in which the government subsidizes aquaculture development. While the enormous efforts and contributions of these organizations is encouraging, this data is also concerning. Many of these organizations are new to the sector and almost all of them depend on grants and some amount of philanthropy to fund their efforts. While funding has been pouring into the state in the last several years, the grant process is highly competitive and the interest and granting agencies in aquaculture could potentially shift. Hernandez et al. (2019) refers to the dependence of the aquaculture sector on NGOs in Bangladesh for financial aid as "insecure funding" and limited for industry growth. If the grant funding slows or is no longer available, and NGOs remain the primary leaders in development of the sector, who will continue

to further aquaculture efforts? In addition, over half of the participating organizations have less than 10 full-time employees and all but two of them focus on an area that spans the coast of Maine or greater. With limitations on capacity in terms of time and staff as well as funding, there is potential for these organizations to overextend themselves and be unable to deliver their now expected services and expertise. Therefore, although NGOs have largely been responsible for facilitating the aquaculture industry's expansion in Maine, their lasting commitment to the industry in the face of their many limitations is of concern. Perhaps Maine's current solution to lack of government assistance in aquaculture development can demonstrate how organizations in other countries lacking government support can assist sustainable development of aquaculture. However, Maine as well as other states and countries should consider what is missing from the formula and how they may deal with this precarious position of NGOs bearing the brunt of development efforts.

Another important consideration for the future of the aquaculture industry in Maine is the lack of a marine planning which creates uncertainty about the future of the marine coastal zone. The lack of planning has become problematic in many instances as various stakeholder groups dispute space. Currently, Maine's coastline has vibrant lobstering and tourism industries as well as provides numerous recreation opportunities and vital marine habitat. Organizations in this study recognize the role NGOs can play within coastal communities in helping to identify and envision the future of the coast. This will likely become an increasingly important feature of coastal communities around the world as population density increases and uses of the marine coastal zone are conflicting with one another (Gustavsson & Morrissey, 2019).

The concerns expressed in this research beg the question of what the future of aquaculture will look like in Maine. This discussion is particularly pertinent since NGOs are greatly helping to shape aquaculture development in Maine and the roles they play in terms of training, funding, outreach, etc. will likely influence the outcome of Maine's aquaculture industry and thus, development of the marine

coastal zone. While all organizations have collaborated with other NGOs, their disparate visions of Maine's future industry could become problematic as the messages they espouse to communities are different. The conflicting visions of the future industry further highlight the need for a broader marine planning effort that would be conducted at both the state level as well as that of the individual coastal communities. As NGOs sometimes serve as facilitators and bridges between diverse stakeholder groups, they might be able to play a key role in this process (Calado et al., 2012; Espinosa-Romero et al., 2014).

4.6. Conclusion

Maine's rapidly developing aquaculture industry has brought the discussion of sustainable coastal development to a head. Non-governmental organizations have become increasingly involved in this conversation within the last five to ten years for a variety of purposes informed by their missions and visions. Although in depth involvement is limited to a dozen or so organizations, each of them has found ways to collaborate and complement the work of other organizations. In the past, NGO involvement in aquaculture development has focused on the opposition of aquaculture development by environmental NGOs.

However, Maine's NGO involvement in aquaculture has been much more supportive and more comparable to the roles of NGOs in other natural resource sectors such as forestry. These organizations are providing services such as education and training to industry members, funding for new farmers, community outreach, and advocacy among others (Pretty & Ward, 2001; Espinosa-Romero et al., 2014; Deighan & Jenkins, 2015; Ashmawy, 2018). One potential explanation as to why the roles of NGOs in Maine appear to be different than elsewhere in the world is the lack of governmental support and funds provided for aquaculture development, in contrast to countries such as Canada that subsidize the aquaculture industry.

This study will provide a more nuanced understanding of the many roles that organizations could play in aquaculture development. While this study is specific to Maine, the aspects of

organizations in question apply to a vast array of non-governmental organizations. As capture fisheries continue to plateau or decline and human populations continue to rise, the efforts to provide alternative protein sources will continue to increase. This research offers insight into how local NGOs may contribute to sustainable use and development of coastal resources to ensure social-ecological sustainability while providing a much-needed food source.

CHAPTER 5

CONCLUSION

5.1. Overview

Within the context of the greater Sustainable Ecological Aquaculture Network (SEANET) project, the second chapter of this dissertation explored the major challenges and opportunities facing Maine's growing aquaculture industry. The third chapter identified the social and ecological variables influencing development of intertidal clam aquaculture from the perspective of municipal shellfish committee members and other key stakeholders in the clam fishery. The fourth chapter explored why and how non-governmental organizations (NGOs) are becoming involved in Maine's aquaculture industry as they have been shown to play significant roles in the management and sustainability of other natural resource sectors. Overall, these studies indicate a lack of proactive thinking on the part of the state government, that could become increasingly problematic as the industry continues to grow. A degree of marine planning could be beneficial to the state as a way to plan for the sustainable use and development of Maine's coastal waters moving into the future.

5.2. Marine Planning

As in other parts of the world, the rapidly growing aquaculture industry in Maine has become a part of the growing conflict in communities over the use of marine space (Jayanthi et al., 2020). More than 50 percent of the population of the United States lives in coastal counties (Dewey et al., 2011) and globally, coastal population growth is only expected to increase (Neumann et al., 2015). As a result, user conflicts are anticipated to grow as well, and much of this can be attributed to inadequate planning of diverse activities (Neumann et al., 2015; Lithgow et al., 2019). One of the proposed solutions for the lack of planning that could potentially be useful in Maine is marine spatial planning (MSP). Marine spatial planning is "a place-based, multi-sectoral decision-making approach that is being widely promoted for reducing the conflicts and impacts commonly encountered in conventional sector-by-sector planning"

(Lester et al., 2018, 2). This process inherently recognizes the conflicting uses of the marine environment and aims to reduce user conflict while also promoting sustainability (Lester et al., 2018). In Maine, aquaculture is a relatively recent addition to many areas of the coast as compared to more traditional uses such as fishing, shipping, tourism, and recreation. As such, aquaculture expansion should be done in consideration of the other existing uses of the coast. Lester et al. (2018) have developed an MSP framework that includes offshore aquaculture with existing uses as well as environmental concerns including wild fisheries, viewshed, and pollution in California. Their findings indicate that using MSP in the context of aquaculture development can minimize tradeoffs while also maximizing economic gains (Lester et al., 2018). Such a framework could be incredibly useful as aquaculture continues to develop along Maine's coast.

A drawback of using an MSP approach is the amount of time and resources necessary to make it effective. This type of spatial planning often covers large areas and requires generating detailed maps and databases as well as significant stakeholder engagement (Nutters & da Silva, 2012; Fairbanks et al., 2019). Despite public participation, decision-making that proves to be equitable for all stakeholders is unlikely (Tafon et al., 2017). Additional problems with the stakeholder engagement process include the different types of knowledge stakeholders possess and the power dynamics and thus, ability to influence decisions differ among stakeholder groups (Jentoft, 2017; Fairbanks et al., 2019). Despite these critiques of MSP, in-depth participation of communities and effective communication across government, research, and private interests are all valuable qualities in a marine planning process that could be adopted in Maine.

One of the most pressing issues for aquaculture development in Maine, as with many other places in the world, is the conflicting uses of marine space. The findings from chapter two corroborate those of Bricknell et al. (2020) that ecologically, Maine has the potential for enormous aquaculture growth. Aquaculture is the only sector that involves formally assigning property rights to a public area of

the marine zone. Therefore, farmers applying for leases and the state are essentially deciding how coastal areas are being shaped. Some amount of marine planning would allow other community stakeholders to be involved in the planning process that could help increase the social sustainability of sustainable ecological aquaculture.

The third chapter of this dissertation examined the potential for soft-shell clam aquaculture development in the intertidal zone. Currently the intertidal zone, though owned by the riparian landowner, is accessible for harvesting soft-shell clams as a fishing practice. While intertidal aquaculture would require permission of the landowner, interviews indicate that privatization of the intertidal is the most important factor influencing development of this area. Marine planning as a participatory process could allow harvesters and others interested in intertidal clam aquaculture to work together with the municipality to identify spaces that could be used for aquaculture. While there is little interest among municipal shellfish committees to allow individual operations currently, several indicated that it would be a consideration if clam populations continue to decline. Aquaculture as a municipal conservation effort could also benefit from a more thorough and participatory planning process to identify areas for group conservation that are not competing with other uses of the intertidal.

The fourth chapter of this dissertation examined the roles of NGOs in Maine's aquaculture industry. The results indicated that not only do most of these organizations want to help aquaculture develop but, develop in an ecologically and socially sustainable manner. As many of the NGOs indicated, the scale and type of aquaculture should vary by what best suits a given community. These organizations already play many roles in the aquaculture industry and are understandably limited in capacity. However, they are uniquely situated to play a significant role in marine planning in communities as these types of organizations have already been shown to help develop community networks (Deighan & Jenkins, 2015), build local capacity (Espinosa-Romero et al., 2014) and foster lasting collective-action (Barnes & van Laerhoven, 2015; McGinnis & Ostrom, 2014). Importantly, marine

planning requires “effective governance and communication between scientists, decision makers and producers” (Lithgow et al., 2019, 297). As third-party participants in the discussion of aquaculture development, they can help facilitate community discussion, provide technical expertise in areas such as map making, and potentially help ensure that participation is an equitable process.

Maine’s coastal waters and communities are extremely heterogeneous. Because of this fact, the scale and type of aquaculture will have different social and ecological limitations in each municipality. Environmental and biological factors such as water temperatures, circulation, pH, predation, and food availability for farmed species can vary greatly. Furthermore, factors such as natural resource dependence, gentrification, tourism, and other uses of marine space can also be drastically different. Therefore, while some amount of marine planning is advisable, the researcher recommends that it occurs at the community level in order to find place-based solutions to current social and environmental problems.

5.3. Significance of Research

5.3.1 Chapter 2 Significance

This research first identified some of the important opportunities and challenges for developing aquaculture in Maine. Because aquaculture has been rapidly increasing over the last decade, it is important to understand how aquaculture can develop in a sustainable fashion. This study identified 5 important areas of focus for further research and development that can help promote sustainable growth of aquaculture in Maine. The five major themes identified are: regulatory, socio-cultural, economic, ecological, and technology. These themes resembled those of global trends with the addition of the regulatory system. The leasing system in Maine is inciting conflict (Hanes, 2018) and excludes various social values that are essential to community well-being. Nonetheless, the creation of limited purpose aquaculture licenses (LPAs) in Maine could help farmers elsewhere start operations or test new sites which could be a valuable tool for understanding the ecological and social landscape of a farm site.

Social and ecological factors that shape aquaculture development are context specific. As such, it is necessary to identify these challenges and opportunities at the local level on a case-by-case basis. Therefore, this type of study was necessary and timely to conduct for Maine's aquaculture industry. The combined effect of case studies like this one has been helpful in other sectors to develop theory towards improving sustainable use and development of natural resources (Ostrom, 2008).

5.3.2 Chapter 3 Significance

The potential development of intertidal soft-shell clam aquaculture is a specific type of aquaculture that has a great deal of uncertainty in relation to the governance system. Research investigating the varying degrees of conservation efforts and the motivations and attitudes that municipal shellfish committees have regarding intertidal aquaculture are important in light of declines in clam populations and increases in environmental threats related to climate change. Intertidal clam aquaculture has the potential to offset declines in clam populations and reduce the vulnerability of clam harvesters and the coastal communities who depend upon this resource, but it has yet to be done. Results indicate that despite the challenges facing the clam fishery, municipal shellfish committees are largely not in favor of privately owned intertidal clam aquaculture farms. While the idea of privatizing the intertidal and clam resource may prevent individual aquaculture enterprises to develop in Maine, participants felt that reseeding and predator exclusion as a municipal conservation effort is a valuable tool. While they do not consider this aquaculture, it remains the most likely form of aquaculture development in Maine's intertidal for the foreseeable future. This finding illuminates a pathway forward for implementing aquaculture practices in municipalities that could help prevent decline in clam populations due to predation while still upholding the ideals of equal opportunity amongst harvesters.

While issues of climate change and an aging harvester population persist, this study has identified options for municipalities to help offset some of these adverse social and ecological factors. Finally, the distrust in the state's management of the clam fishery proves to be an added complexity to

not only clam aquaculture but the success of the wild fishery too. Participants felt the state's actions undermine the co-management system and the lack of trust leaves harvesters not wanting to work with them. The issues with management could intensify other challenges facing clam harvesters and intertidal aquaculture. This study demonstrates a need to revamp the current co-management system in hopes of preventing further adverse impacts on coastal communities.

5.3.3 Chapter 4 Significance

Another important aspect of the governance system examined in this research is the role of NGOs on aquaculture development. Little research exists on the roles of NGOs in aquaculture development globally, and with what is available, the discourse has largely been around environmental NGOs opposing aquaculture development. This study contributes a new understanding of the ways in which NGOs could be moving aquaculture forward as well as why they become involved in the sector. Many of the organizations in Maine have become involved in aquaculture in the last 10 years in response to a growing industry as well as new funding opportunities in this sector. The primary roles in aquaculture development that these organizations feel they serve include research and development, education and training, economic development, public education, information exchange, and participation in the regulatory process. All participating organizations identified NGOs as leaders in the aquaculture industry's development, followed by Maine Sea Grant, and academic institutions. Despite their leading roles in development, funding, number of staff, and time, all prove to be significant constraints to these organizations' involvement. There is reason for concern with this finding because competitive grants are one of the primary sources of funding for most of these organizations. While currently there is considerable funding in the aquaculture sector, this likely will not remain the case permanently.

Though the state's capacity limits the amount of proactive planning that it can provide, many organizations agreed that some amount of marine planning is essential. The need for marine planning is

a service that NGOs could potentially help facilitate in coastal communities as development and user conflicts intensify. This finding could be useful elsewhere in the world with fledgling aquaculture sectors looking for help with development, especially where government capacity is limited.

While this study is specific to Maine, the aspects of organizations in question are generalizable to a vast array of non-governmental organizations. As capture fisheries continue to plateau or decline and human populations continue to rise, the efforts to provide alternative protein sources will continue to increase. Given these trends, aquaculture likely will continue to grow on a global scale. This research offers considerable insight into how local NGOs may contribute to sustainable use and development of coastal resources to ensure social-ecological sustainability while providing a much-needed food source.

5.4. Future Research

Future research should continue to include local level studies regarding the challenges and opportunities for aquaculture growth as they are socially and ecologically specific. As a major component of the governance system with implications for development, the regulatory system should be examined closely in addition to environmental, socio-cultural, economic, and technologic factors influencing aquaculture development. The qualitative study on intertidal aquaculture identified various important factors for development of the sector in Maine using 23 semi-structured interviews. It is possible that a quantitative study, such as a survey, could be administered to all municipalities in attempts to gauge the opinion about individual/versus municipal aquaculture efforts using this study's findings. It is unclear about the potential for developing intertidal aquaculture in municipalities that do not have a municipal shellfish committee as individuals would only need riparian landowner permission and a state lease. The potential for intertidal aquaculture should, therefore, be examined in these towns. Finally, the state would benefit further from additional research examining community interest and the practicality of marine planning as well as what type/combination of marine planning frameworks would be best suited for Maine.

5.5. Research Limitations

As with most research projects, the scale and scope of this research was limited by the time and cost of conducting qualitative research. Interviews are both time intensive as well as dependent upon participant willingness to engage. While fortunate enough to be given the generous time of many research participants over the course of these three studies, many requests for interviews were ignored or declined. The study on intertidal soft-shell clam aquaculture examined less than twenty of the almost sixty municipal shellfish programs. While saturation was reached in these interviews, it is possible that other municipalities could have a different perspective on the development of intertidal aquaculture.

BIBLIOGRAPHY

Adger, W. N. (2000). Social and ecological resilience: are they related? *Progress in Human Geography*, 24(3), 347-364.

Agrawal, A. (2003). Sustainable governance of common-pool resources: Context, methods, and politics. *Annual Review of Anthropology*, 32(1), 243-262.

Anderson, L. E., & Plummer, M. L. (2017). Recreational demand for shellfish harvesting under environmental closures. *Marine Resource Economics*, 32(1), 43-57.

Ariti, A. T., van Vliet, J., & Verburg, P. H. (2018). What restrains Ethiopian NGOs to participate in the development of policies for natural resource management? *Environmental Science & Policy*, 89, 292-299.

Ariti, A. T., van Vliet, J., & Verburg, P. H. (2019). The role of institutional actors and their interactions in the land use policy making process in Ethiopia. *Journal of Environmental Management*, *237*, 235-246.

Ashmawy, I. K. I.M. (2018). NGO involvement in zoo management: A myth or reality? *Environment, Development and Sustainability*, 20(4), 1873-1887.

Asquith, N., Vargas, M. & Wunder, S. (2008) Selling two environmental services: In-kind payments for bird habitat and watershed protection in Los Negros, Bolivia. *Ecological Economics,* 65(4), 675–684.

Balboa, C. M. (2014). How successful transnational non-governmental organizations set themselves up for failure on the ground. *World Development*, 54, 273-287.

Barnes, C., & van Laerhoven, F. (2015). Making it last? Analyzing the role of NGO interventions in the development of institutions for durable collective action in Indian community forestry. *Environmental Science & Policy*, 53, 192-205.

Baron, D., & Lyon, T. (2012). Environmental governance. In P. Bansal & A. Hoffman (Eds.), *The Oxford handbook of business and the natural environment* (pp. 122-139). Oxford, England: Oxford University Press.

Barrington, K., Chopin, T., & Robinson, S. (2009). Integrated multi-trophic aquaculture (IMTA) in marine temperate waters. *Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper*, *529*, 7-46.

Bartley, T. (2007). Institutional emergence in an era of globalization: The rise of transnational private regulation of labor and environmental conditions. *American Journal of Sociology*, 113, 297-351.

Bayazid, Y. (2016). The Daudkandi model of community floodplain aquaculture in Bangladesh: a case for Ostrom's design principles. *International Journal of the Commons*, *10*(2).

Beal, B.F., Parker, M.R., & Vencile, K.W., 2001. Seasonal effects of intraspecific density and predator exclusion along a shore-level gradient on survival and growth of juveniles of the soft-shell clam, Mya arenaria L., in Maine, USA. *Journal of Experimental Marine Biology and Ecology,* 264, 133–169.

Beal, B. F., & Kraus, M. G. (2002). Interactive effects of initial size, stocking density, and type of predator deterrent netting on survival and growth of cultured juveniles of the soft-shell clam, Mya arenaria L., in eastern Maine. *Aquaculture*, 208(1-2), 81-111.

Beal, B.F. (2006). Relative importance of predation and intraspecific competition in regulating growth and survival of juveniles of the soft-shell clam, Mya arenaria L., at several spatial scales. *Journal of Experimental Marine Biology and Ecology,* 336, 1-17.

Beal, B.F. (2006). Biotic and abiotic factors influencing growth and survival of wild and cultured individuals of the soft-shell clam (Mya arenaria L.) in eastern Maine. *Journal of Shellfish Research*, 25, 461-474.

Beal, B. F., Nault, D. M., Annis, H., Thayer, P., Leighton, H., & Ellis, B. (2016). Comparative, large-scale field trials along the Maine coast to assess management options to enhance populations of the commercially important soft-shell clam, Mya arenaria L. *Journal of Shellfish Research*, 35(4), 711-727.

Beal, B. F., Coffin, C. R., Randall, S. F., Goodenow, C. A., Pepperman, K. E., Ellis, B. W., & Protopopescu, G. C. (2018). Spatial variability in recruitment of an infaunal bivalve: Experimental effects of predator exclusion on the softshell clam (Mya arenaria L.) along three tidal estuaries in southern Maine, USA. *Journal of Shellfish Research*, 37(1), 1-27.

Berkes, F., & C. Folke (Eds.). (1998). *Linking social and ecological systems: Management practices and social mechanisms for building Resilience*. Cambridge University Press.

Berkes, F. (2009). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management*, 90(5), 1692-1702.

Bernard, H. R., & Bernard, H. R. (2013). *Social research methods: Qualitative and quantitative approaches*. SAGE Publications.

Binder, C. R., Hinkel, J., Bots, P. W., & Pahl-Wostl, C. (2013). Comparison of frameworks for analyzing social-ecological systems. *Ecology and Society*, 18(4).

Bleakley, P. (2019). Big fish, small pond: NGO–Corporate partnerships and corruption of the environmental certification process in Tasmanian aquaculture. *Critical Criminology (Richmond, B.C.)*, 28(3), 389-17.

Bostick, K. (2008). NGO approaches to minimizing the impacts of aquaculture: A review. In M. Holmer, K. Black, C. M. Duarte, N. Marbà, & I. Karakassis (Eds.), *Aquaculture in the ecosystem* (pp. 227-249). Springer, Dordrecht.

Bostock, J., Mcandrew, B., Richards, R., Jauncey, K., Telfer, T., Lorenzen, K., Little, D., Ross, L., Handisyde, N., Gatward, I., & Corner, R. (2010). Aquaculture: global status and trends. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554), 2897-2912.

Bricknell, I. R., Birkel, S. D., Brawley, S. H., Van Kirk, T., Hamlin, H., Capistrant-Fossa, K., Huguenard, K., van Walsum, G. P., Liu, Z. L., Zhu, L. H., Grebe, G., Taccardi, E., Miller, M., Preziosi, B. M., Duffy, K., Byron, C. J., Quigley, T. C. Q., Bowden. T. J., Brady, D., Beal, B. F., Sappati, P. K., Johnson, T. R., & Moeykens, S. (2020). Resilience of cold-water aquaculture: A review of likely scenarios as climate changes in the Gulf of Maine. *Reviews in Aquaculture*, 1-44.

Brugère, C., Aguilar‐Manjarrez, J., Beveridge, M. C., & Soto, D. (2019). The ecosystem approach to aquaculture 10 years on - A critical review and consideration of its future role in blue growth. *Reviews in Aquaculture*, 11(3), 493-514.

Buck, B. H., Troell, M. F., Krause, G., Angel, D. L., Grote, B., & Chopin, T. (2018). State of the art and challenges for offshore integrated multi-trophic aquaculture (IMTA). *Frontiers in Marine Science, 5*.

Calado, H., Bentz, J., Ng, K., Zivian, A., Schaefer, N., Pringle, C., Johnson, D., Phillips, M. (2012a). NGO involvement in marine spatial planning: A way forward? *Marine Policy*, 36(2), 382-388.

Calado, H., Bentz, J., Ng, K., Zivian, A., Schaefer, N., Pringle, C., Johnson, D., Phillips, M. (2012b). NGO involvement in marine spatial planning: A way forward? *Marine Policy*, 36(2), 382-388.

Cheney, D., Langan, R., Heasman, K., Friedman, B., Davis, J., & Shell, T. (2010). Shellfish culture in the open ocean: Lessons learned for offshore expansion. *Marine Technology Society Journal*, *44*(3), 55–67.

Cinner, J., & Huchery, C. (2014). A comparison of social outcomes associated with different fisheries co-management institutions. *Conservation Letters*, 7(3), 224-232.

Cleaver C., Johnson T.R., Hanes S.P., Pianka K. (2018) From fishers to farmers: Assessing aquaculture adoption in a training program for commercial fishers. *Bulletin of Marine Science*, 94, 1215–1222.

Clough, S., Mamo, J., Hoevenaars, K., Bardocz, T., Petersen, P., Rosendorf, P., Atiye, T., Gukelberger, E., Guya, E., Hoinkis, J. (2020). Innovative technologies to promote sustainable recirculating aquaculture in eastern Africa—A case study of a Nile tilapia (*Oreochromis niloticus*) hatchery in Kisumu, Kenya. *Integrated Environmental Assessment and Management*, 16(6), 934-941.

Cook, N. J., Wright, G. D., & Andersson, K. P. (2017). Local politics of forest governance: Why NGO support can reduce local government responsiveness. *World Development*, 92, 203-214.

Congleton, W. R., Vassiliev, T., Bayer, R. C., Pearce, B. R., Jacques, J., & Gillman, C. (2006). Trends in Maine soft-shell clam landings. *Journal of Shellfish Research*, 25(2), 475-480.

Costa-Pierce, B. A. (2010). Sustainable ecological aquaculture systems: the need for a new social contract for aquaculture development. *Marine Technology Society Journal*, *44*(3), 88-112.

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. SAGE Publications.

Dalton, T. M., & Jin, D. (2018). Attitudinal factors and personal characteristics influence support for shellfish aquaculture in Rhode Island (US) coastal waters. *Environmental management*, *61*(5), 848-859.

Dempster, T., & Sanchez-Jerez, P. (2008). Aquaculture and coastal space management in Europe: An ecological perspective. In M. Holmer, K. Black, C. M. Duarte, N. Marbà, & I. Karakassis (Eds.), *Aquaculture in the ecosystem* (pp. 87-116). Springer, Dordrecht.

Diana, J. S. (2009). Aquaculture production and biodiversity conservation. *Bioscience*, *59*(1), 27-38.

Douvere, F., and Ehler, C. N. (2009). New perspectives on sea use management: Initial findings from European experience with marine spatial planning. *Journal of Environmental Management*, 90, 77–88.

Duarte, C. M., Holmer, M., Olsen, Y., Soto, D., Marbà, N., Guiu, J., Black, K., & Karakassis, I. (2009). Will the oceans help feed humanity? *BioScience*, *59*(11), 967-976.

Ely, M., Anzul, M., Vinz, R., & Downing, M. (1997). *On writing qualitative research: Living by words* (No. 12). Psychology Press.

Espinosa-Romero, M. J., Rodriguez, L. F., Weaver, A. H., Villanueva-Aznar, C., & Torre, J. (2014). The changing role of NGOs in Mexican small-scale fisheries: From environmental conservation to multi-scale governance. *Marine Policy*, 50, 290-299.

Evans, K. S., Athearn, K., Chen, X., Bell, K. P., & Johnson, T. (2016). Measuring the impact of pollution closures on commercial shellfish harvest: The case of soft-shell clams in Machias Bay, Maine. *Ocean & Coastal Management*, 130, 196-204.

Evans, K. S., Chen, X., & Robichaud, C. A. (2017). A hedonic analysis of the impact of marine aquaculture on coastal housing prices in Maine. *Agricultural and Resource Economics Review*, *46*(2), 242-267.

Fairbanks, L. (2016). Moving mussels offshore? Perceptions of offshore aquaculture policy and expansion in New England. *Ocean and Coastal Management*, *130*, 1–12.

Fairbanks, L., Boucquey, N., Campbell, L. M., & Wise, S. (2019). Remaking oceans governance: Critical perspectives on marine spatial planning. *Environment and Society*, *10*(1), 122-140.

FAO. (2018). The State of World Fisheries and Aquaculture 2018-Meeting the sustainable development goals. *Licence: CC BY-NC-SA 3.0 IGO*.

Feeny, D., Berkes, F., McCay, B. J., & Acheson, J. M. (1990). The tragedy of the commons: Twenty-two years later. *Human Ecology*, 18(1), 1-19.

Ferreira, J. G., Hawkins, A., & Bricker, S. (2011). The role of shellfish farms in provision of ecosystem goods and services. In S. E. Shumway (Eds.), *Shellfish aquaculture and the environment* (pp. 3-31). John Wiley & Sons.

Ferreira, J. G., Saurel, C., e Silva, J. L., Nunes, J. P., & Vazquez, F. (2014). Modelling of interactions between inshore and offshore aquaculture. *Aquaculture*, *426*, 154-164.

Folke, C., S. R. Carpenter, B. Walker, M. Scheffer, T. Chapin, and J. Rockström. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society,* 15(4), 20.

Forseth, T., Barlaup, B. T., Finstad, B., Fiske, P., Gjøsæter, H., Falkegård, M., Hindar, A., Atle Mo, T., Rikardsen, A. H., Thorstad, E. B., Vøllestad, L. A., Wennevik, V. (2017). The major threats to Atlantic salmon in Norway. *ICES Journal of Marine Science, 74(6), 1496-1513.*

Galappaththi, E. K., & Berkes, F. (2014). Institutions for managing common-pool resources: The case of community-based shrimp aquaculture in northwestern Sri Lanka. *Maritime Studies*, 13(1), 13.

Gelcich, S., Edwards-Jones, G., Kaiser, M. J., & Castilla, J. C. (2006). Co-management policy can reduce resilience in traditionally managed marine ecosystems. *Ecosystems*, 9(6), 951-966.

Gibbs, M. T. (2009). Implementation barriers to establishing a sustainable coastal aquaculture sector. *Marine Policy*, *33*(1), 83-89.

Graziano, A. M. & Raulin, M. L. (2012). *Research methods: A process of inquiry*. Boston: Allyn and Bacon.

Grebe, G. S., Byron, C. J., Gelais, A. S., Kotowicz, D. M., & Olson, T. K. (2019). An ecosystem approach to kelp aquaculture in the Americas and Europe. *Aquaculture Reports*, *15*, 100-215.

Gubbins M., Bricknell I., Service M. (2013). Impacts of climate change on aquaculture. *MCCIP Science Review*, 2013, 318– 327.

Gustavsson, M., & Morrissey, K. (2019). A typology of different perspectives on the spatial economic impacts of marine spatial planning. *Journal of Environmental Policy & Planning*, 21(6), 841-853.

Hanes, S.P. (2018). Aquaculture and the post-productive transition on the Maine coast. *Geographical Review,* 108(2), 185-202.

Hanna, S. (1998). Managing for human and ecological context in the Maine soft-shell clam fishery. In Berkes, F., Folke, C., & Colding, J. (Eds.) *Linking social and ecological systems: Management practices and social mechanisms for building resilience* (pp. 190). Cambridge University Press.

Henry A. M. & Johnson, T. R. (2015). Understanding social resilience in the Maine lobster industry. *Marine and Coastal Fisheries*, 7, 33–43.

Hernandez, R., Belton, B., Reardon, T., Hu, C., Zhang, X., & Ahmed, A. (2018). The "quiet revolution" in the aquaculture value chain in Bangladesh. *Aquaculture*, 493, 456-468.

Hoerterer, C., Schupp, M. F., Benkens, A., Nickiewicz, D., Krause, G., & Buck, B. H. (2020). Stakeholder perspectives on opportunities and challenges in achieving sustainable growth of the blue economy in a changing climate. *Frontiers in Marine Science*, 6, 795.

Inglis, G., Hayden, B. J., & Ross, A. H. (2000). An overview of factors affecting the carrying capacity of coastal embayments for mussel culture. National Institute of Water & Atmospheric Research. *NIWA Client Report: CHC00/69 Project No. MFE00505*.

Jayanthi, M., Duraisamy, M., Thirumurthy, S., Samynathan, M., Kabiraj, S., Manimaran, K., & Muralidhar, M. (2020). Ecosystem characteristics and environmental regulations based geospatial planning for sustainable aquaculture development. *Land Degradation & Development*, 31(16), 2430-2445.

Jentoft, S., McCay, B. J., & Wilson, D. C. (1998). Social theory and fisheries co-management. *Marine Policy*, 22(4), 423-436.

Jentoft, S. (2000). Legitimacy and disappointment in fisheries management. *Marine Policy*, 24(2), 141-148.

Jentoft, Svein. (2017). Small-scale fisheries within maritime spatial planning: Knowledge integration and power. *Journal of Environmental Policy & Planning,* 19 (3), 266–278.

Johnson, T., Wilson, J., Cleaver, C, and Vadas, R. (2012). Social-ecological scale mismatches and the collapse of the sea urchin fishery in Maine, USA. *Ecology and Society* 17(2), 259-271.

Johnson, T.R., Athearn, K., Randall, S., Garland, M., Ross, K., Cline, K., Peterson, C., Alden, R., & Guenther, C. (2015). Profiles of sixteen eastern Maine fishing communities. Maine Agricultural and Forest Experiment Station. 126.

Johnson, T. R., & Mazur, M. D. (2018). A mixed method approach to understanding the graying of Maine's lobster fleet. *Bulletin of Marine Science*, 94(3), 1185-1199.

Johnson, T.R. & Hanes, S.P. (2018). Considering social carrying capacity in the context of sustainable ecological aquaculture. In J.E. and C.P. Heidkamp (Eds.), *Towards coastal resilience and sustainability*. Routledge.

Johnson, T. R., Beard, K., Brady, D. C., Byron, C. J., Cleaver, C., Duffy, K., Keeney, N., Kimble, M., Miller, M., Moeykens, S., Teisl, M., van Walsum, G. P., & Yuan, J. (2019). A Social-ecological system framework for marine aquaculture research. *Sustainability*, *11*(9), 2522.

Jones, A. C., Mead, A., Kaiser, M. J., Austen, M. C. V, Adrian, A. W., Auchterlonie, N. A., Black, K. D., Blow, l. R., Bury, C., Brown, J. H., Burnell, G. M., Connolly, E., Dingwall, A., Derrick, S., Eno, N. C., Gautier, D. J. H., Green, K. A., Gubbins, M., Hart, P. R., Holmyard, J. M. … Green, K. A. (2015). Prioritization of knowledge needs for sustainable aquaculture: A national and global perspective. *Fish and Fisheries*, 16(4), 668-683.

Kapetsky, J. M., Aguilar-Manjarrez, J., & Jenness, J. (2013). A global assessment of offshore mariculture potential from a spatial perspective. *FAO fisheries and aquaculture technical paper*, (549), I.

Knapp, G., & Rubino, M. C. (2016). The political economics of marine aquaculture in the United States. *Reviews in Fisheries Science & Aquaculture*, *24*(3), 213–229.

Kowalska, J. D., Kazimierczak, J., Sowińska, P. M., Wójcik, E. A., Siwicki, A. K., & Dastych, J. (2020). Growing trend of fighting infections in aquaculture Environment—Opportunities and challenges of phage therapy. *Antibiotics*, 9(6), 301.

Kumar, G. & Engle, C. R. (2016). Technological advances that led to the growth of shrimp, salmon, and tilapia industries. *Reviews in Fisheries Science*, 24(2), 136–152.

Kumar, G., Engle, C., & Tucker, C. (2018). Factors driving aquaculture technology adoption. *Journal of the World Aquaculture Society*, 49(3), 447-476.

Langan, R. (2013). Mussel culture, open ocean innovations. *Sustainable Food Production*, 1229-39.

Lester, S. E., Stevens, J. M., Gentry, R. R., Kappel, C. V., Bell, T. W., Costello, C. J., Gaines, S. D., Kiefer, D. A., Maue, C. C., Rensel, J. E., Simons, R. D., Washburn, L., & White, C. (2018). Marine spatial planning makes room for offshore aquaculture in crowded coastal waters. *Nature Communications*, *9*(1), 1-13.

Lester, S. E., Gentry, R. R., Kappel, C. V., White, C., & Gaines, S. D. (2018). Offshore aquaculture in the United States: Untapped potential in need of smart policy. *Proceedings of the National Academy of Sciences*, 115(28), 7162-7165.

Lithgow, D., de la Lanza, G., & Silva, R. (2019). Ecosystem-based management strategies to improve aquaculture in developing countries: Case study of Marismas Nacionales. *Ecological Engineering*, *130*, 296-305.

Maine DMR. (2019). Maine Landings Data. Augusta, ME: State of Maine Department of Marine Resources. [Accessed 23 Jul 2020]. Available from URL: https://www.maine.gov/dmr/commercial-fishing/index.html.

Maine DMR. (2020). Maine Aquaculture Harvest Data. Augusta, ME: State of Maine Department of Marine Resources. [Accessed 15 Oct 2020]. Available from URL: https://www.maine.gov/dmr/aquaculture/harvestdata/index.html.

Maine Department of Economic & Community Development, (2020). Maine Economic Development Strategy 2020-2029. [Accessed 4 Dec 2020]. Available from URL: https://www.maine.gov/decd/strategic-plan.

Marra, J. (2005). When will we tame the oceans? *Nature*, *436*(7048), 175-176.

McClenechan, L., O'Connor, G. & Reynolds, T. (2015). Adaptive capacity of co-management systems in the face of environmental change: The soft-shell clam fishery and invasive green crabs in Maine. *Marine Policy*, 52, 26-32.

McEvoy, A. F. (1987). Toward an interactive theory of nature and culture: Ecology, production, and cognition in the California fishing industry. *Environmental Review: ER*, 11(4), 289-305.

McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: Initial changes and continuing challenges. *Ecology and Society*, *19*(2).

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd ed.). Thousand Oaks, CA: SAGE

Mizuta, D. D., & Wikfors, G. H. (2020). Can offshore HABs hinder the development of offshore mussel aquaculture in the northeast United States? *Ocean & Coastal Management*, 183, 105022.

Morse, D., & Rice, M. A. (2010). Mussel aquaculture in the northeast. *Northeastern Regional Aquaculture Center Publication*, *211*(10).

Murray, G., Wolff, K., & Patterson, M. (2017). Why eat fish? Factors influencing seafood consumer choices in British Columbia, Canada. *Ocean & Coastal Management*, 144, 16-22.

Neumann, B., Vafeidis, A.T., Zimmermann, J., Nicholls, R.J., 2015. Future coastal population growth and exposure to sea-level rise and coastal flooding – A global assessment. *PLoS One,* 10 (3).

á Norði, G., Simonsen, K., Danielsen, E., Eliasen, K., Mols-Mortensen, A., Christiansen, D. H., Steingrund, P., Galbraith, M. & Patursson, Ø. (2015). Abundance and distribution of planktonic Lepeophtheirus salmonis and Caligus elongatus in a fish farming region in the Faroe Islands. *Aquaculture Environment Interactions*, *7*(1), 15-27.

Nutters, H. M., & da Silva, P. P. (2012). Fishery stakeholder engagement and marine spatial planning: Lessons from the Rhode Island Ocean SAMP and the Massachusetts Ocean Management Plan. *Ocean & Coastal Management*, *67*, 9-18.

Obiero, K. O., Waidbacher, H., Nyawanda, B. O., Munguti, J. M., Manyala, J. O., & Kaunda-Arara, B. (2019). Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya. *Aquaculture International*, 27(6), 1689-1707.

Osmundsen, T. C., & Olsen, M. S. (2017). The imperishable controversy over aquaculture. *Marine Policy*, *76*, 136–142.

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press.

Ostrom, E. (2008). Design principles of robust property–rights institutions: What have we learned. In G. K. Igram & Y. H. Hong (Eds.), Property rights and land policies (215-248). Columbia University Press.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419-422.

Parker, M., & Bricker, S. (2020). Sustainable oyster aquaculture, water quality improvement, and ecosystem service value potential in Maryland Chesapeake Bay. *Journal of Shellfish Research*, 39(2), 269-281.

Pershing, A. J., Alexander, M. A., Hernandez, C. M., Kerr, L. A., Le Bris, A., Mills, K. E., Nye, J. A., Record, N. R., Scannell, H. A., Scott, J. D., Sherwood, G. D., & Thomas, A. C. (2015). Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery. *Science*, *350*(6262), 809-812.

Petersen, J. K., Hasler, B., Timmermann, K., Nielsen, P., Tørring, D. B., Larsen, M. M., & Holmer, M. (2014). Mussels as a tool for mitigation of nutrients in the marine environment. *Marine Pollution Bulletin*, *82*(1-2), 137-143.

Pieck, S. K. (2020). Cristina Balboa: The paradox of scale: How NGOs build, maintain, and lose authority in environmental governance. *Voluntas*, 31(1), 250-251.

Pinkerton, E. (2015). The role of moral economy in two British Columbia fisheries. *Marine Policy,* 61, 410-419.

Pomeroy, R. S., & Berkes, F. (1997). Two to tango: The role of government in fisheries co-management. *Marine Policy*, 21(5), 465-480.

Poret, S. (2019a). Corporate–NGO partnerships through sustainability labeling schemes: Motives and risks. *Sustainability*, 11(9), 2689-19.

Poret, S. (2019b). Corporate–NGO partnerships through sustainability labeling schemes: Motives and risks. *Sustainability*, 11(9), 2689-19.

Potts, T., & Haward, M. (2007). International trade, eco-labelling, and sustainable fisheries—Recent issues, concepts and practices. *Environment, Development and Sustainability*, 9(1), 91–106.

Potts, J., Lynch, M., Wilkings, A., Huppé, G., Cunningham, M., & Voora, V. (2014). *The state of sustainability initiatives review 2014 Standards and the green economy*. London: International Institute for Sustainable Development (IISD) and the International Institute for Environment and Development (IIED).

Pretty, J., & Ward, H. (2001). Social capital and the environment. *World Development*, *29*(2), 209-227.

Raberg, L. M., & Rudel, T. K. (2007). Where are the sustainable forestry projects?: A geography of NGO interventions in Ecuador. *Applied Geography*, 27(3), 131-149.

Ricketts, P. J., & Hildebrand, L. (2011). Coastal and ocean management in Canada: Progress or paralysis? *Coastal Management, 39(1), 4-19.*

Saldaña, J. (2015). *The coding manual for qualitative researchers* (3rd ed.). SAGE Publications.

Schouten, G., Vellema, S., & Wijk, J. V. (2016). Diffusion of global sustainability standards: The institutional fit of the ASC-shrimp standard in Indonesia. *Revista De Administração De Empresas*, 56(4), 411-423.

Sen, K., Erdogan, U. H., & Cavas, L. (2020). Prevention of biofouling on aquaculture nets with eco-friendly antifouling paint formulation. *Coloration Technology*, 136(2), 120-129.

Shava, E., & Gunhidzirai, C. (2017). Fish farming as an innovative strategy for promoting food security in drought risk regions of Zimbabwe. *Jàmbá: Journal of Disaster Risk Studies*, 9(1), 491.

Soto, D., Aguilar-Manjarrez, J., Brugère, C., Angel, D., Bailey, C., Black, K., Edwards, P., Costa-Pierce, B., Chopin, T., Deudero, S., Freeman, S., Hambrey, J., Hishamunda, N., Knowler, D., Silvert, W., Marba, N., Mathe, S., Norambuena, R., Simard, F., Tett, P., Troell, M., & Wainberg, A. (2007). Applying an ecosystem-based approach to aquaculture: Principles, scales and some management measures. In *Building an ecosystem approach to aquaculture. FAO/Universitat de les Illes Balears Expert Workshop*, 7, 15-78.

Spillman, C M, Hartog, J. R., Hobday, A. J., & Hudson, D. (2015). Predicting environmental drivers for prawn aquaculture production to aid improved farm management. *Aquaculture*, *447*, 56–65.

Sultana, P., & Abeyasekera, S. (2008). Effectiveness of participatory planning for community management of fisheries in Bangladesh. *Journal of Environmental Management*, 86(1), 201-213.

Tafon, R. V. (2018). Taking Power to Sea: Towards a Post-Structuralist Discourse Theoretical Critique of Marine Spatial Planning. *Environment and Planning C: Politics and Space*, 36 (2), 258–273.

Tashakkori, A., & Teddlie, C. (Eds.). (2010). *Sage handbook of mixed methods in social & behavioral research.* SAGE Publications.

Thomas, J. E., Nordström, J., Risén, E., Malmström, M. E., & Gröndahl, F. (2018;2017;). The perception of aquaculture on the Swedish West Coast. *Ambio*, 47(4), 398-409.

Thompson, C., Johnson, T., & Hanes, S. (2016). Vulnerability of fishing communities undergoing gentrification. *Journal of Rural Studies*, *45*, 165-174.

Tlusty, M. F., Tyedmers, P., Bailey, M., Ziegler, F., Henriksson, P. J. G., Béné, C., Bush, S., Newton, R., Asche, F., Little, D. C., Troell, M., & Jonell, M. (2019). Reframing the sustainable seafood narrative. *Global Environmental Change*, 59, 101991.

Underwood, J. M. (1996). Intertidal zone aquaculture and the public trust doctrine. *Ocean & Coastal LJ*, 2, 383.

United Nations World Tourism Organization. 2019. Tourism Statistics Data. Madrid, Spain. [Accessed 26 Jan 2021]. Available from URL: https://www.unwto.org/tourism-statistics-data.

Veettil, B. K., Ward, R. D., Quang, N. X., Trang, N. T. T., & Giang, T. H. (2019). Mangroves of Vietnam: Historical development, current state of research and future threats. *Estuarine, Coastal and Shelf Science*, 218, 212-236.

Vormedal, I. (2017). Corporate strategies in environmental governance: Marine harvest and regulatory change for sustainable aquaculture. *Environmental Policy and Governance*, 27(1), 45-58.

Ward, T., & Phillips, B. (Eds.). (2009). *Seafood ecolabelling: Principles and practice*. John Wiley & Sons.

Whitmarsh, D., & Palmieri, M. G. (2008). Aquaculture in the coastal zone: Pressures, interactions and externalities. In M. Holmer, K. Black, C. M. Duarte, N. Marbà, & I. Karakassis (Eds.), *Aquaculture in the Ecosystem* (pp. 251-269). Springer, Dordrecht.

Wijen, F., & Chiroleu-Assouline, M. (2019). Controversy over voluntary environmental standards: A socioeconomic analysis of the marine stewardship council. *Organization & Environment*, 32(2), 98-124.

Wright, G., Wright, G., Andersson, K., & Andersson, K. (2013). Non-governmental organizations, rural communities and forests: A comparative analysis of community-NGO interactions. *Small-Scale Forestry*, 12(1), 33-50.

World Travel and Tourism Council. (2020). Economic Impact Reports. London, United Kingdom. [Accessed 25 Jan 2021]. Available from URL: https://wttc.org/Research/Economic-Impact.

Young, N., Brattland, C., Digiovanni, C., Hersoug, B., Johnsen, J. P., Karlsen, K. M., Kvalvik, I., Oloffsen, E., Simonsen, K., Solås, A. & Thorarensen, H. (2019). Limitations to growth: Social-ecological challenges to aquaculture development in five wealthy nations. *Marine Policy*, 104, 216–224.

BIOGRAPHY OF THE AUTHOR

Molly Miller was born in Berlin, New Hampshire on August 15, 1988. She was raised in Medway, Massachusetts and graduated from Medway High School in 2006. She attended Vassar College and graduated in 2010 with a Bachelor's degree in Biology with a concentration in French. She worked at the Mount Desert Island Biological laboratory from 2011 to 2012 doing eelgrass conservation and restoration. She then attended the University of Hawai'i at Mānoa where she received a Master of Science in Natural Resource and Environmental Management and a concentration in Ecology, Evolution and Conservation Biology in 2014. She returned to Maine and entered the Ecology and Environmental Science graduate program at The University of Maine in the fall of 2015. Molly is a candidate for a Doctor of Philosophy degree from the University of Maine in May, 2021.