Barriers to and Opportunities for Adoption in Maine’s Aquaculture Industry

Caitlin Cleaver
University of Maine, caitlin.cleaver@maine.edu

Follow this and additional works at: https://digitalcommons.library.umaine.edu/etd

Part of the Aquaculture and Fisheries Commons, and the Environmental Sciences Commons

Recommended Citation
Cleaver, Caitlin, "Barriers to and Opportunities for Adoption in Maine’s Aquaculture Industry" (2022). Electronic Theses and Dissertations. 3729.
https://digitalcommons.library.umaine.edu/etd/3729

This Open-Access Dissertation is brought to you for free and open access by DigitalCommons@UMaine. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of DigitalCommons@UMaine. For more information, please contact um.library.technical.services@maine.edu.
BARRIERS TO AND OPPORTUNITIES FOR ADOPTION IN

MAINE'S AQUACULTURE INDUSTRY

By

Caitlin Cleaver

B.A. Colby College, 2006

M.P.A. Columbia University, 2010

M.S. and M.S. University of Maine, 2014

A DISSERTATION

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

(in Ecology and Environmental Science)

The Graduate School

The University of Maine

December 2022

Advisory Committee:

Teresa R. Johnson, Associate Professor, School of Marine Sciences, Advisor

Christopher Davis, Executive Director, Maine Aquaculture Innovation Center

Samuel P. Hanes, Associate Professor and Chair, Department of Anthropology

Paul Rawson, Professor, School of Marine Sciences

Mario Teisl, Professor and Director, School of Economics
BARRIERS TO AND OPPORTUNITIES FOR ADOPTION IN

MAINE’S AQUACULTURE INDUSTRY

By Caitlin Cleaver

Dissertation Advisor: Dr. Teresa Johnson

An Abstract of the Dissertation Presented
in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy
(in Ecology & Environmental Sciences)
December 2022

Aquaculture, or the farming of marine species, can diversify coastal economies, but development of this industry is hindered by negative perceptions or regulatory constraints. Commercial fishers are logical adopters of aquaculture, but can also mount opposition to its growth. This dissertation utilized innovation theory to understand fishers’ perceptions of and willingness to adopt aquaculture and drivers of and barriers to scallop aquaculture development in Maine (USA).

Through a mail survey, lobster fishers’ perceptions of Maine’s aquaculture industry and their willingness to adopt aquaculture were assessed (Chapter 2). Individuals who were more satisfied with government management of aquaculture held more positive views while those who believed the number of farms and rate of aquaculture growth in the area in which they fished were too high and that aquaculture damaged the environment were more likely to hold negative views. Those who viewed aquaculture positively, had considered it in the past, had fished longer, and were diversified within fisheries were more likely to consider adoption while older individuals who derived a greater percentage of their income from commercial fishing were less likely to consider adoption.

Given the interest in facilitating fisher adoption of aquaculture, this dissertation explored the adoption process through interviews with fishers who had taken aquaculture training programs or were farming (Chapter 3). The majority were farming species with established husbandry practices or markets
and that aligned with commercial fishing activities. Fishers who would consider aquaculture in the future identified start-up costs as a barrier.

Innovation system approaches consider the broader context within which individual adoption occurs. Applying the Technological Innovation Systems framework to data collected through interviews with key informants and a document analysis, factors important to scallop aquaculture development were identified. These included a need to increase market demand and establish all aspects of the supply chain (Chapter 4).

To facilitate fisher adoption, training efforts should focus on younger fishers and business models that allow aquaculture operations to be viable at multiple scales should be supported. Given the variability in commercial fisheries, aquaculture is an opportunity to maintain Maine’s working waterfronts and maritime heritage (Chapter 5).
ACKNOWLEDGEMENTS

I would like to thank my advisor and committee members who offered their guidance and were incredibly patient as I navigated this degree program while also working. I am also deeply appreciative of the individuals who were willing to participate in interviews and surveys. Without their participation, this research would not have been possible. This work was supported by the National Science Foundation award #IIA-1355457 to Maine EPSCoR at The University of Maine, The University of Maine Graduate Student Government, and Maine Sea Grant Program Development Funds.

I am indebted to my supervisors who saw the value in my pursuit of a PhD while also working for various organizations over the years. I truly appreciate the opportunity to continue my education while also gaining applied, real-world experience working on coastal issues and I hope that some of what I learned throughout my PhD program made me more effective in my work. Of course, this would not have been possible without the support of my partner. Throughout this degree program, we navigated having two children, three job changes, starting a lobstering business, moving from Thomaston to Brunswick, and the global COVID-19 pandemic. It has been a long road and I appreciate the constant encouragement and support throughout. To my parents, friends and colleagues, thank you for your time spent watching the kids, cooking meals, listening to me talk through my ideas, providing guidance, reading drafts, etc. This has truly been a collective effort.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS .............................................................................................................................. ii

LIST OF TABLES ............................................................................................................................................... vi

LIST OF FIGURES .......................................................................................................................................... viii

1. INTRODUCTION ........................................................................................................................................... 1
   1.1. Researcher Background ......................................................................................................................... 1
   1.2. Aquaculture Development .................................................................................................................... 3
   1.3. Innovation Theory .................................................................................................................................. 6
   1.4. Summary of Research ............................................................................................................................ 9
   1.5. Significance ............................................................................................................................................ 11

2. FACTORS INFLUENCING LOBSTER FISHERS' PERCEPTIONS OF AQUACULTURE AND THEIR WILLINGNESS TO ADOPT ................................................................................................................. 12
   2.1. Introduction ............................................................................................................................................. 12
   2.1.1. Stakeholder Perceptions of Aquaculture .......................................................................................... 13
   2.1.2. Aquaculture as a Diversification Strategy ......................................................................................... 15
   2.1.3. Adoption of Aquaculture .................................................................................................................. 16
   2.2. Study Site .............................................................................................................................................. 18
   2.3. Methods .................................................................................................................................................. 21
   2.3.1. Survey Distribution .......................................................................................................................... 21
   2.3.2. Data Analysis .................................................................................................................................... 22
   2.4. Results ................................................................................................................................................... 28
   2.4.1. Characteristics of Survey Respondents ............................................................................................. 28
   2.4.2. Perceptions of Aquaculture ............................................................................................................... 29
   2.4.3. Ordinal Logistic Regression for View of Aquaculture ...................................................................... 30
LIST OF TABLES

Table 2.1. Variables used in the Ordinal Logistic Regression models to determine factors driving an individual’s view of Maine’s marine aquaculture industry (View). ................................................................. 24

Table 2.2. Variables used in the Ordinal Logistic Regression models to determine factors driving an individual’s interest in being employed or adopting aquaculture (Adopt). ........................................................................................................ 26

Table 2.3. Statistically significant results for chi-square test of independence when comparing variables by lobster management zone...................................................... 27

Table 2.4. Survey distribution and returns by lobster management zone.......................... 28

Table 2.5. Percentage of responses in each category of Likert-scale type statements about different aspects of aquaculture (N=number of respondents. Mean and Standard Deviation calculated based on responses to 6-point Likert scale responses, possible responses were SD1=Strongly disagree, D=Disagree, SD2=Somewhat disagree, SA2= Somewhat agree, A=Agree, SA1=Strongly agree.) ........................................................................................................ 30

Table 2.6. Ordinal logistic regression parameter estimates, standard errors, and odds ratios of views of aquaculture for lobster license holders in Maine. (n=283)........................................................................................................ 31

Table 2.7. Percentage of responses to the question: “Have you ever considered or tried marine aquaculture as an alternative or addition to your occupation?” (n=390)........................................................................................................ 32
Table 2.8  Ordinal logistic regression parameter estimates, standard errors and odds ratios of being employed in aquaculture within the next 5 years for lobster license holders in Maine (n=256).

Table 3.1  Table 3.1. Characteristics of respondents summarized as all respondents and by adoption status, including adopters, potential adopters and non-adopters.

Table 3.2  Education level by adoption status.
LIST OF FIGURES

Figure 2.1. New Limited Purpose Aquaculture licenses applied for each year between 2007 and 2021. (Maine DMR, 2022a) ......................................................... 19

Figure 2.2. New leases issued per year between 2009 and 2021. (Maine DMR, 2022a) .......... 20

Figure 4.1. Number of events by function over 5-year time periods from 1986 - 2020.
Events include research projects, meetings, workshops, conference presentations and other activities related to scallop aquaculture development. ................................................................. 82

Figure 4.2. Total number of active standard and experimental leases with sea scallops listed as a cultured species. Data includes lease information from 1987 to 2022. (Data source: Maine DMR data request, May 2022) ................. 84

Figure 4.3. Total number of active Limited Purpose Aquaculture licenses (LPAs) with sea scallop as a listed cultured species from 2005 through 2022.
(Data source: Maine DMR data request, May 2022) ........................................ 84

Figure 4.4. Percent of research projects by scallop farming stage that have been implemented between 1985 - 2020 by stage of the scallop farming process. ........ 85
CHAPTER 1

INTRODUCTION

1.1. Researcher Background

My research interests are within the applied marine social and ecological sciences and I seek to support community stakeholder questions through scientific research approaches. Working as a practitioner on coastal issues, I have helped develop a policy toolkit for preserving working waterfronts, collaborated with commercial fishers to understand the effect of a small-scale closed area on the local sea scallop population, and supported a community project to build an oyster reef in coastal Maine waters. Additionally, I have lived and worked in Maine coastal communities for more than ten years and I am tied to the lobster and scallop fishing and aquaculture industries through personal relationships and professional service. These connections and my vested interest in the improving the resilience of coastal communities to withstand social and ecological changes have influenced my research interests and approach. Ultimately, I believe in conducting scientific research that helps address real-world problems through an applied approach and with the goal of informing solutions (Ivankova, 2014). Given this, I align most closely with the pragmatist research paradigm, which allows for shifting between different paradigms depending on the research question being explored (Creswell & Clark, 2017).

I believe it is important to acknowledge my personal connections to the Maine lobster industry and fishers who are considering the adoption of aquaculture, which are the focus of Chapter 2 and Chapter 3 as well as to the development of the scallop aquaculture industry, which is the focus of Chapter 4. My partner is a lobster license holder and a full-time lobster fisher. He is also a member of Interstate Co-op in Harpswell, Maine. Given the uncertainty in the Maine lobster fishery, he has future plans to implement kelp aquaculture as a diversification strategy to buffer against these potential changes. Since 2018, I have served on the board of the Maine Aquaculture Co-op (MAC) as secretary. The MAC supports individuals in farming the Atlantic sea scallop (*Placopesten magellanicus*). My role...
has primarily entailed coordinating MAC meetings, writing proposals to secure grant funding and conducting collaborative research in partnership with MAC members.

These personal connections influenced my research interests and approach, which also led me to work with Dr. Teresa Johnson at the University of Maine who considers herself an applied marine social scientist. She and her students were conducting ongoing research with the Aquaculture in Shared Waters program, a course aimed at training commercial fishers in aquaculture (i.e., Pianka, 2016). Additionally, she and others at The University of Maine secured funding through the National Science Foundation (Award #IIA-1355457) to support sustainable aquaculture development in Maine. The Sustainable Ecological Aquaculture Network (SEANET) was an interdisciplinary team of faculty, researchers and students from over nine different disciplines focused on informing aquaculture development through research; my dissertation research fell within SEANET’s efforts.

In terms of the research process for this dissertation, the development of interview guides and survey instruments was done in partnership with Dr. Johnson, other faculty and graduate students, relying on past guides and interviews used in similar research. I believe this helped minimize bias from my personal connections and experience with the commercial fishing and aquaculture industries in Maine. To identify respondents to participate in this research, individuals were selected in three different ways – 1) randomly from a Maine Department of Marine Resources lobster license holder list for the mail survey (Chapter 2), 2) purposively, using participant sign-up and attendance lists from aquaculture training programs with some of these individuals having participated in past surveys and interviews conducted by the Johnson lab (Chapter 3) and 3) through personal connections from work with the Maine Aquaculture Co-op and via snowball sampling from names given by key informants or individuals knowledgeable and involved in scallop aquaculture industry development in Maine (Chapter 4). In building rapport with respondents during interviews, I did occasionally, but not consistently mention that my partner was also a commercial fisher. When I mentioned this connection to the fishing
industry, it likely influenced responses. In some cases, this detail may have allowed individuals to feel more comfortable with me, recognizing that we may have had some shared experiences resulting in them speaking more freely while in other instances, it may have limited their responses or they may have said what they thought I wanted to hear, knowing that I was familiar with the commercial fishing industry.

In analyzing survey results and interpreting interview transcripts, I was well aware that in Maine, aquaculture development can be contentious and that practitioners are interested in aquaculture being a diversification strategy for commercial fishers while also seeing one of the phenomena I was studying (i.e., fisher adoption of aquaculture) play out within my own household; my partner started his own lobstering operation in 2019 after having worked on lobster boats for a number of years. He had also completed the 2016 Aquaculture in Shared Waters training program and had plans to eventually farm kelp once his lobstering business was more established. I did rely on my personal observations of my partner’s process of adoption to confirm some of the themes emerging from coding the interviews in Chapter 3. Finally, I also care deeply about the future of Maine coastal communities and have a vested interest in maintaining Maine’s working waterfrocks and livelihoods. Given that, my interpretation of results and recommendations made from the results are likely biased towards balancing aquaculture development with commercial fishing and also for facilitating fisher adoption of aquaculture with a focus on ways to reduce barriers to entering the aquaculture industry.

1.2. Aquaculture Development

Aquaculture production, or the farming of marine and aquatic organisms, generates more than half of the global supply of seafood and continues to outpace the growth of production from wild-capture fisheries (FAO, 2020). Aquaculture can contribute to the world’s food supply, decrease seafood trade deficits, diversify coastal community economies and fishing-dependent livelihoods, and reduce pressure on declining wild stocks (FAO, 2020). Many countries aim to increase aquaculture activity
within their coastal waters through supportive policies and investments in research, technology and infrastructure related to aquaculture development (Young et al., 2019).

In 2018, the US ranked 17\textsuperscript{th} in global aquaculture production with a total of 680 million pounds produced valued at $1.5 billion (National Marine Fisheries Service, 2021). Comparing marine aquaculture production and value in 2018 to the previous year, production increased by 9.4 million pounds or by 10.7\% and increased in value by $8.4 million or by 2\% (National Marine Fisheries Service, 2021). Atlantic salmon is the primary species farmed for marine finfish while oysters dominate shellfish production. The Gulf of Mexico produces the highest volume of shellfish while the Atlantic and Pacific coasts produce more shellfish by value (National Marine Fisheries Service, 2021). The US imports approximately 70 to 85\% of its seafood, of which more than half is produced through aquaculture (National Marine Fisheries Service, 2021). US aquaculture development has been plagued by negative public perception, lack of education and awareness about the industry, conflict with others users over ocean space, and governance issues (Knapp & Rubino, 2016; Lester et al., 2018). However, Zajicek et al. (2021) critique these assumptions about the constraints to marine aquaculture growth in the US and believe that this narrative, which focuses on barriers to development has undermined public support for aquaculture. Regardless, studies have found that the growth of aquaculture leads to conflicts between various coastal stakeholders in some situations (Knapp, 2012; Noakes et al., 2003; Hanes, 2018).

In Maine, the aquaculture sector is growing and is an important contributor to the local economy (Sadusky et al., 2022). The total economic impact of aquaculture in Maine increased three-fold since 2007 (Cole et al., 2016). Maine aquaculture production and value are dominated by the Atlantic salmon (\textit{Salmo salar}), Eastern oysters (\textit{Crassostrea virginica}), blue mussel (\textit{Mytilus edulis}), and more recently sugar kelp (\textit{Saccharina latissimi}), skinny kelp (\textit{Saccharina angustissima}), and winged kelp (\textit{Alaria esculenta}) (Maine Department of Marine Resources, 2022a). Other species grown include: Atlantic sea
scallops (*Placopecten magellanicus*), quahogs (*Mercenaria mercenaria*), and razor clam (*Ensis directus*) (Maine Department of Marine Resources, 2022a).

In order to grow marine species in Maine coastal waters, individuals or firms must submit a lease application to the Maine Department of Marine Resources, which if approved, provides access to a defined area of ocean space (Maine Department of Marine Resources, 2022a). Individuals or businesses can obtain a standard lease which permits aquaculture activities within an area up to 100 acres and for 20 years, with the option for the lease term to be renewed. Experimental leases permit activities for three years without the option to renew unless the aquaculture activity is for educational or scientific purposes. Experimental leases can be up to four acres in size. The Limited Purpose Aquaculture license (LPA) is only available to individuals, not businesses, and provides access to 400 square feet for one year with the option to renew. By 2021, there were 187 active experimental or standard leases totaling approximately 1,700 acres and 804 active Limited Purpose Aquaculture licenses (Maine Department of Marine Resources, 2022a).

The Maine lobster fishery, the largest commercial fishery in the state, is in a precarious situation with increasing rates of shell disease and regulatory oversight to protect the endangered North Atlantic right whale as well as continued market uncertainty; all of which are unfolding within the context of a rapidly warming Gulf of Maine (Acheson & Acheson, 2020). Aquaculture development is increasing and is viewed as an opportunity to diversify traditional maritime industries and working waterfronts at a time of high economic and environmental uncertainty in commercial fisheries (Sadusky et al., 2022). Livelihood diversification as a strategy to stabilize fishing-dependent livelihoods is well established (e.g., Kasperski & Holland, 2013) and aquaculture is often a livelihood alternative advocated for commercial fishers (e.g., Weeks, 1992; Jeffrey et al., 2021). Indeed, commercial fishers are often adopters of aquaculture (Weeks, 1992; Jeffrey et al., 2021; Conejo-Watt et al., 2021). To identify barriers and opportunities to aquaculture development and its potential as a livelihood diversification strategy,
researchers have applied adoption of innovation as well as systems of innovation theories (e.g., Tango-Lowy & Robertson, 2002; Pianka, 2016; Joffre et al., 2017; Cleaver et al., 2018; Joffre et al., 2018). Given the changes occurring in fisheries and aquaculture and the potential for aquaculture to be a diversification strategy for commercial fishers, Maine provides an excellent case study to explore the implications of a growing aquaculture sector within the context of environmental and social change in coastal communities (Johnson et al., 2019).

1.3. Innovation Theory

An innovation is defined as a belief, object or practice that is perceived to be new to the individual considering the uptake or adoption of that innovation (Rogers, 2003). Diffusion is the process of innovation invention or modification followed by information spread about the innovation among members of a social system where individuals decide to adopt or reject the innovation (Rogers, 2003). The process of diffusion results in social change where the structure or function of a social system is altered as a result of innovation adoption or rejection by individuals within that system (Rogers, 2003).

Four elements are important in studies of diffusion and include 1) aspects of the innovation or technology, 2) communication channels through which information about the innovation or technology spreads, 3) the period of time over which individuals are considering the uptake of the focus technology, and 4) the individuals in the social group or system (Rogers, 2003).

Rogers (2003) and others from a number of different social science disciplines have explored patterns in adoption decisions by relating individual characteristics to decisions to adopt or reject an innovation. Certain characteristics, including education, age or income level for example, have been found to be relevant in a number of different adoption studies allowing for the generalization about individuals who tend to adopt innovations as compared to those individuals who tend to not adopt innovations (Rogers, 2003). Researchers have critiqued this approach and the potential to generalize about adopters and non-adopters citing the importance of a match between the potential adopter’s
needs and characteristics of the innovation to adoption decisions (Acheson & Reidman, 1982). In other words, adoption decisions can be situational where in one instance an individual may choose to adopt while in another, that same individual would not adopt or the decision whether or not to adopt can change over time. Levine and McCay (1987) confirmed the importance of the match between the potential adopter’s situation and aspects of the innovation in order to facilitate adoption of the innovation.

Commercial fishers are often considered innovative in that they regularly adapt their fishing techniques and equipment to match changing ecological and regulatory environments. In one study involving commercial fishers, learning about an innovation through peers facilitated adoption of that innovation (Acheson & Wilson, 1980). In additional studies specific to commercial fishers, education level played a role in their adoption of innovations (Acheson & Reidman, 1982; Dewees & Hawkes, 1988). Few studies have specifically examined the adoption of aquaculture by commercial fishers. Tango-Lowy and Robertson (2002) found that fishers who were more likely to adopt had less commercial fishing experience in terms of the number of years participating in fisheries, but they were more diversified in the number of fisheries they accessed. Tango-Lowy and Robertson (2002) reasoned that those individuals who had spent more time in commercial fisheries were more entrenched in their existing livelihood of fishing and therefore, adopting an alternative livelihood, such as aquaculture, was unlikely (Tango-Lowy & Robertson, 2002). Jeffrey et al. (2021) conducted an extensive literature review and explored cases where commercial fisheries and finfish, seaweed and shellfish aquaculture had been integrated. Barriers to integration included lack of capital, regulations, competition over ocean space, negative perceptions of aquaculture, and individual characteristics such as age, education, and skills as well as a commitment to occupational identity associated with commercial fishing (Jeffrey et al., 2021). Jeffrey et al. (2021) recommended providing capital, clarifying regulations and not underestimating the impact of economies of scale in aquaculture where the level of investment required to attain
profitability of operation can be quite great in well-established aquaculture industries such as finfish. They also highlighted the overlap between commercial fisheries and aquaculture and that fishers likely possess the skills necessary to be successful with aquaculture (Jeffrey et al., 2021).

A number of studies that conceptualize innovation as it relates to aquaculture focus on technology transfer at the farm level, ignoring the complex system within which individuals are making adoption decisions and innovations are developing and diffusing (Joffre et al., 2017). Systems approaches to understanding the innovation process can identify system-level factors important to developing that particular innovation (Joffre et al., 2017) and facilitating subsequent adoption and diffusion within a social system. Diffusion of an innovation is a coevolutionary process linking technical knowledge, socio-cultural values, social innovation and power structures (Haasnoot et al., 2016; Paredis, 2011). To capture the complexity and multidimensional context within which innovation development and diffusion takes place, a systems approach examines the “…economic, social, political, organizational, institutional and other factors that influence development, diffusion, and use of innovations” (Edquist, 1997, p. 14). Utilizing a systems approach to understand innovation within aquaculture could anticipate and identify potential negative consequences associated with the intensification of aquaculture development and ultimately, lead to more ecologically and socially sustainable outcomes (Joffre et al., 2017; Bush & Marschke, 2014).

Using the case of Maine (US) and applying innovation theories, this dissertation examines the following questions:

1. What factors drive general aquaculture perceptions and willingness to adopt aquaculture among Maine’s lobster license holders? (Chapter 2)

2. For commercial fishers who have participated in one or more commercial fisheries in Maine and who are adopting aquaculture: Who are they (characteristics and fishing history)? What
motivated their decision to adopt? What challenges did they face at the time of adoption? How are they balancing (or not) aquaculture and commercial fishing? (Chapter 3)

3. For commercial fishers who considered, but chose not to adopt: What barriers did they face? Would they consider implementing aquaculture in the future and if so, what would they need to get started? (Chapter 3)

4. What factors drive or inhibit adoption and diffusion of aquaculture at the industry level? (Chapter 4)

1.4. Summary of Research

In Chapter 2, this dissertation sought to understand the factors that drive Maine lobster fishers’ perceptions of aquaculture and their willingness to adopt aquaculture. Through a structured mail survey to Maine lobster license holders and using two separate Ordinal Logistic Regression models, several factors driving aquaculture perceptions and willingness to adopt aquaculture were identified. Findings from this study contribute to the literature on commercial fisher perceptions of aquaculture and to the literature on livelihood diversification for commercial fishers. In this case, commercial fishers did not express negative perceptions of aquaculture which is contrary to some studies that have highlighted conflicts between the commercial fishing and aquaculture sectors. Additionally, this study confirmed that certain individual and fishing history characteristics as well as perceptions of aquaculture indicated a predisposition for aquaculture adoption among only a minority of lobster license holders. However, the survey sample was older, could be close to retirement and may not be considering a new business venture such as aquaculture adoption. Based on this study, aquaculture as a diversification strategy will likely not be a solution for a majority of Maine lobster fishers, particularly for those who are older.

Acknowledging that the decision to adopt an innovation can be a complex process over a period of time and requires a match between the attributes of the innovation and the potential adopter’s situation, the study in Chapter 3 examined the experience of commercial fishers who had considered
aquaculture and either decided to adopt aquaculture or not. Forty-two semi-structured interviews were conducted with individuals who had participated in commercial fisheries and had indicated some interest in aquaculture either by signing up for an aquaculture training program or having obtained an aquaculture lease or license. Results indicated that the majority of those who had adopted aquaculture at the time of the interviews were also interested in maintaining their commercial fishing activities. They were most interested in farming species that aligned with their commercial fishing activities or had established husbandry practices, a low cost of entry, or established markets such as kelp or oysters. Most individuals who did not adopt aquaculture at the time of the interview, said that they would consider aquaculture again in the future and that they would need financial support and more time in order to implement aquaculture. This highlights that non-adopters may be eventual adopters and that categorizing individuals as a non-adopter or adopter can be somewhat arbitrary. A non-adopter may shift to adopter if their individual circumstances change. To facilitate fisher adoption of aquaculture, barriers such as the cost of getting started should be addressed.

Individual level adoption decisions happen within a broader context and system-level factors such as the regulatory environment can play a role in influencing adoption decisions. Therefore, the study in Chapter 4 shifts from a focus of individual level adoption to a systems perspective where the complexity of the innovation process was examined through a case study of the Maine scallop aquaculture industry. The Technological Innovation System functional performance framework was used to identify areas where the scallop aquaculture industry can be improved to further facilitate development and diffusion of the technology. Semi-structured interviews were conducted with industry experts and farmers and a process analysis was carried out. A database of events was collated by reviewing documents, reports and newspaper articles related to scallop aquaculture development from 1985 to 2021. Findings indicated that the Maine scallop aquaculture industry was performing well in the Technological Innovation System functions of knowledge development, knowledge exchange and
resource mobilization, in terms of human and financial capital, but would benefit from additional efforts to create a market for farmed scallops and establish all aspects of the supply chain such as encouraging marine supply companies to stock equipment needed to farm scallops and to service specialized equipment needed to increase the scale of farm operation.

1.5. Significance

Overall, this dissertation contributes to innovation theory as it relates to aquaculture development, both at the individual and the systems levels. Findings inform a deeper understanding of the potential role aquaculture can play in diversifying fishing-dependent livelihoods and how individuals can balance commercial fishing and aquaculture, specifically in Maine where aquaculture is growing and the future of commercial fisheries is uncertain. At a systems level, identifying the challenges and opportunities for developing culture techniques and establishing an aquaculture industry for a species not previously farmed can help inform the development of a more diverse aquaculture sector in terms of the number of species cultivated. Additionally, the systems level approach shows the complexity of the context within which individuals are considering the adoption of innovations. A more diverse sector could potentially make Maine aquaculture more resilient to environmental and market variability (Bricknell et al., 2021).
CHAPTER 2
FACTORS INFLUENCING MAINE LOBSTER FISHERS’ PERCEPTIONS OF AQUACULTURE AND THEIR WILLINGNESS TO ADOPT

2.1. Introduction

Globally, aquaculture production continues to increase and is often looked to as an opportunity to diversify coastal communities and improve resilience to environmental and market variability. A number of countries have significant potential to increase aquaculture production; however, aquaculture activity is growing more slowly than anticipated in many developed nations, including the US (Young et al., 2019). Barriers to aquaculture growth include negative perceptions of the industry by different stakeholder groups (Knapp & Rubino, 2016). Commercial fishers are a stakeholder group often in opposition to aquaculture for a number of reasons including fears that aquaculture species will negatively impact or directly compete with wild-capture product in the market and that aquaculture activity will occur in ocean space traditionally used for commercial fishing (Chu et al., 2010; Tiller et al., 2013). Despite these areas of conflict between aquaculture and commercial fisheries, aquaculture is often considered a diversification strategy for coastal communities should the productivity of wild-capture fisheries decline (Jeffrey et al., 2021; Bricknell et al., 2021). The success of this strategy is dependent upon the willingness of individual fishers to implement or adopt aquaculture. Therefore, understanding commercial fishers’ perceptions of aquaculture and their willingness to adopt aquaculture is important and has implications for the growth of the aquaculture industry.

Maine provides an excellent opportunity to understand fishers’ perceptions and willingness to adopt aquaculture given its long history in both commercial fisheries and aquaculture, which are important components of the state’s economy and maritime tradition (Sadusky et al., 2022). The Maine aquaculture industry includes operations that grow Atlantic salmon (Salmo salar), Eastern oysters (Crassostrea virginica), blue mussels (Mytilus edulis), kelps (Saccharina latissima) and seaweeds, Atlantic
sea scallops (*Placopecten magellanicus*), and various clam species in coastal waters. Currently, the American lobster (*Homarus americanus*) fishery is the most valuable fishery in the state, but its future remains precarious due to potential impacts from climate change, increasing regulations, economic variability (Acheson & Acheson, 2020) and the graying of the fleet (Johnson & Mazur, 2018). The objectives of this study were twofold: 1) to assess perceptions of aquaculture by Maine lobster fishers and identify which factors influence these perceptions and 2) to determine lobster fishers’ willingness to adopt aquaculture and identify the factors that might predispose an individual to consider adoption.

### 2.1.1. Stakeholder Perceptions of Aquaculture

A number of studies have explored stakeholder perceptions in relation to support or opposition to aquaculture development and expansion. In Canada and the US, user conflicts have hindered aquaculture growth (Knapp, 2012) with environmental non-governmental organizations, ecotourism and commercial fishing sectors driving stakeholder opposition (Noakes et al., 2003). The environmental impacts versus the economic benefits is a common dichotomy in the aquaculture development debate (Hanes, 2018; Johnson & Hanes, 2019). Mazur & Curtis (2008) also identified this divide, through interviews and a mail survey of various stakeholder groups including individuals who represented commercial fishing; people were supportive of the economic benefits of aquaculture, but were concerned about the potential negative environmental impacts. Furthermore, they found that people’s perception of aquaculture was related to their perception of the government agency that managed aquaculture; in one region, respondents who had higher levels of trust in the government were more likely to be satisfied with the regulations imposed on aquaculture to curb environmental impacts (Mazur & Curtis, 2008).

Whitmarsh and Palmieri (2009) conducted a mail survey of the general public and stakeholder groups to understand attitudes towards salmon farming and the potential expansion of the industry in Scotland. Industry members, economic development agency staff and independent experts valued
aquaculture’s economic benefits over minimizing the negative environmental impacts while wild-capture fishers, environmental groups and consumers valued the opposite (Whitmarsh & Palmieri, 2009). In addition to values related to aquaculture development varying by stakeholder group, perceptions of aquaculture varied regionally. This regional variation in levels of opposition or stakeholder conflict, although not specific to commercial fishers, was also found in Maine through an analysis of lease hearing transcripts (Hanes, 2018; Johnson & Hanes 2018). Additionally, Whitmarsh and Palmieri (2009) found that lower income areas tended to value the socioeconomic benefits of aquaculture while more affluent areas tended to focus on the potential negative environmental outcomes. Therefore, income level could be an indicator of support or opposition to aquaculture development.

When comparing stakeholder perceptions of aquaculture in the US and Norway by different stakeholder groups (i.e., environmental organizations, aquaculturists, commercial fishers, researchers, consultants and government officials), Chu et al. (2010) found that stakeholders who perceived aquaculture to have environmental and economic benefits supported aquaculture expansion and believed that regulations minimized the negative impacts. Chu et al. (2010) also highlighted that the perception that wild fisheries and aquaculture were in conflict was a misconception and that commercial fishers and aquaculturists did not fully understand the key differences and connections between fisheries and aquaculture. Chu et al. (2010) recommended exploring case studies to collect information regarding the perceptions of different stakeholders regarding aquaculture and its potential overlap with commercial fishing. They also suggested training commercial fishers in aquaculture techniques (Chu et al., 2010).

Memery and Birch (2016) conducted qualitative interviews in the UK and found that respondents in the fishing sector were cautiously supportive of aquaculture development as long as conflict between fisheries and aquaculture could be mitigated. In Europe, conflicts between aquaculture
and commercial fishing developed when access to fishing grounds was restricted or aquaculture caused negative environmental impacts to fisheries (Mente et al., 2007; Ertör & Ortega-Cerdà, 2015). In southern Europe, aquaculture conflicts surfaced due to a belief that aquaculture threatened traditional livelihoods such as fishing (Schlag & Ystgaard, 2013; Mente et al., 2007). The concern that aquaculture could impact a way of life was also found in British Columbia; interview respondents were primarily concerned with the potential impact of aquaculture on access to wild fisheries and ultimately, the way of life associated with wild-capture fisheries (Joyce & Canessa, 2009). Negative perceptions of aquaculture can also be caused due to a lack of transparency and involvement in the permitting or leasing process (Ertör & Ortega-Cerdà, 2015).

Dalton et al. (2017) explored perceptions of aquaculture by residents and coastal users in Narragansett Bay, Rhode Island and found that fishers were not supportive of even low levels of aquaculture development (Dalton et al., 2017). Dalton et al. (2017) also found that levels of support decreased with increasing aquaculture activity. Dalton and Jin (2018) studied perceptions of aquaculture by Rhode Island residents and found education level and whether or not the respondent’s home had a view of coastal waters were predictors of a higher level of support for aquaculture. Katranidis et al. (2003) compared the perceptions of aquaculture between island residents and tourists in two Greek island communities and found that aquaculture had little impact on tourism.

Thus, perceptions of aquaculture are complex and can vary by stakeholder group and individual characteristics. Regarding fisher perception of aquaculture, evidence exists for instances where commercial fishers support aquaculture activity and expansion of the industry and other instances where fishers oppose aquaculture.

2.1.2. Aquaculture as a Diversification Strategy

Theoretically, aquaculture is an opportunity for livelihood diversification and can stabilize or supplement fisheries-dependent incomes by reducing uncertainty (Rubino & Stoffle, 1990). Aquaculture
can reduce market uncertainty by controlling production to meet demand and produce a consistent supply when wild stocks or market price might fluctuate or fisheries regulations limit catch (Bailey et al., 1996; Aarset & Foss, 1996). Some potential limitations to this assumption include fundamental differences between the two occupations including that fishing is more similar to hunting and aquaculture to farming (Weeks, 1992). Griffith and Dyer (1996) highlighted that fishers may be hesitant to adopt aquaculture due to potential loss of their occupational identity as commercial fishers.

Other studies have shown that while livelihood diversification can buffer against variability in fishing incomes, the process of diversifying can be costly and time-consuming resulting in loss of specific knowledge and requiring capital investment (Cline et al., 2017). Cline et al. (2017) found a diminishing rate of return with diversification suggesting that at a certain point, adding additional species to a fishing portfolio does not necessarily benefit the individual. An ideal diversification opportunity would vary asynchronously with the primary target species for a commercial fisher (Cline et al., 2017).

One approach to understanding which commercial fishers would consider integrating aquaculture as a livelihood activity is to apply the adoption of innovation theory. This approach involves relating individual socioeconomic and demographic characteristics and attitudes, perception or behaviors to an individual’s decision about whether to adopt or reject an innovation (Rogers, 2003). Results have been mixed as to which variables are consistently most important in determining the outcome of adoption decisions; regardless, the approach has been helpful in understanding the adoption of aquaculture and highlighting characteristics of individuals who may be more willing than others to consider implementing aquaculture (Tango-Lowy & Robertson, 2002).

2.1.3. Adoption of Aquaculture

Individual characteristics associated with adoption have included education and income levels where those with higher levels of education and income tended to more readily adopt innovations (Ryan & Gross, 1943; Agbamu & Orhorhororo, 2007). This was also the case in studies that focused on
commercial fisher adoption of fishing technologies (Acheson & Reidman, 1982; Dewees & Hawkes, 1988). Age tended to be negatively correlated with adoption decisions where older individuals were less likely to adopt (Acheson & Reidman, 1982; Dewees & Hawkes, 1988). Alexander et al. (2016) found that older individuals were more resistant to change and less likely to adopt new seafood harvesting techniques to include aquaculture.

Individuals who were more connected within social networks in terms of kinship ties or participation in organized groups were more likely to adopt (Tango-Lowy & Robertson, 2002; Acheson & Reidman, 1982), although Dewees and Hawkes (1988) found kinship to be less of a factor in fishers’ adoption of fishing technologies as compared to Acheson and Reidman (1982). Additionally, those who were considered community leaders or self-identify as innovators tended to be more likely to adopt (Ryan & Gross, 1943; Coleman et al., 1966). In some instances, the percent of income derived from a particular occupation has been linked to decisions to adopt innovations within that occupation as was found with crawfish farmers in Louisiana (Nyaupane & Gillespie, 2011). Additionally, the more diversified in harvesting or income-generating activities, the more likely individuals were to adopt additional activities or new technologies. This has included growing multiple crops in an agricultural setting (Nyaupane & Gillespie, 2011) or accessing multiple species within a commercial fishery setting (Tango-Lowy & Robertson, 2002).

Regarding fisher adoption of aquaculture, Robertson et al. (2001) found that the longer individuals had been participating in commercial fisheries, the less likely they were to adopt aquaculture. Robertson et al. (2001) suggested that adopting aquaculture was different than adopting new fishing technologies, because starting aquaculture was a new occupation as opposed to adopting a new fishing technology that increased the efficiency or productivity of an existing livelihood activity (Robertson et al., 2001). Having previous knowledge of the innovation or knowing someone who was successful at implementing the innovation has had a positive influence on an individual’s decision to
adopt (Miyata & Manatunge, 2004). Miyata and Manatunge (2004) found that knowing someone who was successful was the most influential driver in determining the outcome of adoption decisions for others. One individual’s proven success reduced the uncertainty and risk involved with adopting fish farming for others.

Optimism about current and future fishing conditions significantly influenced adoption of fishing technologies; those who had favorable perceptions of fishing conditions, both present and future were more likely to adopt (Acheson & Reidman, 1982; Dewees & Hawkes 1988). Tango-Lowy and Robertson (2002) hypothesized that those fishers who viewed current and future conditions of fishing favorably would be less likely to adopt aquaculture since aquaculture represented an occupational shift away from fishing and they believed they would continue to do well in commercial fishing. Fishers who had generally positive perceptions of aquaculture exhibited a greater willingness to consider implementing aquaculture or be employed in aquaculture in the future (Tango-Lowy & Robertson, 2002).

Barriers to fisher diversification outside of commercial fishing do exist. Pollnac and Poggie (2008) highlight aspects of commercial fishing that appeal to individuals and often result in individuals staying in commercial fishing even when economic standards indicate that a shift out of commercial fishing would be most beneficial. This is a widespread phenomenon found in both developed and developing countries. They point to non-monetary benefits derived from a fishing occupation and suggest that any alternative livelihood activity introduced would need to provide similar non-monetary benefits as fishing (Pollnac & Pogie, 2008), such as the risks and thrill of fishing. Additionally, diversifying can be costly requiring financial investments, but also in terms of the time spent learning a new livelihood activity (Cline et al., 2017).

2.2. Study Site

In the 1970s, coastal marine aquaculture started in Maine with additional aquaculture activity increasing rapidly within the last decade (Maine Department of Marine Resources, 2022a). In order to
farm seafood, individuals or firms must apply for a lease or license to the Maine Department of Marine Resources, which when approved, provides access to a defined area of ocean space. Standard leases are granted to individuals or businesses for up to 20 years with the option to renew and can be up to 100 acres in size. Experimental leases cannot exceed 4 acres in size and are for three years without the option to renew unless the farming is for educational or research purposes. The Limited Purpose Aquaculture license (LPA) is only available to individuals, not businesses, and provides access to 400 square feet for one year with the option to renew. Between 2009 and 2021, aquaculture activity grew and includes 187 active or pending experimental or standard leases totaling approximately 1,700 acres and 804 active Limited Purpose Aquaculture licenses (Maine Department of Marine Resources, 2022a). Since 2015, over 150 new LPAs were being issued each year (Figure 2.1) and in 2019, over 20 new leases being issued per year (Figure 2.2).

![Figure 2.1 New Limited Purpose Aquaculture licenses applied for each year between 2007 and 2021. (Maine DMR, 2022a)](image-url)
The American lobster (*Homarus americanus*) dominates commercial fisheries in Maine, contributing 48% to total landings by live pounds and 79% of ex-vessel value in 2020 (Maine Department of Marine Resources, 2022b). The lobster fishery in Maine experienced a period of increasing landings and stable markets from the mid-1980s until relatively recently due to favorable environmental conditions, the implementation of effective regulations, and a conservation ethic among fishers (Acheson & Acheson, 2020). However, changes are underway in this fishery, including an increase in the incidence of shell disease in lobster, rapidly warming waters in the Gulf of Maine, additional restrictions being proposed and implemented to protect the endangered North Atlantic right whale, variable market dynamics (Acheson & Acheson, 2020), and graying of the fleet (Johnson & Mazur, 2018). In 2020, there were approximately 4,000 active lobster fishers (Maine Department of Marine Resources, 2022b).

Since 2013, there have been two aquaculture training programs geared towards commercial fishers, the Aquaculture in Shared Waters Program and the Aquaculture Business Development Program (e.g. Sadusky et al., 2022; Pianka 2016; Cleaver et al., 2018; Love, 2016; Cowperthwaite & Murphy, 2019). The Aquaculture in Shared Waters program is hosted by Maine Sea Grant, Maine Aquaculture Association, Coastal Enterprises, Inc., Maine Aquaculture Innovation Center and The University of
Maine. It was started in 2013 and targeted commercial fishers and members of the public for training in shellfish and seaweed aquaculture techniques. In 2015, the Island Institute, a community development organization based in Rockland, Maine supported three cohorts of commercial fishers interested in starting an aquaculture business.

2.3. Methods

2.3.1. Survey Distribution

A mail survey was distributed to a stratified random sample of commercial lobster license holders in Maine. The 2017 list of lobster license holders was obtained from the Maine Department of Marine Resources in the summer of 2018. Individuals under the age of 18 were excluded from the sample. An equal number of individuals were randomly selected from each of the seven lobster management zones using a random number generator in Excel 2019 Version 16.0. Since the lobster management zones vary in the total number of license holders per zone, the sample overrepresented the zones with fewer lobster license holders. Data collected by the survey included demographic and socioeconomic characteristics, information about participation and experience in commercial fisheries, and perceptions of aquaculture. Individuals were also asked about their current participation in aquaculture and their level of agreement with a statement about the likelihood that they would be employed in the marine aquaculture industry within the next five years.

For survey distribution, a modified Tailored Design Method was used where an initial letter describing the project was mailed followed by a second letter and a copy of the survey three weeks later (Dillman et al., 2014). Individuals who did not return a survey received two additional mailings three weeks apart that each included a copy of the survey. As an incentive to increase participation, individuals had the opportunity to enter a raffle after completing the survey. A total of 2,569 surveys were mailed, 201 were undeliverable and removed from the next round of surveys mailed. Of the 2,368 surveys that were deliverable addresses, 5 individuals returned a blank survey booklet and 424
individuals completed some portion of the survey questions for a 16.5\% response rate. A number of respondents returned incomplete surveys and rather than eliminate incomplete records from the sample, a separate sample size was calculated for each variable reported in the results.

2.3.2. Data Analysis

Descriptive statistics were calculated in Excel 2019 Version 16.0 to summarize respondents’ demographic and socioeconomic characteristics, history and experience within the commercial fishing industry and perceptions of aquaculture. For Likert scale statements about respondents’ perception of different aspects of aquaculture, the percentage of respondents choosing each response category were reported (Warmbrod, 2014).

In SPSS Version 27, Ordinal Logistic Regression analyses (OLRs) were carried out for two separate response variables, including one’s view of the Maine marine aquaculture industry on a 6-point Likert scale ranging from very negative to very positive and a 10-point Likert scale for one’s level of agreement with a statement about their willingness to be employed in the Maine marine aquaculture industry within the next five years. Both response variables were converted to three response categories for consistency. The 6-point Likert scale was divided so that responses 1 and 2 turned into 1; 3 and 4 combined into 2; and 5 and 6 turned into 3. The 10-point Likert scale was recoded to three response categories to ensure an adequate sample size for each response category so that responses 1, 2, and 3 turned into 1; responses 4, 5, 6, and 7 turned into 2; and, responses 8, 9, and 10 became 3.

The first OLR model discussed was an explanatory model of the factors driving lobster fishers’ view of marine aquaculture. The explanatory variables used included those determined to be relevant in other studies about perceptions of aquaculture including education and income levels and perceptions about the environmental impacts and the economic benefits of aquaculture (Table 2.1). Fishing history and experience variables were also included because this study focused on commercial lobster license holders’ perception of aquaculture (Table 2.1). The second OLR model was an explanatory model of the
factors driving fishers’ level of agreement with the statement that they would be employed in the marine aquaculture industry within the next 5 years (Table 2.2). The model included the demographic characteristics of age, education level, and household income level; the commercial fishing characteristics of percent income derived from lobster fishing, years spent in commercial fishing, a sum of the total number of state fisheries participated in and federal fisheries permits held, level of agreement regarding optimism about the future of the lobster fishery on a scale of one to 10, and one’s view of the marine aquaculture industry in Maine on a scale of one or very negative to six or very positive (Table 2.2).

The purpose of these regression analyses was to determine which independent variables best explained the ordinal responses of the response variables. OLR is an appropriate regression analysis method when the response variable is ordered and categorical, producing “a single set of regression coefficients that estimate the relationship between” explanatory and response variables (Osborn, 2017, p. 147). For both OLR models, the Likelihood Ratio Chi-Square test was used to test whether or not there was a significant improvement in the fit of the full model relative to the Intercept-only model. OLR requires that the assumption of proportional odds is met or the relationship between the independent variables are the same “across all possible comparisons” between each category of the dependent variable (Osborn, 2017, p. 147). A nonsignificant test result from the test of parallel lines means the assumption was met (Osborn, 2017). The models were assessed for multicollinearity between variables, including the tolerance where values less than 0.1 and Variance Inflation Factor (VIF) where values greater than 10 would indicate multicollinearity.
Table 2.1. Variables used in the Ordinal Logistic Regression models to determine factors driving an individual’s view of Maine’s marine aquaculture industry (View).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Response variable</th>
<th>Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>View</td>
<td>Overall, would you say your views of Maine’s marine aquaculture industry are...? 6-point Likert scale from very negative to very positive</td>
<td>Whitmarsh &amp; Palmieri, 2009</td>
</tr>
<tr>
<td>Independent variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income</td>
<td>Household Income (“What was your total household income before taxes for 2017?”; 10 response categories from less than $10,000 to more than $200,000; median of category in model) Hypothesis: Those with a higher level of household income, more likely to hold negative views.</td>
<td>Dalton &amp; Jin, 2018</td>
</tr>
<tr>
<td>Education</td>
<td>Education (“What is the highest level of education you have completed?”; 5 response categories from 0-11 years to Postgraduate; median of each bin used in model) Hypothesis: Those with a higher level of education, more likely to hold positive views.</td>
<td>Dalton &amp; Jin, 2018</td>
</tr>
<tr>
<td>Ocean view</td>
<td>Can you see or access the ocean from where you received this survey? (Three response categories: “I can see, I can access, I cannot see nor access the ocean from any of my properties” recoded to binary: see/access=1; no access or see=0) Hypothesis: Those who have a view or access to the water, more likely to hold positive views.</td>
<td>Dalton &amp; Jin, 2018</td>
</tr>
<tr>
<td>Aq mgmt.</td>
<td>In general, how satisfied are you with the government’s management of marine aquaculture in Maine? (Level of satisfaction on a 6-point Likert scale response from very unsatisfied to very satisfied) Hypothesis: Those who are satisfied with government management, more likely to hold positive views.</td>
<td>Mazur &amp; Curtis, 2008</td>
</tr>
<tr>
<td>Num Farms</td>
<td>In the area where you fish, how many marine aquaculture farms are there currently? (Response categories: 1-Far too few, 2-Too few, 3-About the right number, 4-Too many, 5-Far too many) Hypothesis: Those who perceive that there are too many farms, more likely to hold negative views.</td>
<td>Dalton et al., 2017</td>
</tr>
<tr>
<td>Aq Rate</td>
<td>At what speed do you think Maine’s marine aquaculture industry is growing in the area where you fish? (Response categories: 1-Far too slowly, 2-Too slowly, 3-About the right speed, 4-Too quickly, 5-Far too quickly) Hypothesis: Those who perceive the industry is growing too quickly, more likely to have negative view.</td>
<td>Hanes, 2018</td>
</tr>
<tr>
<td>Personal enjoyment</td>
<td>Has your personal use and/or enjoyment of Maine’s coast been impacted by marine aquaculture? (Binary response Yes/No) Hypothesis: Those whose personal enjoyment is affected by aquaculture, more likely to have a negative view.</td>
<td>Dalton &amp; Jin, 2018; Katranidis et al., 2003</td>
</tr>
<tr>
<td>Beauty</td>
<td>Aquaculture spoils natural beauty. (Level of agreement on a 6-point Likert scale from strongly disagree to strongly agree) Hypothesis: Those who agree that aquaculture spoils the beauty, more likely to hold negative views of aquaculture.</td>
<td>Dalton &amp; Jin, 2018; Katranidis et al., 2003</td>
</tr>
<tr>
<td>Damages</td>
<td>Aquaculture damages the marine environment. (Level of agreement on a 6-point Likert scale from strongly disagree to strongly agree) Hypothesis: Those who agree that aquaculture damages the marine environment, more likely to hold negative views of aquaculture.</td>
<td>Dalton &amp; Jin, 2018; Katranidis et al., 2003</td>
</tr>
</tbody>
</table>
### Table 2.1 continued

<table>
<thead>
<tr>
<th>Category</th>
<th>Statement</th>
<th>Hypothesis</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Econ boost</td>
<td><strong>Aquaculture boosts the local economy.</strong> (Level of agreement on a 6-point Likert scale from strongly disagree to strongly agree) Hypothesis: Those who agree that aquaculture boosts local economy, more likely to hold positive view of aquaculture.</td>
<td></td>
<td>Dalton &amp; Jin, 2018; Katranidis et al., 2003</td>
</tr>
<tr>
<td>Tourism</td>
<td><strong>Aquaculture enhances tourism.</strong> (Level of agreement on a 6-point Likert scale from strongly disagree to strongly agree) Hypothesis: Those who agree that aquaculture enhances tourism, more likely to hold positive views of aquaculture.</td>
<td></td>
<td>Katranidis et al., 2003</td>
</tr>
<tr>
<td>Jobs</td>
<td><strong>Aquaculture provides good jobs to year-round residents.</strong> (Level of agreement on a 6-point Likert scale from strongly disagree to strongly agree) Hypothesis: Those who agree that aquaculture provides good jobs, more likely to hold positive views of aquaculture.</td>
<td></td>
<td>Whitmarsh &amp; Palmieri, 2009; Chu et al., 2010; Katranidis et al. 2003</td>
</tr>
</tbody>
</table>
Table 2.2. Variables used in the Ordinal Logistic Regression models to determine factors driving an individual’s interest in being employed or adopting aquaculture (Adopt).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Response variable</th>
<th>Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adopt</strong></td>
<td>How much do you agree or disagree with the following statement?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“I will be employed in marine aquaculture in the next 5 years.” 10-point Likert</td>
<td></td>
</tr>
<tr>
<td></td>
<td>scale response recoded to 3 response categories: disagree, neutral, agree</td>
<td></td>
</tr>
<tr>
<td><strong>Independent variables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>Age: “In what year were you born?”</td>
<td>Tango-Lowy &amp; Robertson 2002;</td>
</tr>
<tr>
<td></td>
<td>Hypothesis: Older individuals less likely to adopt.</td>
<td>Acheson &amp; Reidman, 1982; Dewees &amp; Hawkes, 1988</td>
</tr>
<tr>
<td><strong>Income</strong></td>
<td>Household Income (“What was your total household income before taxes for 2017?”;</td>
<td>Ryan &amp; Gross, 1943; Agbamu &amp; Orhorhoro, 2007; Acheson &amp; Reidman, 1982;</td>
</tr>
<tr>
<td></td>
<td>10 response categories from less than $10,000 to more than $200,000; median of</td>
<td>Dewees &amp; Hawkes, 1988</td>
</tr>
<tr>
<td></td>
<td>each category used in model)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypothesis: Higher income, more likely to adopt.</td>
<td></td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td>Education (“What is the highest level of education you have completed?”; 5</td>
<td>Ryan &amp; Gross, 1943; Agbamu &amp; Orhorhoro, 2007; Acheson &amp; Reidman, 1982;</td>
</tr>
<tr>
<td></td>
<td>response categories from 0-11 years to Postgraduate; median of each bin used in</td>
<td>Dewees &amp; Hawkes, 1988</td>
</tr>
<tr>
<td></td>
<td>model)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypothesis: Higher level of education, more likely to adopt.</td>
<td></td>
</tr>
<tr>
<td><strong>Innovator</strong></td>
<td>I consider myself to be an innovator (check if applies)</td>
<td>Ryan &amp; Gross, 1943; Coleman, Katz, &amp; Menzel, 1966</td>
</tr>
<tr>
<td></td>
<td>Hypothesis: Self-identify as innovators, more likely to adopt.</td>
<td></td>
</tr>
<tr>
<td><strong>Lobster income</strong></td>
<td>Income from lobstering: Estimated percent of total household income from lobster</td>
<td>Robertson et al. 2001</td>
</tr>
<tr>
<td></td>
<td>fishing in 2017</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypothesis: Greater percentage of income from lobster fishing, less likely to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>adopt.</td>
<td></td>
</tr>
<tr>
<td><strong>Fisheries</strong></td>
<td>State fisheries participated in including state lobster license and federal</td>
<td>Tango-Lowy &amp; Robertson, 2002</td>
</tr>
<tr>
<td></td>
<td>permits held including federal permit for lobster (#):</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypothesis: The more licenses and permits held, the more likely to adopt.</td>
<td></td>
</tr>
<tr>
<td><strong>Years fishing</strong></td>
<td>Years in lobster fishing: total number of years in commercial fishing.</td>
<td>Robertson et al. 2001, Tango-Lowy &amp; Robertson, 2002</td>
</tr>
<tr>
<td></td>
<td>Hypothesis: The more years in commercial fishing, the less likely to adopt.</td>
<td></td>
</tr>
<tr>
<td><strong>Optimism</strong></td>
<td>Optimism about the future of the lobster fishery: 10-point Likert scale from 1-</td>
<td>Tango-Lowy &amp; Robertson, 2002</td>
</tr>
<tr>
<td></td>
<td>strongly disagree to 10 – strongly agree with the following statement: “I am</td>
<td></td>
</tr>
<tr>
<td></td>
<td>optimistic about the future of the Maine lobster industry.”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypothesis: If optimistic about future of lobster, less likely to adopt.</td>
<td></td>
</tr>
<tr>
<td><strong>Considered aq</strong></td>
<td>Have you ever considered or tried marine aquaculture as an alternative or</td>
<td>Chu et al., 2010; Nyaupane &amp; Gillespie, 2011; Bosma et al., 2012</td>
</tr>
<tr>
<td></td>
<td>addition to your occupation? (Binary considered aquaculture at some point = 1;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>other=0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypothesis: If considered aquaculture, more likely to adopt.</td>
<td></td>
</tr>
<tr>
<td>**View of</td>
<td>Overall, would you say your views of Maine’s marine aquaculture industry are...?</td>
<td>Tango-Lowy &amp; Robertson, 2002</td>
</tr>
<tr>
<td>aquaculture**</td>
<td>6-point Likert scale from very negative to very positive)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypothesis: If have a positive view about aquaculture, more likely to adopt.</td>
<td></td>
</tr>
</tbody>
</table>
To test for differences between zones, cross tabulations and Chi-square test statistics were calculated for categorical variables and a One-way Analysis of Variance (ANOVA) was carried out for continuous variables, including age, years of education, household income, percent of income from lobster fishing, and years in commercial fishing. Only percent of income from lobster fishing was significantly different between lobster management zones (Sum of squares: 24376.087, Degrees of Freedom: 6, Mean Square: 4062.681, F: 3.355, Sig.: .003).

A significant relationship existed between lobster management zone and level of agreement about being employed in aquaculture within the next 5 years; management zone and perceptions of the number of aquaculture farms; management zone and the rate of aquaculture growth in the area in which one fished; lobster management zone and level of satisfaction with government’s management of aquaculture; and, lobster management zone and optimism about the future of the lobster fishery (Table 2.3). Given the significant differences in some of the independent variables by lobster management zone, both of the OLR models were weighted by zone. A weight was created for each survey record by taking the number of lobster licenses per management zone divided by the number of surveys mailed to that zone and applied to both OLR models (Table 2.4).

Table 2.3. Statistically significant results for Chi-Square test of independence when comparing variables by lobster management zone.

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Value</th>
<th>Df</th>
<th>Asymptotic significance (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adopt</td>
<td>407</td>
<td>28.725</td>
<td>12</td>
<td>.004</td>
</tr>
<tr>
<td>Optimism</td>
<td>412</td>
<td>91.214</td>
<td>54</td>
<td>.001</td>
</tr>
<tr>
<td>Num of farms</td>
<td>366</td>
<td>67.113</td>
<td>24</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Aq rate</td>
<td>395</td>
<td>75.185</td>
<td>24</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Aq mgmt</td>
<td>392</td>
<td>49.089</td>
<td>30</td>
<td>.015</td>
</tr>
</tbody>
</table>
Table 2.4. Survey distribution and returns by lobster management zone.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Total licenses in 2017 (#)</th>
<th>Surveys mailed (＃)</th>
<th>% of total licenses</th>
<th>Surveys returned (＃)</th>
<th>% of sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1377</td>
<td>367</td>
<td>27</td>
<td>62</td>
<td>15</td>
</tr>
<tr>
<td>B</td>
<td>741</td>
<td>367</td>
<td>50</td>
<td>58</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>1245</td>
<td>367</td>
<td>29</td>
<td>54</td>
<td>13</td>
</tr>
<tr>
<td>D</td>
<td>1242</td>
<td>367</td>
<td>30</td>
<td>75</td>
<td>18</td>
</tr>
<tr>
<td>E</td>
<td>504</td>
<td>367</td>
<td>73</td>
<td>52</td>
<td>12</td>
</tr>
<tr>
<td>F</td>
<td>877</td>
<td>367</td>
<td>42</td>
<td>62</td>
<td>15</td>
</tr>
<tr>
<td>G</td>
<td>409</td>
<td>367</td>
<td>90</td>
<td>61</td>
<td>14</td>
</tr>
</tbody>
</table>

2.4. Results

2.4.1. Characteristics of Survey Respondents

Respondents were predominantly male (96%) with a mean age of 58 years old. This is older than the mean age of lobster fishers from 2015 which was 49.5 years old (Johnson & Mazur, 2018).

Respondents had an average of 36 years of commercial fishing experience (+/- 15 SD, n=400, range= 1 to 80 years). Sixty-seven percent of respondents considered themselves to be full-time fishers or only employed within the commercial fishing industry, 27% identified as part-time fishers or employed in commercial fishing and another industry and 6% held a state lobster license, but were employed outside of commercial fishing (n=421). Fifty-eight percent of respondents derived between 67 to 100% of their income from lobster fishing while 25% made between 0-33% of their income from commercial lobster fishing (n=395). Seventy-one percent of respondents were a high school graduate or had a higher level of education (n=411). Seventy-four percent of respondents had a household income between $50,000-$74,999 or greater (n=379). Individuals were not excluded from the analysis based on holding a lobster license and being employed in another industry or the percent of income derived from lobster fishing since it is difficult to know more details about individual situations regarding their participation in commercial fishing.
2.4.2. Perceptions of Aquaculture

Overall, 73% of the respondents viewed Maine’s marine aquaculture industry somewhat positive to very positive (n = 389). Regarding the government’s management of the marine aquaculture industry, 16% of respondents were very satisfied or satisfied with 38% somewhat satisfied. Seventeen percent of the respondents were very unsatisfied or unsatisfied while 25% were somewhat unsatisfied (n = 392). With regard to the number of aquaculture farms in the area in which they fish, 48% of respondents believed that the number of farms was about the right number with 13% saying there were too many or far too many aquaculture farms and 38% saying there were too few or far too few (n = 366). Regarding the rate at which Maine’s marine aquaculture industry was growing in the area in which they fished, 56% of respondents believed the rate of growth was about the right speed while 19% believed it was growing too quickly or far too quickly while 24% believed it was growing too slowly or far too slowly (n = 395).

In response to questions related to respondents’ perception of aquaculture’s contribution to the economy by providing good jobs to year-round residents, boosting the local economy or enhancing tourism, responses were relatively evenly divided across response categories (Table 2.5). Similarly, responses were relatively evenly divided across response categories for statements about aquaculture damaging the marine environment or spoiling the beauty of the ocean (Table 2.5).
Table 2.5. Percentage of responses in each category of Likert-scale type statements about different aspects of aquaculture (N=number of respondents. Mean and Standard Deviation calculated based on responses to 6-point Likert scale responses, possible responses were SD1=Strongly disagree, D=Disagree, SD2=Somewhat disagree, SA2= Somewhat agree, A=Agree, SA1=Strongly agree.)

<table>
<thead>
<tr>
<th>Statement</th>
<th>N</th>
<th>Mean (SD)</th>
<th>SD1</th>
<th>D</th>
<th>SD2</th>
<th>SA2</th>
<th>A</th>
<th>SA1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquaculture provides good jobs to year-round residents.</td>
<td>397</td>
<td>3.62 (1.77)</td>
<td>18</td>
<td>12</td>
<td>17</td>
<td>19</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>Aquaculture boosts the local economy.</td>
<td>398</td>
<td>3.57 (1.7)</td>
<td>17</td>
<td>12</td>
<td>17</td>
<td>22</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>Aquaculture enhances tourism.</td>
<td>395</td>
<td>3.55 (1.68)</td>
<td>15</td>
<td>14</td>
<td>20</td>
<td>12</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Aquaculture damages the marine environment.</td>
<td>402</td>
<td>3.54 (1.69)</td>
<td>17</td>
<td>12</td>
<td>19</td>
<td>22</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Aquaculture spoils the beauty of the ocean.</td>
<td>396</td>
<td>3.57 (1.70)</td>
<td>16</td>
<td>13</td>
<td>19</td>
<td>19</td>
<td>14</td>
<td>19</td>
</tr>
</tbody>
</table>

2.4.3 Ordinal Logistic Regression for View of Aquaculture

One significant positive predictor (one’s level of satisfaction with the government’s management of the aquaculture industry) led to more positive views of Maine’s marine aquaculture industry (Table 2.6). Three independent variables were significant negative predictors of a respondent’s view of Maine’s marine aquaculture industry, 1) one’s perception about the amount of aquaculture farms in the area in which they fished, 2) one’s perception about the rate of aquaculture growth in the area in which they fish, and 3) level of agreement with the statement that aquaculture damages the marine environment.
Table 2.6. Ordinal logistic regression parameter estimates, standard errors, and odds ratios of views of aquaculture for lobster license holders in Maine. (n=283)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter estimate (SE), p-value</th>
<th>Odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>View 1</td>
<td>-2.424 (0.7433), p-value .001**</td>
<td>0.089</td>
</tr>
<tr>
<td>View 2</td>
<td>1.578 (0.7244), p-value .029*</td>
<td>4.847</td>
</tr>
<tr>
<td>Education</td>
<td>0.064 (0.0328), p-value .053</td>
<td>1.066</td>
</tr>
<tr>
<td>Income</td>
<td>5.134E-7 (1.2796E-6), p-value .688</td>
<td>1.000</td>
</tr>
<tr>
<td>Ocean View</td>
<td>-0.160 (0.1915), p-value .402</td>
<td>0.852</td>
</tr>
<tr>
<td>Aq Mgmt</td>
<td>0.550 (0.0776), p-value &lt;.001**</td>
<td>1.734</td>
</tr>
<tr>
<td>Num Farms</td>
<td>-0.129 (0.0235), p-value &lt;.001**</td>
<td>0.879</td>
</tr>
<tr>
<td>Rate of Growth</td>
<td>-0.051 (0.0214), p-value .017*</td>
<td>0.950</td>
</tr>
<tr>
<td>Beauty</td>
<td>0.070 (0.0503), p-value .164</td>
<td>1.073</td>
</tr>
<tr>
<td>Damage</td>
<td>-0.180 (0.0513), p-value &lt;.001**</td>
<td>0.836</td>
</tr>
<tr>
<td>Jobs</td>
<td>-0.067 (0.0475), p-value .161</td>
<td>0.936</td>
</tr>
<tr>
<td>Econ boost</td>
<td>0.094 (0.0496), p-value .057</td>
<td>1.099</td>
</tr>
<tr>
<td>Tour</td>
<td>0.017 (0.0489), p-value .721</td>
<td>1.018</td>
</tr>
<tr>
<td>Personal enjoyment</td>
<td>0.094 (0.2395), p-value .695</td>
<td>1.098</td>
</tr>
</tbody>
</table>

*, ** represent significance at the 5% and 1% respectively

Likelihood ratio Chi-square: 256.877, 12df, p=.000
2.4.4. Participation and Willingness to Adopt Aquaculture

Approximately 4% or 15 of the respondents reported that they “had tried aquaculture and it worked out for them” so could be considered adopters of aquaculture. Three percent had tried aquaculture, but were unsuccessful and 55% responded that they had never had any interest in trying it; essentially, non-adopters at the time this survey was distributed (Table 2.7, n=390). Approximately 19% hoped to try aquaculture in the future and could be considered potential or future adopters of aquaculture. Seventy-three percent of respondents disagreed with the statement that “I will be employed in marine aquaculture in the next 5 years” while 19% were neutral and 8% agreed (n=407).

Table 2.7. Percentage of responses to the question: “Have you ever considered or tried marine aquaculture as an alternative or addition to your occupation?” (n=390).

<table>
<thead>
<tr>
<th>Response Category</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I tried it and it worked out for me.</td>
<td>4</td>
</tr>
<tr>
<td>I hope to try it in the future.</td>
<td>19</td>
</tr>
<tr>
<td>I tried it, but it didn’t work out for me.</td>
<td>3</td>
</tr>
<tr>
<td>I considered it, but decided not to try it.</td>
<td>19</td>
</tr>
<tr>
<td>I have never had any interest in trying it.</td>
<td>55</td>
</tr>
</tbody>
</table>

2.4.5. Ordinal Logistic Regression for Willingness to Adopt Aquaculture

Four significant positive predictors related to one’s level of agreement with the statement of being employed in the aquaculture industry within the next five years. These included: 1) whether the individual had considered aquaculture in the past, 2) the individual’s view of the marine aquaculture industry on a scale from very negative to very positive, 3) the total number of fisheries participated in, and 4) the number of years in lobster fishing (Table 2.8). Individuals who had considered doing aquaculture in the past, held more positive views of the marine aquaculture industry, participated in more fisheries, and had spent more time in commercial fishing were more likely to agree that they would consider being employed in aquaculture in the future.

Two significant negative predictors of one’s willingness to be employed in aquaculture included two variables: 1) an individual’s age and 2) the percent of income from lobster fishing (Table 2.8).
Table 2.8. Ordinal logistic regression parameter estimates, standard errors and odds ratios of being employed in aquaculture within the next 5 years for lobster license holders in Maine (n=256).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate (SE), p-value</th>
<th>Odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>AqAdopt 1 “Disagree”</td>
<td>2.566 (0.8810), p-value .004**</td>
<td>13.099</td>
</tr>
<tr>
<td>AqAdopt 2 “Maybe”</td>
<td>4.066 (0.8933), p-value &lt;.001**</td>
<td>58.352</td>
</tr>
<tr>
<td>Age</td>
<td>-0.046 (0.0100), p-value &lt;.001**</td>
<td>0.955</td>
</tr>
<tr>
<td>Education</td>
<td>0.079 (0.0492), p-value .066</td>
<td>1.082</td>
</tr>
<tr>
<td>Income</td>
<td>-1.385E-7 (1.6450E-6), p-value .933</td>
<td>1.000</td>
</tr>
<tr>
<td>Innovator</td>
<td>0.346 (0.2205), p-value .116</td>
<td>1.414</td>
</tr>
<tr>
<td>Lobster income</td>
<td>-0.012 (0.0032), p-value &lt;.001**</td>
<td>0.988</td>
</tr>
<tr>
<td>Fisheries</td>
<td>0.121 (0.0523), p-value .020*</td>
<td>1.129</td>
</tr>
<tr>
<td>Years fishing</td>
<td>0.023 (0.0110), p-value .032*</td>
<td>1.024</td>
</tr>
<tr>
<td>Lobster optimism</td>
<td>0.032 (0.0444), p-value .476</td>
<td>1.032</td>
</tr>
<tr>
<td>View</td>
<td>0.365 (0.875), p-value &lt;.001**</td>
<td>1.441</td>
</tr>
<tr>
<td>Considered aq</td>
<td>1.395 (0.2085), p-value &lt;.001**</td>
<td>4.036</td>
</tr>
</tbody>
</table>

*, ** represent significance at the 5% and 1% respectively

Likelihood ratio test: 141.589, 10df, p= < 0.001

2.5 Discussion

Commercial fishers are an important stakeholder group when considering aquaculture development. While they are considered logical adopters of aquaculture, their opposition has been shown to inhibit growth. In Maine, the aquaculture industry continues to grow and the lobster fishery is anticipated to become more variable in response to climate change, market dynamics and regulations;
given these dynamics, the state offers an excellent opportunity to study commercial fisher perceptions of aquaculture development and their willingness to consider its adoption. This study of Maine lobster fishers held relatively neutral views towards the marine aquaculture industry in Maine suggesting that lobster fishers might be willing to withstand additional aquaculture activities in the areas in which they fish, but there is also likely a limit to the amount of activity (e.g., number of farms, rate of growth) they will tolerate.

In this study, lobster fisher views of aquaculture appear influenced by perceptions of the negative environmental impacts of aquaculture (perceptions that aquaculture damages the marine environment), which is similar to a number of studies. Given that the perceptions about aquaculture’s negative environmental impacts are significant predictors of Maine lobster fisher perceptions of aquaculture, it is critical for messaging about aquaculture to clarify the risks and benefits of aquaculture. The Maine aquaculture industry through organizations such as Maine Sea Grant and the Maine Aquaculture Association does benefit from messaging and materials that focus on the economic benefits of aquaculture and dispelling the perception of negative environmental impacts where appropriate.

Consistent with previous studies, being satisfied with government’s management of aquaculture was a significant positive factor related to positive views of aquaculture by lobster fishers in Maine. Maine DMR notifies the public of all standard and experimental lease applications and if more than five individuals raise a concern with the application, a public hearing is held (Hanes, 2018). Hanes (2018) highlighted that public hearings, in regions where conflicts with aquaculture are relatively low, served as an opportunity for the lease applicant and the community, specifically landowners, to discuss aspects of the proposed aquaculture activity and in this way, leases can be modified to fit needs of the community members while still achieving the applicant’s goals for aquaculture. The scoping sessions and public hearing process may also be an opportunity to dispel fears about environmental impacts about proposed aquaculture activity. Johnson and Hanes (2018) concluded that lease hearings provide a rare
opportunity for face-to-face interactions to build trust between community members and the applicant. The public lease hearings, in addition to initiatives like the Aquaculture in Shared Waters Program, the Aquaculture Business Development Program and the Maine Aquaculture Hub, could help minimize conflicts between new or expanded aquaculture activity and established uses, such as commercial fishing (Sadusky et al., 2022).

Regarding lobster fisher perceptions of aquaculture, one limitation with the survey was that questions asked about aquaculture generally rather than focusing on the different types of aquaculture practiced in Maine in terms of species farmed, scale of operation, and type of husbandry practices in use; these different types of aquaculture could illicit different levels of fisher support and it may be that fishers have particular preferences for the types of aquaculture taking place in shared ocean and coastal space. Additionally, fishers’ level of agreement with statements about the perceived negative economic impacts, such as competing with wild-capture product in the market or environmental benefits, such as oyster farming improving water quality were not explored.

Regarding fisher adoption of aquaculture, this study finds: younger, individuals who are more diversified, derive a lower percentage of their income from lobster, or are less experienced in commercial fishing. In addition, having considered aquaculture and having a positive perception of aquaculture is more likely to lead to adoption.

A small percentage of the respondents had an interest in trying aquaculture and this could be due to several reasons including, 1) attachment to fishing as a livelihood (Pollnac & Pogie, 2008), 2) diversifying can be costly (Cline et al., 2017), and 3) adoption of aquaculture depends on a match between the innovation and the need of the adopter (Acheson & Reidman, 1982). In this instance, it may be that Maine lobster fishers do not believe they would derive similar non-monetary benefits from aquaculture as they do from lobster fishing (Pollnac & Pogie, 2008).
In this case, the lobster fishery has undergone increasing landings and value over the last several decades and at the time the survey was distributed, individuals may not have believed there was a need to diversify their livelihoods. However, with the future of the Maine lobster fishery uncertain with increasing threats from regulatory oversight and changing socioeconomic and environmental conditions, aquaculture as a diversification strategy may become increasingly important. Finally, the survey respondents were older, could be considering retirement and may not be interested in adopting a new activity like aquaculture at this point in their careers. To maximize efforts, training programs, funding and policy measures intended to facilitate fisher adoption should focus on younger fishers, individuals who are already diversified, and have considered aquaculture in the past.

Dewees and Hawkes (1988) point out the limitations of studies similar to this survey where the survey captures an individual’s thinking about an innovation and adopting that innovation at a single point in time. A longitudinal study where an individual’s thinking and actions are followed over a period of time may be a more accurate way of understanding the process individuals go through when considering the adoption of an implementation. The designation between adopter and non-adopter can be fluid if an individual’s situation changes making adoption of the innovation a necessity. This could be particularly important given the precarious nature of the lobster fishery in Maine.

Another limitation of this study is the focus on commercial fishers participating in the Maine lobster fishery only. There are a number of other commercial fisheries in Maine and participants in these fisheries may feel differently about the marine aquaculture industry and their willingness to consider the adoption of aquaculture. In addition, the lobster license holder list does not include crew who work on lobster boats and individuals who were under the age of 18 at the time of the survey were excluded from participating in the survey. Younger fishers and crew who work within the fishery, but do not hold a license may also be interested in adopting aquaculture since a number of Maine’s commercial fisheries are closed to new entrants and aquaculture provides an opportunity to own a business and continue to
work on the water. Future studies should attempt to understand the perceptions of aquaculture and willingness to adopt among individuals who participate in other fisheries, who are younger or who work within the lobster fishery, but do not hold a lobster license.

Findings from this study are significant to Maine because practitioners are interested in understanding the potential for aquaculture to be a diversification strategy for Maine’s coastal communities and working waterfronts. More broadly, this study contributes to livelihood diversification and innovation adoption literature, specifically adding to the content on aquaculture and commercial fishing integration in a developed nation.
CHAPTER 3

CHALLENGES AND OPPORTUNITIES FOR INTEGRATING AQUACULTURE WITH COMMERCIAL FISHING IN MAINE

3.1. Introduction

Fisheries are inherently variable and are expected to become more so in the face of climate change (Kasperski & Holland, 2013). Diversification either through additional species fished or through alternative income-generating activities, such as aquaculture, may provide a buffer against interannual variation and stabilize fishing-dependent incomes and livelihoods reducing impacts from climate change (Kasperski & Holland, 2013). Livelihood diversification increases the number of income-generating activities an individual or household participates in and is often a strategy utilized to buffer against shocks and stresses, minimizing vulnerability and risk (Olale & Henson, 2012; Olale & Henson, 2013). Beyond increasing or stabilizing income at the individual or household level, Torrell et al. (2010) found ancillary benefits of livelihood diversification efforts to include improved resilience, strengthened social ties, increased local government coordination, and empowerment.

3.1.1. Commercial Fishers and Aquaculture

In the early 1990s, Weeks (1992) described the interest by regulators to recruit commercial fishers into aquaculture to buffer against declining fish stocks and environmental uncertainty. However, not all efforts to encourage commercial fishers to adopt aquaculture have been successful. Rubino and Stoffle (1990) highlighted the design and implementation of aquaculture projects to match the needs of the community within which the project is being introduced. Weeks and Sturmer (1996) studied the implementation and outcomes of efforts to introduce oyster aquaculture to commercial fishers in two communities in Florida, US; one project was successful while the other was not. The unsuccessful project was implemented after a natural disaster which accelerated the timeline for implementation. The need for a rapid response to address the impacts of the natural disaster prevented robust
community participation in the design of the project. This, in turn, minimized community buy-in and acceptance of the efforts to introduce aquaculture as an alternative livelihood. For the other project, its design was based on knowledge about the existing social structures and target industry and its approach and implementation matched the introduced technology to the local context leading to more successful project outcomes (Weeks & Sturmer, 1996). In Norway, small-scale fishers implemented aquaculture as a way to cope with fluctuations in wild stocks. They tended to adopt aquaculture technologies that were established and proven to be successful and profitable rather than experiment with the cultivation of new species or husbandry techniques for which profitability and outcomes were uncertain (Bailey et al., 1996).

In New England, Robertson et al. (2001) surveyed federal commercial fishing permit holders about their interest in adopting offshore aquaculture technology. They found that some respondents agreed that aquaculture would provide jobs for displaced commercial fishers and believed that fishers could adapt to aquaculture jobs (Robertson et al., 2001). From that same survey of federally permitted commercial fishers, Tango-Lowy and Robertson (2002) found that one third of the respondents were willing to consider starting aquaculture while another third of the respondents were unsure about implementing aquaculture. Individuals with less fishing experience, participated in more fisheries and had knowledge of the innovation or aquaculture were more likely to consider adoption (Tango-Lowy & Robertson, 2002). Tango-Lowy and Robertson (2002) reasoned that these individuals may not be as well established in fishing and thus more flexible in considering diversification activities such as aquaculture. Additionally, participating in a number of different fisheries could indicate a willingness and ability to try new livelihood activities, such as aquaculture (Tango-Lowy & Robertson, 2002). However, the more time fishers spent commercial fishing each year and the more resources they had invested in commercial fishing gear, the less likely they were to consider the adoption of aquaculture; these individuals were considered entrenched in commercial fishing and less flexible in considering alternative
or additional livelihood opportunities (Tango-Lowy & Robertson, 2002). These findings suggest that the path to introducing aquaculture to commercial fishers as an alternative livelihood activity can be complex (Tango-Lowy & Robertson, 2002).

More recently, Conejo-Watt et al. (2021) explored the potential for the inshore fleet in England to implement finfish, marine algae and shellfish aquaculture. They identified barriers to entry, including cost, spatial conflict between aquaculture and other ocean uses, and uncertainty about aquaculture’s profitability and consumer perceptions of aquaculture products (Conejo-Watt et al., 2021). Additionally, interest in implementing aquaculture was dependent upon the individual characteristics of fishers such as age, education level and knowledge or skills, and occupational pride in commercial fishing (Conejo-Watt et al., 2021). Findings suggested that fishers differ in their viewpoints about the potential for aquaculture implementation, but also, that certain groups of fishers might be more willing to consider aquaculture than others. Conejo-Watt et al. (2021) recommended that policymakers provide fishers with training and guidance to increase their technical knowledge of aquaculture while increasing public awareness about aquaculture techniques and products to improve social acceptance and profitability of the aquaculture operations. They also suggested that pilot projects could be implemented to demonstrate successful colocation of aquaculture and fisheries.

Jeffrey et al. (2021) conducted an extensive literature review to identify barriers to integrating or transitioning to aquaculture from commercial fishing and through expert interviews, described cases where fishers attempted, successfully or not, to adopt finfish, kelp, or shellfish aquaculture in the United Kingdom. Barriers to aquaculture adoption included factors such as a lack of startup capital, competition for ocean space with other uses, negative perceptions of aquaculture products based on past transgressions by the aquaculture industry, particularly in finfish operations, regulatory barriers or confusing and lengthy permitting processes, and the importance of economies of scale (Jeffrey et al., 2021). Economies of scale was particularly relevant for types of aquaculture that required high capital
investment to implement an operation and had well established aquaculture industries, such as salmon aquaculture. In order to be competitive within an established industry, a newer operation needed to be relatively large-scale, which might be difficult for a commercial fisher to attain when first starting aquaculture (Jeffrey et al., 2021). At the individual level, barriers included the combination of an individual’s characteristics such as experience, knowledge, skills, age and education, an individual’s social capital, network and access to entrepreneurs, and one’s commitment to occupational identity with commercial fishing (Jeffrey et al., 2021). Jeffrey et al. (2021) concluded that commercial fishing and aquaculture were complimentary and that fishers had the on-the-water skills and knowledge of species characteristics and markets to successfully implement aquaculture. Jeffrey et al. (2021) called for the creation of a more supportive policy environment and to simplify the process for fishers to engage in the aquaculture sector. Ultimately, Jeffrey et al. (2021) highlighted the need for additional research in high income countries to understand the patterns of commercial fishing and aquaculture activity to inform future efforts to support aquaculture uptake by commercial fishers. Barriers to adoption of aquaculture exist and are well understood in a number of cases (Conejo-Watt et al., 2021; Jeffrey et al., 2021), but knowledge of how fishers are integrating aquaculture into their livelihoods remains limited.

In Maine, US, efforts have been underway to aid fisher adoption of aquaculture through several training programs (Sadusky et al., 2022). The Aquaculture in Shared Waters program (Shared Waters program) was started in 2013 to train commercial fishers in shellfish and seaweed aquaculture techniques (Pianka, 2016; Cleaver et al., 2018). The Shared Waters program is organized by Maine Sea Grant, the Maine Aquaculture Innovation Center, the Maine Aquaculture Association, and Coastal Enterprises, Inc. Generally, the course is held on a weekly basis for 8 – 12 weeks and involves lectures, guest speakers and field trips to existing aquaculture farms, aquaculture gear manufacturers, hatcheries and other locations relevant to the aquaculture value chain. Course topics include species biology, husbandry techniques, the leasing and regulatory process, biosecurity as well as community relations.
and business diversification opportunities such as farm tours. Cleaver et al. (2018) found that most commercial fishers who participated in the 2013, 2015, 2016 and 2017 Shared Waters cohorts were interested in aquaculture as a diversification opportunity (61%). The 2015 cohort was most concerned about the regulatory process and associated paperwork to secure a lease to start aquaculture while the 2016 and 2017 cohorts were more concerned with getting an aquaculture operation running successfully followed by concerns related to the leasing process (Cleaver et al., 2018). The Island Institute, a community development organization based in Rockland, Maine ran a business development program geared towards commercial fishers starting aquaculture from 2016 through 2019 (Island Institute, 2019). Commercial fishers were mentored through the process of identifying a species to farm, selecting a site and submitting the paperwork to secure a lease as well as counseled on business practices. The 2022 Aquaculture Roadmap, a 10-year vision for aquaculture development in Maine, highlighted an interest in encouraging commercial fishers to consider aquaculture as an option to diversify and maintain Maine’s maritime and working waterfront heritage (Sadusky et al., 2022).

Given the interest in facilitating the integration of commercial fishing and aquaculture in Maine, this study aimed to understand the motivations of commercial fishers who have considered doing aquaculture or are implementing aquaculture, describe their experience with aquaculture and identify barriers to aquaculture implementation. More specifically, for those who have started an aquaculture operation, this study sought to determine who they are in terms of their socioeconomic characteristics and commercial fishing experience, their motivations for considering aquaculture, barriers they have experienced in their process of implementing aquaculture and their plans related to commercial fishing and farming. Similarly, this research aimed to better understand individuals who had considered aquaculture, but then decided not to pursue starting an operation. This study describes the factors informing their decision and their needs if they were to try aquaculture in the future.
3.2. Study Site

Maine provides an excellent opportunity to examine the adoption of aquaculture among commercial fishers. With more than 3,000 miles of coastline, a reputation for producing and distributing high quality wild harvested and farmed seafood, and close proximity to large population centers, Maine’s aquaculture sector is experiencing an unprecedented period of growth (Sadusky et al., 2022). Optimism for the future growth of shellfish and seaweed aquaculture in Maine is high with the aquaculture sector having had a direct economic impact of $73.4 million in output (Cole et al., 2016).

In order to farm seafood, individuals or firms must apply for a lease or license to the Maine Department of Marine Resources. Once the lease or license application is approved, the individual or firm gains access to a defined area of ocean space to implement aquaculture activities (Johnson & Hanes, 2019). Standard leases are approved for 20 years with the option to renew and can be up to 100 acres in size. Experimental leases cannot exceed 4 acres in size and are for three years without the option to renew unless the farming is for educational or research purposes. The Limited Purpose Aquaculture license (LPA) is only available to individuals, not businesses, and provides access to 400 square feet for one year with the option to renew. By 2021, there were 158 active experimental or standard leases totaling 1,416 acres and 769 active Limited Purpose Aquaculture licenses (Maine Department of Marine Resources, 2022a). An additional 30 leases totaling 353 acres are pending review, which include new applications, standard leases that are in the process of being renewed or experimental leases that are in the process of being converted to a standard lease (Maine Department of Marine Resources, 2022a).

Maine coastal communities, historically supported by diverse fisheries, are now predominantly dependent on the American lobster (Homarus americanus) fishery making these communities potentially vulnerable to fluctuations in the lobster stock or price. In 2020, lobster made up 79% of total landed value of commercial fisheries (Maine Department of Marine Resources, 2022b). Over the last
three decades, landings and the value of lobster continued to increase and the fishery is touted as a rare example of marine resource sustainability (Acheson & Acheson, 2020). The fishery’s success is due in large part to effective regulations, the conservation ethic of participating commercial fishers, and favorable environmental conditions (Acheson & Acheson, 2020). However, the Gulf of Maine is warming at an incredibly fast rate (Pershing et al., 2015). In addition to climate change, other threats exist such as increasing regulations to protect the endangered North Atlantic right whale and economic uncertainty which bring into question the resilience of the industry to withstand these external threats (Acheson & Acheson, 2020). Overreliance on a single species poses a precarious socioeconomic situation for Maine’s coastal communities (Steneck et al., 2011; Johnson et al., 2014). Aquaculture provides a potential diversification strategy for commercial fishers to buffer against social and ecological changes in fisheries (e.g., Cleaver et al., 2018), but aquaculture also conflicts with commercial fishing for use of ocean space (Hanes, 2018; Johnson & Hanes, 2019).

3.3. Methods

This study is based on 42 semi-structured interviews with individuals who were current or past participants in the commercial fishing industry and were involved in aquaculture by actively farming, had participated in an aquaculture training program or both. This study compiled a sample frame from the Aquaculture in Shared Waters and Aquaculture Business Development Program enrollment lists as well as from expert knowledge about individuals who participated in both commercial fishing and aquaculture. Both of the training programs were run over multiple years, the Aquaculture in Shared Waters program in 2013, 2015, 2016, 2017, and 2018 and the Aquaculture Business Development program in 2016, 2017 and 2018. The compiled sample frame included 186 individuals. Course instructors reviewed the list and identified 15 individuals who had participated in a training program, but were not commercial fishers and so these individuals were removed from the sample frame. An additional 22 were removed due to the lack of a contact email or phone number and one individual was
removed due to a language barrier. The remaining 148 individuals were called or emailed at least once in an attempt to schedule an in-person interview between December 2019 and March 2020 or a phone interview in May and June of 2020. One hundred four individuals did not answer or return phone calls or respond to emails requesting an interview. Two individuals who were contacted, but refused to participate due to time constraints or a lack of interest in the study.

All respondents were asked about individual demographics, such as age and education level, their participation in the commercial fishing industry, motivations for considering aquaculture, and barriers to aquaculture adoption. Individuals were asked different questions based on their level of involvement in the aquaculture industry. Those who were actively farming (adopters) were asked about how they got started in aquaculture, which species and location they chose to farm and why, the status of their aquaculture operation today, where they purchase equipment and sell their product as well as if they work with other farmers or organizations in implementing their aquaculture operations. Individuals who had plans, but were not actively farming an aquaculture species (potential adopters) were asked about those plans, including which species and location they would choose to farm and if they had plans to apply for an aquaculture lease and license or a lease application submitted. They were also asked what they would need to successfully implement aquaculture and about any challenges they have faced in starting their operation. Finally, those individuals who were not actively engaged nor planning to engage in aquaculture (non-adopters) were asked why they had decided not to start aquaculture, if they would consider it in the future, and what they would need to get started.

A total of 19 interviews were conducted in-person in December 2019 through March 2020 and then another 23 interviews were done by phone in May and June 2020. Interviews ranged in length from 15 minutes to 2.5 hours with an average length of approximately 45 minutes. With the respondent’s permission, interviews were recorded and transcribed using the Verbal Ink transcription service. Transcriptions were analyzed for themes and insights in NVivo 12 Pro software. For analysis, a code
book was developed based on the major thematic areas of the interview guide. All transcripts were read line-by-line to identify content related to the themes identified in the code book (Miles et al., 2014). Transcripts were reviewed again and additional themes and subthemes were identified through an inductive approach (Bernard, 2011).

Ninety percent of the respondents shared the town in which they live. Thirty-seven percent of the respondents were from Cumberland County, three percent from Sagadahoc County, three percent from Lincoln County, 32% from Knox County, three percent from Waldo County, 18% from Hancock County and five percent from Washington County. For analysis, respondents were divided into three categories depending on their level of aquaculture activity. Adopters (n = 24) were participating in aquaculture meaning they have secured a lease or LPA and were actively growing a species; potential adopters were those individuals who had applied and possibly secured a lease or LPA, but were not yet actively growing an aquaculture species as well as those individuals who expressed plans to implement aquaculture within the next five years (n=6); and, non-adopters (n=12) were those who tried to do aquaculture and stopped or those who never developed plans to implement aquaculture after having participated in part of or had completed an aquaculture training program. When asked, some of the non-adopters did say they would consider doing aquaculture in the future, but with no specific timeline for implementation or specific details about which species or location they would like to farm. Whether an individual is considered an adopter, potential adopter or non-adopter is fluid; however, for the purposes of the analysis in this study, evidence gathered through the one interview with each individual informed the categorization of each respondent at this time.

3.4. Results

3.4.1. Respondent Characteristics

The average age of respondents was 49 years old (Table 3.1). Respondents had worked in commercial fishing for an average of 34 years (Table 3.1) and seventy percent of the respondents
considered themselves to be full-time commercial fishers, 15% were part-time and 15% worked outside of commercial fishing, but had fished in the past (n=40). Individuals participated in the following fisheries: lobster (62%), scallop (24%), sea urchin (17%), shellfish (17%), halibut (12%), menhaden (10%), rockweed (7%), tuna (7%), elver (5%), groundfish (5%), herring (5%), mackerel (5%), periwinkle (5%), mussels (2%), green crab (2%), shrimp (2%), squid (2%), and swordfish (2%). The majority of respondents had at least graduated from high school, had some college education or a graduate degree (Table 3.2).

Eighty-four percent of the respondents had participated in an aquaculture training program (n=33).

Table 3.1. Characteristics of respondents summarized as all respondents and by adoption status, including adopters, potential adopters and non-adopters.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter</th>
<th>Total sample</th>
<th>Adopters</th>
<th>Potential Adopters</th>
<th>Non-adopters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>n</td>
<td>30</td>
<td>18</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Mean (S.D.)</td>
<td>49(14)</td>
<td>52(14)</td>
<td>34(9.3)</td>
<td>49(13)</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>18-72</td>
<td>18-72</td>
<td>23-40</td>
<td>25-63</td>
</tr>
<tr>
<td>Experience in fisheries (years)</td>
<td>n</td>
<td>34</td>
<td>19</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Mean (S.D.)</td>
<td>34(15)</td>
<td>36(16)</td>
<td>20(7.8)</td>
<td>37(12)</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>2-55</td>
<td>2-55</td>
<td>11-31</td>
<td>14-52</td>
</tr>
<tr>
<td>Past fisheries (#)</td>
<td>n</td>
<td>42</td>
<td>24</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Mean (S.D.)</td>
<td>3(2)</td>
<td>4(2)</td>
<td>4(1)</td>
<td>3(1.7)</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>1-8</td>
<td>1-8</td>
<td>3-4</td>
<td>1-7</td>
</tr>
<tr>
<td>Current fisheries (#)</td>
<td>N</td>
<td>42</td>
<td>24</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Mean (S.D.)</td>
<td>2(2)</td>
<td>2(2)</td>
<td>2(1.4)</td>
<td>2(1.3)</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>0-10</td>
<td>0-10</td>
<td>0-4</td>
<td>0-4</td>
</tr>
</tbody>
</table>

Table 3.2. Education level of respondents by adoption status.

<table>
<thead>
<tr>
<th>Education level (%)</th>
<th>Total sample</th>
<th>Adopters</th>
<th>Potential adopters</th>
<th>Non-adopters</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>31</td>
<td>18</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Some high school (%)</td>
<td>6.45</td>
<td>5.5</td>
<td>0</td>
<td>12.5</td>
</tr>
<tr>
<td>H.S. graduate (%)</td>
<td>29.03</td>
<td>33.3</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Some college (%)</td>
<td>19.35</td>
<td>11.1</td>
<td>20</td>
<td>37.5</td>
</tr>
<tr>
<td>College degree (%)</td>
<td>35.48</td>
<td>38.8</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Post-graduate (%)</td>
<td>9.68</td>
<td>5.5</td>
<td>40</td>
<td>0</td>
</tr>
</tbody>
</table>
3.4.2. Motivations for Considering Aquaculture

Four themes emerged among respondents regarding motivations for considering aquaculture, including 1) an interest in diversifying their fishing livelihood or income, 2) their network or access to resources that facilitated aquaculture adoption, 3) being drawn to aquaculture for the way of life it could provide (e.g., the opportunity to work on the water, be a business owner, live and work in Maine), and 4) the belief that aquaculture plays a role in sustainability. Adopters predominantly mentioned an interest in diversification and stabilizing fishing-dependent incomes as well as having personal and professional connections that introduced them to aquaculture.

In regards to aquaculture as a diversification strategy, several respondents mentioned declines in their commercial fishery as a reason for considering aquaculture. As one wild shellfish harvester and oyster aquaculture adopter explained about when he first considered doing aquaculture:

[It was] probably around 2012, because the green crabs really did a number on clams around here, to the point where people couldn't make a living. People that had been for years making a living at it, couldn't do it. So, it seemed like if you could grow stuff [like oysters] and bring it back without it being devastated by green crabs, then that was a good thing.

Others mentioned wanting to round out their seasonal income from commercial fishing with an activity that they could do when they are not fishing consistently. One of the non-adopters said:

I think it was because the time of the year that we were thinking about doing it [kelp farming] was the time that we wouldn’t be making much money, and I think it was something that we thought, ‘Maybe we can use this as an alternative income source.’

Other individuals discussed elements of aquaculture that they found appealing for the type of work that they wanted to pursue. Aquaculture was viewed as a way to live and work in Maine, continue working on the water, own a business and provide high quality seafood to their local communities. As one adopter who had worked on a lobster boat while starting an oyster operation stated:
I had moved back home to Maine after working abroad on boats for a number of years, and I was looking for something that I could do here for work on the water and be self-employed and start my own business. And aquaculture really was the shining star that I could find.

Other respondents had family, friends or professional contacts who had encouraged them to consider aquaculture and had helped them find the resources and support to do so. One adopter discussed how their town marine warden and now harbormaster had encouraged fishers to consider aquaculture as an opportunity:

And we've got a pretty active marine resources committee in town...and a marine warden - or was a marine warden, now he's a harbormaster - he kind of, I don't want to say pushed it, but kind of brought it to people's attention that it might be an alternative.

Sustaining coastal communities and providing an opportunity for future generations to continue working on the water was also mentioned. One adopter said:

I guess that’s where the interest comes from, that aquaculture is a way towards sustainability...

Obviously I'd like to make a little money at it someday but my real drive behind it would be I've got a son that fishes, a nephew, a grand-nephew, maybe another grand-nephew that might go fishing. So, for guys like that, or women, whoever – the younger generation – some of them are going to hopefully use this maybe for an opportunity to diversify.

3.4.3. The Adopters

3.4.3.1. Getting Started

Adopters were asked how they chose which species to start farming. Species chosen included oysters, kelp, mussels, scallops, and quahogs. In terms of the reason for choosing these species, two themes emerged: 1) individuals selected species that had established husbandry techniques or markets and perceived the start-up costs to be relatively low; these species were viewed as easier to get into than farming species with no existing market or with higher costs associated with getting started and 2)
the species’ husbandry techniques and growing season aligned with commercial fishing activity both at
the individual and community level.

Species farmed by the adopters included: oysters, kelp, mussels, sea scallops and quahogs. Nineteen out of the 24 adopters were farming one species only while the remaining five were farming two species. Two of these five individuals were farming oysters and kelp, one was farming oysters and scallops, one was farming oysters and quahogs, and one was farming kelp and mussels. A total of 17 adopters had chosen to farm oysters, including those individuals who were farming two species. These individuals selected oysters because they were well known by consumers and had a strong market, proven profitability, and well-established husbandry practices. As one respondent said:

It seemed like the best investment of time and bang for the buck at the time. There [was] no
research on quahogs at the time. Seaweed seemed like just a winter thing…. [J]ust reading up on
oysters. Just thought there was an unlimited market. Hopefully, it keeps [going] that way, and
the market doesn't get saturated with so many people getting into it.

Six individuals had adopted kelp, three of whom were also farming a secondary species. Kelp was
identified as complimentary to the lobster fishery since the growing season for kelp and time of harvest
are a different time of year than the height of the lobstering season. This was perceived as beneficial at
the individual and community levels in that individuals could work on kelp during their off season from
fishing for lobster and aquaculture operations were generally perceived as more easily accepted by
other lobster fishers since aquaculture gear would be out of the water by the time lobster fishers are
setting their traps. As one respondent said: “Well, [I chose] seaweed because it's my off season. Take
the traps out, put the kelp in. Take the kelp out; put the traps in. So, it makes a lot of sense.”

In deciding where to farm, respondents considered a number of factors including relying on
their knowledge of existing use and landowners in the area as well as trying to identify locations where
they thought the species of choice would grow well. As one respondent mentioned:
Well, personally, I, first and foremost, looked for areas that would not have a conflict. Being a fisherman myself, I realize the importance of that because if you are a fisherman, you know where people are going to want to be and when they're going to want to be there. So that should be the first and foremost thing that you look for, is, ‘How can I not piss off my neighbors? How can I make this work for everybody?’

At least three of the respondents had individuals with aquaculture expertise confirm their site location as sufficient for the intended culture species. Other factors that were important in siting their operations included proximity to their house and waterfront access to get to their site relatively easily.

Regarding the process of filling out paperwork to obtain an aquaculture lease or license to start farming, adopters were evenly split on their perception of the process being difficult or being relatively easy and straightforward. Approximately half said that they did not have any problems at all. One adopter did express challenges associated with the length of time it took between submitting the lease application and being granted the lease, but he did not have issues with filling out the application. He said, “Took a long time. It was well over a year.”

Three themes emerged for those who believed the paperwork process was difficult, including individuals characterizing themselves as not being good at paperwork, the application requiring a level of detail that was difficult to complete without mistakes, and the length of time it took to complete the application. One individual essentially said he did not have the patience to sit and fill out the lease application:

I'm not a paper person. I am not a paper person.... I'll bet I've got seven to nine lease applications, half-done at my house. Because when you do too much, you do nothing well. So, I get about half or three quarters the way through it, run into a little stumbling block, say, ‘Screw this. I'm going fishing.’
One respondent, speaking to the level of detail required and the length of time it took to submit a fully complete application, described the process as:

It takes a lot of time to go through everything and there was a lot of whiteout on my first application, and I did that wrong. So, they sent it back and then I reapplied and then I think we changed it-- I think I went through it three times before it was finally submitted.

Several respondents mentioned how responsive and helpful the Maine DMR was in reviewing and correcting applications. Some of the adopters discussed how they had a partner or a practitioner help them with the application process. As one wild shellfish harvester who had adopted oyster aquaculture said:

I did all the applications myself. Well, not myself, but it was myself and my wife, and it was challenging. Well, we did it. A lot of late nights doing drawings. We figured it out. Drawings. Definitely not easy. I'm glad I went to school architectural engineering, so. I dragged out all my hand-drafting tools and did it.

Other adopters interviewed had purchased existing oyster aquaculture operations. One discussed the challenges associated with learning how to farm oysters, but being beholden to the farm setup specified in a lease designed by a different farmer. This individual had to amend the existing lease and go through that process, saying:

When you buy a farm, you don't anticipate certain things -- we had trouble with some of our anchors moving around and that was a struggle. So, I've had to put in for an amendment that, changed some gear configurations there. But it's always difficult when you want to do things a certain way and you can't [because it's not specified in the existing lease]. So, everything is a process. So, that's what I've learned. Everything is a process.
3.4.3.2. Aquaculture Activity

Adopters were asked to recall the year in which they first considered aquaculture in terms of taking an aquaculture course or having learned about aquaculture from a personal or professional contact and then recall the year in which they applied for and secured a lease or Limited Purpose Aquaculture License to implement aquaculture. The average length of time between when they first considered aquaculture and when they applied for a lease was approximately three years (n=19) with a minimum of starting aquaculture within the same year as when they first considered it and a maximum of starting aquaculture 22 years after first considering it. However, there is a high potential for recall bias in the responses to these questions because respondents were asked about the specific years in which they first considered aquaculture and when they secured their first lease or license to implement aquaculture. Six of the respondents started aquaculture by securing a lease or LPA before 2015 while 14 started after 2015 (n=20) so at the time of the interviews, 14 had been participating in aquaculture for five years or less.

Sixteen adopters were utilizing Limited Purpose Aquaculture (LPAs) licenses as part of their operation, two of these adopters also held an experimental lease and two also held a standard lease. The number of LPAs per operation ranged from one to twelve; those who were operating with more than four, which is the maximum number of LPAs legally allowed per individual, mentioned that they were working with partners who held additional LPAs. Three adopters had standard leases only while two had both standard and experimental leases.

Of the 24 adopters, 17 are growing oysters, six kelp, three scallops, one quahogs, and one mussels. None of the respondents in this sample participate in finfish aquaculture. For the 15 adopters who are currently participating in the lobster fishery, but were not shellfish harvesters, nine were growing oysters, five kelp, three scallops and one mussel. Five adopters fished for shellfish, including soft-shell clams and quahogs, but did not fish for lobster; three of these individuals were participants in
the Aquaculture in Shared Waters 2015 cohort which targeted shellfish harvesters specifically. All of these individuals were growing oysters and one was experimenting with quahogs. Additionally, one expressed interest in expanding their operation in the future to include quahogs and another was interested in eventually expanding to include soft-shell clams, quahogs and razor clams.

### 3.4.3. Balancing Fishing and Farming

One of the adopters had decided to completely transition out of fishing and pursue farming. Eleven of the adopters were implementing aquaculture while maintaining their commercial fishing activities. Individuals who were farming species with seasons that coincided with their fishing activities expressed the reality that doing both required long days and working most days of the season. For example, one respondent discussed how during the summer, he would be working seven days a week and on certain days, he would haul lobster traps until early afternoon and then work on the oyster farm into the evening. Shellfish harvesters discussed how they were able to work a low tide on the mudflats to harvest wild clams and then work on their oyster farm during the high tide. Lobster fishers growing kelp talked about balancing their aquaculture work during the offseason to lobstering.

### 3.4.4. Potential Adopters

Six respondents were considered potential adopters of aquaculture. These were individuals who may have secured a lease or LPA, but were not yet actively farming at the time of the interview or had specific plans for starting aquaculture within the next five years. One of these individuals was in the process of applying for leases or LPAs to start growing product while two individuals had secured an experimental lease or an LPA, but were not yet actively growing any product. The remaining three individuals had plans to implement aquaculture within the next five years.

One of the potential adopters was in the midst of applying for four LPAs and was also working on a lease application. He had decided to sell his lobster boat and gear to be able to focus on aquaculture. As he stated:
My plan is to stop fishing this year. I still have 700 traps in the water, but as soon as they go on
the bank, I'm selling my boat... and starting my farm up. I'm working on my lease application
right now for mussels, kelp. Mussels and kelp to start. Probably throw in some scallops at some
point. It's happening. I'm taking the plunge. I mean, a lot of guys are calling me crazy because
the fishing is still good. But I think, "Now's the time." And I'm just ready. I'm ready to do it.

This individual had previous experience working on an aquaculture farm and now was working with the
riparian landowner next to the proposed farm site as a business partner to plan the mussel and kelp
operation. Additionally, this individual was having a boat built specifically for aquaculture.

The two potential adopters who both went through the leasing and licensing process, have plans
within the next two to five years to grow kelp. They both mentioned the complimentary nature of the
kelp season aligning with a lull in the lobster season as a reason for pursuing kelp aquaculture. As one of
them said:

For me, the idea of the crossover with kelp farming seems like a good fit because it's a little bit
of a slower time for lobstering and those sites would be ideally located where if it's a day where
you can't get out because of the wind to haul your traps, you can scoot in and monitor your
farm and make sure things are looking good. So, I think it would be a fairly seamless sort of way
to do both. I think that's the appeal of kelp farming. I don't want to complicate my life.

They both intend to finance as much of the start-up costs as possible out-of-pocket and plan to sell their
product to Atlantic Sea Farms in Biddeford, Maine; a company that buys product from a number of
fisher-farmers along the coast (Atlantic Sea Farms, n.d.). One mentioned that the delay in implementing
aquaculture was due to the timing of when he started lobstering on his own. He needed time to
establish his lobstering business before putting effort into starting an aquaculture operation. He said: “I
would like to grow kelp in the future, but I need to figure how to have a sustainable and successful
lobster business first before I spread myself too thin... I would like to say [that I’ll start aquaculture] within five years.”

One of the three potential adopters was waiting until he completed a project in which he was building a prototype for a seaweed harvesting boat. He needed the cash flow from selling that boat to be able to afford starting an aquaculture operation. Another individual continues to refine his plans and is working to identify a potential partner to help with establishing an aquaculture operation within the next five years.

3.4.5. Non-adopters

Twelve respondents were categorized as non-adopters with four individuals having taken some steps to implement aquaculture, but then deciding to discontinue their efforts while the other eight did not pursue any aquaculture activity. Nine of the non-adopters mentioned that they did not have the time to implement aquaculture or they had chosen to pursue another opportunity around the same time they had considered doing aquaculture. Individuals who are not currently participating in aquaculture mentioned the uncertainty of starting something new, specifically not knowing which species to farm or the expected profitability of implementing aquaculture as well as challenges in aligning the timing and financing of securing a lease, growing product to market size and finding a buyer for that product as reasons why they had not pursued implementing aquaculture. Additionally, respondents claimed that they lacked capacity, primarily financial, but also the time, knowledge and labor to adequately implement aquaculture. One respondent pointed out that aquaculture is physically intense and time-consuming and he acknowledged that he was not sure that he wanted to do it given the uncertainty of success. He said: “But the other thing about starting an aquaculture [operation] from scratch... it's a lot of hard work and investment. So that's a risk.” Another individual’s family had owned an oyster farm that he had worked on in the past, but he decided that continuing to do aquaculture alongside other job responsibilities was too much work. As he explained,
I did [work on the farm] for a little while, but it was just a lot of work.... It's really [a] lot-- it's time-consuming. There's a lot of good money in it. If we didn't do anything else besides the oyster farm, it would have been a very good business to have. But since we were juggling buying and delivering clams and lobsters ... it kind of was too much to bear.

Two respondents mentioned the amount of paperwork required to secure a lease as a reason they didn’t pursue aquaculture. One respondent mentioned that after considering aquaculture, his stubbornness in not wanting to try something new and stick to what he knew, which is lobstering prevented him from pursuing aquaculture.

Of the four individuals who considered aquaculture and started taking steps to implement aquaculture, two submitted lease applications; one was rejected and the other had an application deemed complete by Maine DMR, but then did not complete the leasing process. The rejected lease application faced severe community backlash for the proposed location. The individual described that he and his two partners pulled the application together quickly, choosing a site that was relatively close to their home harbor and was protected from the elements, but in selecting that site, they had not talked to the riparian landowners before submitting their application, which is an important step that had been suggested to them during the aquaculture training program. In addition, this group had deployed gear to collect larval scallops and lost all of that gear by spring. Given these two outcomes, they decided not to pursue implementing aquaculture. This respondent did reflect that if he were to try aquaculture again in the future, he would need financial support either through a partner who had those means or through grant funding or other financing as well as support from the riparian landowner or community adjacent to the potential aquaculture site.

The second individual was interested in growing kelp and the Maine DMR had deemed his lease application complete, but he decided to withdraw his application. He was concerned about aligning the
timing of full lease approval with starting the farming operation and lining up a buyer for his product at the end of the season. He said:

So basically, even if I had gotten my 16 acres in 2019 and had harvested this spring. They [the product buyers] probably wouldn't have been able to take that amount that I was going to be able to produce. And they said [that] probably by 2021 they would be [able to purchase product]. But it was quite a big gamble to front all that money and stress and not really know if your product was going to be even accepted.

He estimated that the site setup would cost between $50,000 and $60,000 and he was worried that he might lose his gear and crop to a winter storm or that the limited processing capacity for kelp would mean that he would not be able to sell his product at the end of the season. He also began to question whether he had chosen the right site. He explained that upon further inspection, the proposed lease site seemed potentially too exposed to withstand winter storms and he raised concerns about the location of the proposed lease being in an area where he owns a coastal home, but not in an area in which he fishes. He was uncertain that he would be able to reassure the local fishers that his aquaculture operation would not be in their way.

Another individual was not able to secure a lease for the species he was interested in farming because he also holds a commercial fishing license for the same species. Current regulations did not permit this individual to maintain his state and municipal wild shellfish harvesting license while also farming clams as some of the clams in his aquaculture operation would likely be smaller than the legal minimum size of wild harvested clams. Regulators were concerned that they would not be able to differentiate between clams that this individual had harvested from the wild and those he was growing on a permitted aquaculture site. Ultimately, this regulatory hurdle prevented this particular individual from pursuing aquaculture at this time. This same individual expressed an interest in growing scallops, but he cited the husbandry practices and market for the farmed product still being in developmental
stages. The risks of starting a scallop operation were too great considering the level of investment required to start a farm. He discussed his willingness to wait until others had figured out husbandry practices and the potential profitability of a scallop farm before he would reconsider starting to farm scallops.

The fourth individual had not yet attempted to fill out a lease application, but had deployed gear to collect scallop larvae. Unfortunately, this effort did not end well; the gear became entangled with commercial fishing gear and the bags were lost. He described the attempt: “… I didn't have very good luck because by the time I was trying to catch the spat, there were still fishermen in the bay and oh, it got to be a heck of a mess.” When asked if he would consider trying aquaculture in the future, he said that he would like to and that he just needed to stop being lazy and try it.

3.4.5.1. Needs to Implement Aquaculture

Ten of the non-adopters who were asked if they would consider doing aquaculture in the future said they would while one was unsure given the leasing process and needing to deal with the fishing and coastal community in siting a lease location. One respondent who was in his 60s would not consider aquaculture again given how close he believed he was to retiring. When asked what they would need to get started, the most frequently mentioned answer was financial capital or money (mentioned 8 times) followed by finding the right location to farm (mentioned 6 times), having more time to focus on implementing aquaculture (mentioned 5 times), and gaining additional knowledge or having someone help them with the process of getting a farm started (mentioned 1 time).

3.5 Discussion

Given the interest in aquaculture as a diversification strategy for Maine commercial fishers, this study aimed to understand the motivations of commercial fishers who considered doing aquaculture, describe their experience with aquaculture and identify barriers to aquaculture implementation. Motivations for considering aquaculture included the variability or declines in their current fisheries.
Additionally, personal and professional connections were important to fishers in their consideration of adopting aquaculture. In this instance, personal and professional connections were important in informing fishers about training opportunities and other resources that may have helped facilitate fisher adoption of aquaculture. If fisher adoption is a policy priority or a strategy for preserving Maine’s working waterfront and maritime heritage (Sadusky et al., 2022), efforts to increase or facilitate fisher uptake of aquaculture may require the involvement of these types of individuals who are actively connecting fishers to aquaculture opportunities. Currently, there are a number of organizations that do facilitate this type of outreach including Maine Sea Grant, Coastal Enterprises, Inc., Maine Aquaculture Association, and Maine Aquaculture Innovation Center. Continuing to support this type of work is likely important to facilitating fisher adoption.

These personal and professional contacts and additional resources were also important to the adopters in their decisions around where to farm or site selection, filling out paperwork, or completing other aspects of running an aquaculture business alongside a commercial fishing operation. Some of the adopters and non-adopters in this study cited issues with completing the paperwork, including challenges related to the length of time and level of detail required to complete the application and the length of time it took for a lease to be approved. Jeffrey et al. (2021) recommended simplifying the regulatory process to facilitate fisher adoption of aquaculture, which is one option. Another option could be to increase resources available to fishers to successfully complete the paperwork required for the leasing process. Aquaculture training programs could include an aspect where instructors or others provide ongoing support like a workshop or one-on-one meetings specifically focused on filling out the lease application.

For the adopters who had implemented aquaculture, they predominantly had chosen to farm species where start-up costs were relatively low such as kelp and oysters, avoiding the cost barrier to entry. Cost has been identified as a barrier to fisher adoption of aquaculture in a number of studies (e.g.,
Jeffrey et al., 2021; Conejo-Watt et al., 2021). To facilitate fisher adoption of aquaculture, financial institutions and other entities could provide low interest loans or grants to eliminate the barrier start-up costs pose to new entrants. Additionally, species selected for farming tended to have well understood husbandry techniques and established markets; farming these species, specifically oysters and kelp, can reduce the uncertainty around the potential success and profitability of the aquaculture operation. These findings are similar to Bailey et al. (1996) where Norwegian fishers chose to continue their commercial fishing activities and to farm species that were well established rather than risk investing their limited resources in farming an experimental species with no market. The adopters interviewed for this study needed to have some certainty that their efforts in aquaculture would pay off before they were willing to take the risk to diversify into aquaculture. Additionally, there appears to be a match between the species farmed, its husbandry practices and the species fished for and harvesting practices. Adopters also expressed interest in implementing aquaculture and continuing their commercial fishing activities. This pattern was evident among the wild shellfish harvesters who were choosing to farm oysters and the lobster fishers who were farming kelp. This match between the innovation and the adopters is critical to successful adoption of innovations and is supported in the innovation literature (Downs & Mohr, 1976; Acheson & Reidman, 1982).

Jeffrey et al. (2021) highlighted economies of scale being critical to the integration of aquaculture with commercial fisheries; they discussed the example of salmon aquaculture in Scotland and acknowledged that any fisher who wants to enter that industry would need to make a significant investment at a large scale in order to be competitive in the well-established salmon aquaculture industry. The economies of scale issue as highlighted by Jeffrey et al. (2021) encompasses a number of factors that seem to influence fisher adoption in Maine, including the decision about which species to farm where there is an interest in established culture species, the level of investment required to establish a profitable aquaculture operation where costs can be a barrier to getting started and the
interest in being able to maintain their commercial fishing activities while also doing aquaculture so selecting to farm species where the husbandry activities compliment their fishing activities. These factors could have implications for the scale of operation and level of production fishers can achieve. Many of these decisions will depend upon an individual’s situation; however, if practitioners and others value aquaculture as a diversification option for commercial fishers should fisheries decline (e.g., Sadusky et al., 2022) then policy action may be required to ensure various scales of aquaculture operations can be viable entities.

The majority of non-adopters did express an interest in potentially trying aquaculture in the future and for some of the adopters, there was a considerable amount of time between first considering to do aquaculture and then actually implementing aquaculture. This highlights that the individual adoption process is complex, can unfold over a long period of time (Rogers, 2003), and that individuals can shift from non-adopters to adopters if their situation changes and the new situation creates a better match between the innovation and the individual (Acheson & Reidman, 1982). Ultimately, individuals who are currently designated as non-adopters should not necessarily be ignored for extension efforts since they may become adopters if their situation changes in the future. Efforts to facilitate fisher adoption should be consistently available which will require considerable financial and human resources to provide training programs and other opportunities regularly.

One limitation of this study is that it relied on participant lists from aquaculture training programs and expert knowledge of individuals who were commercial fishers and participating in aquaculture. This sample frame did not necessarily include a broad representation of fishers who may have considered aquaculture, but did not sign up for a training program or others who had tried aquaculture, but then stopped. This limits the amount of evidence collected related to the reasons commercial fishers did not pursue the implementation of aquaculture and the needs required to get started in aquaculture in the future. Another limitation is that data collected about each individual was
from a single interview. It is difficult to capture the complexity of the adoption decision process in a single interview as opposed to following an individual over a period of time through a longitudinal study. Additionally, by not following individuals throughout their adoption decision process and instead, asking individuals to reflect on their past decisions regarding their interest in aquaculture and aquaculture adoption could have introduced recall bias into the results. To address both of these limitations, following individuals through the course of the adoption process from the time they first consider adopting through implementation and either continued implementation or transitioning out of aquaculture would be ideal.

Future research should continue to explore how fishers are implementing aquaculture and if their interest in adopting aquaculture changes given increasing threats to commercial fisheries. Ultimately, aquaculture can provide a diversification strategy for some commercial fishers and will likely continue to do so into the future.
CHAPTER 4
FROM FORMATIVE TO ESTABLISHED: A FUNCTIONAL APPROACH TO UNDERSTANDING SCALLOP AQUACULTURE DEVELOPMENT IN MAINE

4.1. Introduction

The aquaculture sector has undergone incredible growth over the last few decades with the rate of aquaculture production increasing more rapidly than wild-capture fishery production on a global scale (FAO, 2020). Additionally, the sector is considered an opportunity for economic development in many countries, including the US (Knapp & Rubino, 2016). Interest in growing the US aquaculture sector is driven by the amount and quality of marine and coastal waters suitable for aquaculture development here as well as the potential for domestic production to offset the current trade imbalance for seafood products (Kapetsky et al., 2013; Knapp & Rubino, 2016). However, barriers to growth exist, such as issues with permitting aquaculture activity in coastal waters, aquaculture competing with other uses for ocean space, and negative public perceptions of aquaculture (Knapp & Rubino, 2016; Lester et al., 2018).

Understanding and analyzing how the innovation processes that underlie aquaculture development are managed can facilitate the growth and sustainability of the sector (Joffre et al., 2017). To date, analyses of the innovation processes in aquaculture have focused primarily on technology transfer at the farm level limiting knowledge about the broader context within which aquaculture innovation takes place (Joffre et al., 2017). Joffre et al. (2017) called for the application of systemic approaches in understanding aquaculture innovation to identify the multi-dimensional aspects of complex aquaculture systems influencing the trajectory of the sector’s development. Technological Innovation Systems (TIS) approaches, which focus on the development of a specific technology, have been widely applied to understand innovation in the transportation and energy sectors, but few studies have applied the framework to aquaculture. Given the relevance of the Technological Innovation Systems in understanding development and diffusion of an emerging technology and the need for more
systemic approaches to understand aquaculture development, the TIS functional performance framework was selected to explore the structure, dynamics and performance of the developing aquaculture industry for the Atlantic sea scallop (*Placopecten magellanicus*) in Maine.

4.1.1. Innovation in Aquaculture

An innovation is defined as a new or modified technology or idea that is introduced into a social group or system for the first time (Rogers, 2003). Diffusion of an innovation is the process by which that innovation is adopted or taken up over time by a group of individuals within a social system (Rogers, 2003). Joffre et al. (2017) analyzed how innovation is conceptualized in aquaculture to identify research needs and inform future innovation models to support the growth of the aquaculture sector and to contribute to the development of sustainable food systems. Joffre et al. (2017) found that the majority of studies involving innovation and aquaculture have focused on the farm or individual farmer as the unit of analysis, specifically analyzing the process of technology transfer and individual adoption of aquaculture technologies. Findings from these types of studies highlight individual characteristics and aspects of the innovation that facilitate or hinder successful adoption of new technologies by individuals within a social group. Recommendations resulting from these studies tend to focus on opportunities to improve the likelihood of individual adoption and focus on the role that additional extension services and organizational support can have in facilitating individual adoption or uptake of aquaculture technologies (e.g., Baticados et al., 2014; Blythe et al., 2017). These types of studies often do not consider the broader institutional, biophysical, technical and political context that likely impacts development and diffusion of the technology (Joffre et al., 2017).

The diffusion of an innovation is not linear nor rational, but instead is coevolutionary and dependent upon links between technical knowledge and developments, socio-cultural values, social innovation and power structures (Haasnoot et al., 2016; Paredis, 2011). To account for this nonlinear process and the multidimensional context within which innovation development and diffusion takes
place, a systems approach to innovation examines the “...economic, social, political, organizational, institutional and other factors that influence development, diffusion, and use of innovations” (Edquist, 1997, 14). The systems approach views innovation as an interactive and iterative social learning process (Coenen & Diaz Lopez, 2010).

Applying an innovation systems approach to understanding the process of aquaculture development could help mitigate some of the negative consequences associated with the intensification of aquaculture. Tailoring recommendations that address the multi-dimensional aspects of the context within which aquaculture growth occurs could lead to more ecologically and socially sustainable outcomes (Joffre et al., 2017; Bush & Marschke, 2014). To assess the economic, ecological and social sustainability of shrimp aquaculture development in Thailand and Vietnam, Lebel et al. (2002) applied an innovation systems approach and highlighted a mismatch between the technology in use, industrial organization, and knowledge systems. This mismatch led to negative social and environmental outcomes (Lebel et al. 2002). Furthermore, existing government policies facilitated the intensification of the shrimp aquaculture industry, exacerbating the negative environmental and social outcomes (Lebel et al., 2002).

Belton and Little (2008) compared industry development and outcomes of integrated finfish aquaculture to intensive shrimp aquaculture in Thailand and found that global and national market dynamics greatly influenced the profitability of the two different ventures. The finfish aquaculture industry was only made possible by the development of a local market driven by the demand from a wealthier urban class whereas the establishment and intensification of shrimp aquaculture relied on demand from a global market. The shrimp aquaculture industry, reliant on global demand, experienced boom and bust dynamics, preventing small-scale operators from achieving consistent profitability and the farming practices in place degraded the environment (Belton & Little, 2008). The finfish aquaculture technology was better suited to cultural practices, had a lower cost of entry, and aligned with existing
livelihood activities. Ultimately, farmers reliant on the finfish aquaculture that supplied the local market were more resilient than the shrimp farmers who struggled to match their production with the global market dynamics and experienced the negative effects of environmental degradation from the intensification of shrimp farming (Belton & Little, 2008).

Joffre et al. (2018) utilized an innovation systems approach to identify the constraints and mechanisms prohibiting the transition of the expanding shrimp aquaculture sector towards sustainable outcomes in Asia. By doing so, Joffre et al. (2018) was able to generate specific recommendations to facilitate expansion of the shrimp industry while aligning industry expansion and intensification with sustainable outcomes. Utilizing innovation system approaches within the aquaculture sector can provide a useful conceptual framework and analytical tool to inform recommendations and interventions to promote and facilitate sustainable growth in the sector (Edquist, 1997; Coenen & Diaz Lopez, 2010).

4.1.2. Analytical Framework: Technological Innovation Systems

Characterizing innovation systems and understanding how they function can help to identify activities or structures that inhibit or promote the innovation process; these blocking and inducing mechanisms are often areas where policy interventions and other actions can focus to either remove a blocking mechanism or further facilitate an inducing mechanism to ultimately support the development and diffusion of new technologies (Hekkert et al., 2007). Coenen and Diaz Lopez (2010) compare and contrast three frameworks used in systems innovation analyses including the Sectoral Systems of Innovation (SSI) where the boundaries of the system are based on a sector such as energy, the Technological Innovation Systems (TIS) where the boundaries are defined by a particular technology and the Socio-Technical Transformation systems (STT), which encompasses a focus on a societal function such as communication (Coenen & Diaz Lopez, 2010). Coenen and Diaz Lopez (2010) compare how the different frameworks define boundaries (e.g., geopolitical boundaries, a specific technology, or a specific sector), individuals and firms involved with the new technology, and the institutions, both formal and
informal that influence development, adoption and diffusion of the particular technology and the innovation system. They compare and contrast how these different innovation system approaches conceptualize knowledge and analyze dynamics and change (Coenen & Diaz Lopez, 2010). They find that the SSI approach is most appropriate when the system components are relatively stable, such as for an established and widely used technology whereas the TIS is appropriate for emerging technologies. The STT approach moves beyond firm-centered analyses and offers the most inclusive contextual approach to understanding innovation and technological change; however, moving beyond firms as the unit of analysis can make understanding innovation system function and performance more difficult and complex (Coenen & Diaz Lopez, 2010). The three approaches also differ in the outcomes from analyses; SSI focuses on providing recommendations for performance of firms within the innovation system, TIS focuses on facilitating the adoption and diffusion of emerging technologies, and STT on transitioning systems towards sustainability (Coenen & Diaz Lopez, 2010).

Bergek et al. (2008) proposed an analytical framework to assess TIS performance by categorizing system activity into specific functions. The functional pattern of an innovation system can be documented and mapped through time to understand the overall performance of the system (Jacobsson & Johnson, 2000). By describing these functions relative to the development of a specific technology, researchers can develop a characterization of the system to understand strengths and weaknesses as well as identify barriers to and drivers of adoption and diffusion (Lundvall et al., 2002; Hekkert et al., 2007). The TIS functional framework is focused on providing a mechanism to identify areas where intervention could facilitate the innovation process (Coenen & Diaz Lopez, 2010).

Function 1: Entrepreneurial activities involve the experimentation and risks taken by innovators or entrepreneurs when adopting the new technology. These activities reduce uncertainty related to use of the new technology and prompt a social learning process that facilitates technological change (Kemp et al., 1998; Bergek et al., 2008). Entrepreneurs are responsible for translating new knowledge, networks and markets into business opportunities (Negro et al., 2007). Entrepreneurial experimentation or activity is arguably one of the most important functions within a TIS. The performance of this function is measured by the number of business startups or new entrants using or developing the new technology and by the number of existing companies that diversify to include use or development of the new technology (Hekkert et al., 2007; Esmailzadeh et al., 2020). A well-functioning TIS is one in which entrepreneurial activity is supported and facilitated (Hekkert et al., 2007). Without experimentation and refinement by entrepreneurs, the innovation would not exist; however, the success of entrepreneurial experimentation is dependent upon the level of performance in other system functions (Hekkert et al., 2007; Negro et al., 2007).

Function 2: Knowledge development is a mechanism for learning about the social, economic and technical aspects of the innovation (Hekkert et al., 2007; Esmailzadeh et al., 2020). Knowledge development can be assessed in its breadth and depth, how it changes over time and in comparing knowledge development within the local TIS to the global TIS (Bergek et al., 2008). Knowledge can be distinguished by type, including scientific, technical, production, and market and source such as Research and Development (R&D), learning from new applications and imitation (Bergek et al., 2008).

Function 3: Knowledge exchange and diffusion maps how information about the technology moves through networks, raising awareness, building capacity and sharing resources to facilitate technology development and uptake (Esmailzadeh et al., 2020). Knowledge exchange occurs between researchers and industry members, users of the technology and its producers, and individuals developing the technology (Esmailzadeh et al., 2020). This exchange is critical for R&D that supports the
innovation process, but also for policy development so that R&D efforts and policy agendas are aligned (Negro et al., 2007). This function can be measured by the number of workshops and conferences focused on sharing information about the technology (Hekkert et al., 2007; Negro et al., 2007).

Function 4: Influence on the direction of search identifies the societal level factors that affect technological innovation. The innovation process is influenced by beliefs in growth potential of the technology (Bergek et al., 2008), societal preferences (Hekkert et al., 2007), customer or market preferences and government priorities through incentives or regulatory pressures (Bergek et al., 2008). Typically, the direction of search is a cumulative process where innovation producers and users as well as a number of other actors shape the trajectory of the technology’s development (Hekkert et al., 2007). One goal of this function is to reduce the uncertainty and risks associated with producing and using a new technology (Esmailzadeh et al., 2020). To measure the performance of this function, targets or goals established by governments or industries related to development of the new technology can be mapped over time.

Function 5: Market formation is the activities carried out to enhance the market opportunities for new technologies or innovations (Esmailzadeh et al., 2020). Often, a barrier to the diffusion of new technologies is that they compete directly with established technologies and there is a need to establish and develop a new market for the new technology (Rosenberg, 1976; Hekkert et al., 2007). Therefore, to facilitate diffusion and adoption of new technologies, policy intervention may be needed to create temporary niche markets (Schot et al., 1994), provide tax incentives, or establish minimal consumption quotas to facilitate uptake of the new technology among consumers (Hekkert et al., 2007).

Function 6: Resource mobilization maps how human and financial capital are being used to develop the technology (Hekkert, et al. 2007). A variety of resources are needed to develop a new technology and facilitate its adoption. Critical resources can include the amount of human capital available in relevant fields from scientific research and technology development to entrepreneurship,
management and finances (Bergek et al., 2008) or financial resources available to further develop the technology. Resource mobilization is a difficult function to measure and is typically based on the perception of the availability of different types of resources by individuals involved in developing the new technology (Hekkert et al., 2007; Negro et al., 2007).

Function 7: The creation of legitimacy is the process by which the new technology overcomes resistance to change, is accepted by key actors and policymakers and aligns with relevant institutions (Hekkert et al., 2007; Bergek et al., 2008; Esmailzadeh et al., 2020). Groups that benefit from the status quo where the innovation is not well established may attempt to undermine the process of building legitimacy for a new technology; however, advocacy groups in support of the new technology can potentially counteract these efforts (Bergek et al., 2008). Advocacy groups increase awareness about the technology (F4), work to accumulate resources to support this technology (F6), and lobby for favorable policies that carve out market space for the new technology (F5) (Hekkert et al., 2007). The legitimacy of the technology and its proponents are critical to mobilizing resources (F6), developing consumer demand or forming a market (F5), and for developers or users of the new technology to build political influence (Bergek et al., 2008). This function can be measured by tracking the development and growth of advocacy groups and their actions (Hekkert et al., 2007). Creating legitimacy is a lengthy, dynamic process that is the result of intentional actions by different individuals and organizations working to overcome the new technology’s ‘liability of newness’ (Zimmerman & Zeitz, 2002, 414; Bergek et al., 2008).

Function 8: Development of positive externalities is critical to the innovation process and includes the development of new firms and services focused on addressing bottlenecks while also facilitating the creation of legitimacy (F7) and market formation (F5) to increase demand for the new technology (Bergek et al., 2008). Increasing the number and different types of firms involved in
4.1.3 Context for Scallop Aquaculture & Its Development

Scallops are marine bivalves in the mollusca phylum typically found in coastal waters up to 200 m deep (Hardy, 2006). There are approximately 360 species of scallops found throughout the world (Hardy, 2006). Scallop aquaculture is well established in Japan and other parts of the world utilizing different species of scallops than the Atlantic sea scallop or the species of interest for aquaculture in Maine. Japan’s scallop aquaculture industry is often looked to as a model for other developing scallop aquaculture industries. In Japan, experimental work to develop scallop aquaculture began in the 1930s. After 30 years of experimental trials, successful seed collection and intermediate culture techniques were established in 1964 (Kosaka, 2016). The industry is dependent on natural scallop seed collected from wild populations, which is less expensive than hatchery-produced seed (Kosaka, 2016). Intermediate culture involves sorting and putting the juvenile scallops in pearl nets to be hung on suspended longlines (Kosaka, 2016). After intermediate culture, scallops are placed in suspended or bottom culture for grow out to market size.

Approximately 703 km² in Hokkaido and 500 km² in Mutsu Bay are designated for suspended culture and licenses to work these areas are issued to fisheries cooperatives by the government. Approximately, 1300 vessels work in Hokkaido and 1000 vessels in Mutsu Bay (Kosaka, 2016). Vessels are outfitted with multiple pieces of equipment, including a derrick for lifting longlines and nets, a washing machine for cleaning biofouling from the nets, and a rope-hanging hauler (Kosaka, 2016). Scallop products include frozen, dried, canned, adductor muscle, and boiled meat. There are concerns about the consistency of the natural seed supply and about reduction in growth rates during grow-out due to overcrowding (Kosaka, 2016). Even so, the industry has been very productive since the 1970s (Kosaka, 2016).
Researchers, commercial fishers, and aquaculturists have experimented with culture techniques for different species of scallops elsewhere with varying degrees of success. Some countries have developed commercial-scale industries while others completely abandoned experimental efforts. Often, a decline in wild scallop fisheries prompted initial efforts to explore aquaculture techniques as an opportunity to rebuild or enhance wild stocks, which ultimately, led to efforts to culture scallops to market size (Ruiz-Verdugo et al., 2016; Guo & Luo, 2016). For those countries where a successful scallop aquaculture industry has developed, some commonalities include cultivating a species that is large and reaches market size within one to three years (Parsons et al., 2016) as well as the species having an established market, a consistent and plentiful seed supply either through wild collection or hatchery production (Guo & Luo, 2016), and the grow out techniques align with the species’ biology and the surrounding environment (Guo & Luo, 2016; Robinson et al., 2016).

Where scallop aquaculture industries have been less successful, aspects of the species’ biology, such slow growth rates, can result in long production cycles limiting the economic efficiencies of aquaculture (Strand et al., 2016). In addition, a lack of a consistent and abundant seed supply either from wild stocks or hatchery production can hinder scallop aquaculture development (Dredge et al., 2016). Other barriers to scallop aquaculture include high rates of predation or biofouling during the farming process (Dredge et al., 2016), the cultured product competing directly with an established wild fishery (Ruiz-Verdugo et al., 2016), high costs associated with the farming process including the initial investment, equipment and labor (von Brand et al., 2016; Robinson et al., 2016), and issues related to biotoxins and harmful algal blooms (Robinson et al., 2016).

In Maine, the process of scallop farming involves first securing a lease or license from the Maine Department of Marine Resources, the state agency that is responsible for permitting aquaculture activity. Individuals or firms can apply for a standard lease, which grants exclusive access to a defined area up to 100 acres in size for 20 years with the option to renew the lease terms. An experimental lease
permits access to an area up to 4 acres in size for three years without the option to renew the lease unless the farming is for scientific or educational purposes. The Limited Purpose Aquaculture license (LPA) is only available to individuals, not businesses, and provides access to 400 square feet for one year with the option to renew.

Farmers secure a spat collection license from Maine DMR to collect scallop larvae from the wild. Then, in early fall, they deploy lines of spat bags, which are devices for collecting larvae. Once larvae are collected, farmers move them to a permitted aquaculture site to grow until the larvae reach market size. In the spring, farmers sort scallops from the spat bags and put them into lantern nets or pearl nets for intermediate culture. The farming process involves periodically thinning or grading scallops to reduce scallop density in lantern nets and eventually moving any scallops growing in pearl nets to lantern nets. For final grow-out, farmers are using two different techniques. Some are continuing to grow scallops to market size in lantern nets while others are using a combination of lantern nets and experimenting with a Japanese technique called ear hanging. The ear hanging method involves drilling a hole in the scallop shell then hanging those individuals from a dropper or vertical line in the water column. Pearl and lantern nets and the ear hanging method are considered suspended culture techniques.

4.2. Methods

In 2018, eleven semi-structured interviews were conducted in-person with ten key informants who are involved in the development of the scallop aquaculture industry in Maine. Respondents included individuals from two nonprofit organizations, cooperative extension, the state agency that regulates aquaculture, an individual involved in marketing and selling scallops, and five farmers who are experimenting with growing scallops. The interview guides differed depending on the individual’s position within the scallop aquaculture industry. Farmers and individuals involved in sales of farmed scallops were asked about their motivations for adopting scallop aquaculture, their process for learning how to farm scallops and information sources, barriers to adoption, and opportunities for scallop
aquaculture in Maine. Nonprofit, state agency and cooperative extension staff were asked about the history of scallop aquaculture industry development, including major milestones, barriers to adoption both for individuals and to the diffusion of the industry, and their perspective on the future trajectory of scallop aquaculture in Maine.

Interviews ranged in length from 30 minutes to 97 minutes and were audio recorded with the respondent’s permission. Audio recordings of the interviews were transcribed by a third-party transcription service. Transcriptions of the interviews were coded in NVivo Pro Software Version 12. Transcripts were read multiple times before beginning the coding process. Then initial coding was done (Corbin & Strauss, 2015) followed by more in-depth coding matching interview data to the Technological Innovation System functional performance framework proposed by Bergek et al. (2008).

Aquaculture lease and Limited Purpose Aquaculture license data were obtained from the Maine Department of Marine Resources. The number of leases and LPAs that included scallops as a listed species were counted over time as an indication of the level of activity taking place in the Maine scallop aquaculture industry.

4.2.1. Process Analysis

To assess the amount and type of activities related to scallop aquaculture industry development over time, a process or event analysis was carried out (Hekkert et al., 2007). This involved cataloging the order and content of events related to scallop aquaculture industry development in Maine and coding each event by Technological Innovation System performance function per Bergek et al. (2008). This type of analysis can help to identify the system functions that are supporting or inhibiting development of the focus technology. Relevant sources used in identifying events related to technological development include newspaper and journal articles, reports and workshops or meetings (Hekkert et al., 2007). In November 2021, the Proquest News and Newspapers database was searched using the terms “scallop” AND “aquaculture” AND “Maine”. The New York Times (1960 – 2021), the Boston Globe (1960 – 1990),
the Washington Post (1960 – 2021), the Wall Street Journal Eastern Edition (1984 – 2021), the Lewiston Sun Journal (2006 – 2021), the Portland Press Herald (1995 – 2021), and the Bangor Daily News (July 1, 1993 – November 7, 2021) were searched. In addition, the term “scallop aquaculture” was searched for on the Fishermen’s Voice (1998 – 2020) and MaineBiz websites to find additional relevant articles. Organizational websites for the Maine Aquaculture Association, Maine Aquaculture Innovation Center, Aquaculture Research Institute, Island Institute, Downeast Institute, Maine Sea Grant publications through Digital Commons, Coastal Enterprises, Inc., and the National Sea Grant Library were searched for the term “scallop aquaculture” to find descriptions of grant-funded projects and other organizational work happening that related to scallop aquaculture development in Maine.

One hundred sixty-seven documents that summarized events related to Maine scallop aquaculture development were collated into a database in Excel 2019. The events were organized by year and then coded by TIS function per Bergek et al. (2008). A single event could be coded as contributing to more than one system function. For example, many research projects which primarily resulted in knowledge development (F2) also involved farmers who were growing scallops and contributed to entrepreneurial activities (F1). In these instances, one event was categorized as both Function 1: Entrepreneurial activities and Function 2: Knowledge development. The analysis involved mapping the number of events that happened each year for each function. When these events were plotted over time for a specific function, it gave an indication of the performance of that function. Those functions with a lot of activity related to it were deemed as performing well while those where there were few to no activities taking place related to it were deemed as areas where additional effort could be focused to help grow the scallop aquaculture industry per Hekkert et al. (2007) and Bergek et al. (2008).
4.3 Results

4.3.1 Overview of the Maine Scallop Aquaculture Industry

The Maine scallop aquaculture industry includes farmers and aquaculture businesses starting de
 novo or existing businesses diversifying to include scallop farming as well as other firms involved in
different stages of the scallop aquaculture value chain (e.g., seed and equipment suppliers, distributors,
etc.). In addition, regulatory agencies that permit aquaculture activities and sales of farmed product,
research and nonprofit organizations, and industry associations are involved in the development of the
scallop aquaculture industry. The Maine Department of Marine Resources (Maine DMR) regulates
aquaculture activity within state coastal waters. Aquaculture permitting also involves the Army Corps of
Engineers that reviews lease applications to ensure aquaculture infrastructure does not interfere with
navigation. Sea scallops are susceptible to developing high levels of toxicity from consuming certain
species of phytoplankton, which pose a risk to people when consumed. Thus, the Maine DMR Public
Health Bureau manages product grown for public safety implications.

Several organizations are involved in supporting different aspects of industry development. The
Maine Aquaculture Association (MAA) supports and advocates for aquaculture interests at the state and
federal level and supports growers through education and outreach. The Maine Aquaculture Innovation
Center (MAIC) provides research and funding support for a number of initiatives including scallop
aquaculture research projects. Maine Sea Grant and Cooperative Extension (Sea Grant) and Coastal
Enterprises, Inc. (CEI) have focused their efforts in terms of staff support and pursuing and securing
grant funding on technology and knowledge transfer from the Japanese scallop aquaculture industry
and experiments to test different grow-out techniques and equipment in Maine. CEI is exploring the
commercial viability of a scallop farming operation and the feasibility of using machines developed for
the Japanese scallop aquaculture industry. These organizations, in addition to MAIC, have been
instrumental in building relationships between scallop farmers in Maine and farmers as well as gear and equipment producers in Japan.

MAA, MAIC, Maine Sea Grant, and CEI also partner to deliver aquaculture training programming to new entrants. These organizations, along with the Aquaculture Research Institute, also form the Maine Aquaculture Hub, which has provided funding to the scallop industry (Sadusky et al., 2022). Other researchers at the University of Maine secured funding in partnership with Maine Sea Grant to explore the potential of sea scallop aquaculture in Maine based on siting criteria important to scallop biology (e.g., Coleman et al., 2021a; Coleman et al., 2021b). Additionally, University of Maine researchers are working to model population dynamics of scallop populations along the coast with implications for the developing scallop aquaculture industry and to develop hatchery-raised scallop seed at the Downeast Institute (DEI). The Hurricane Island Center for Science and Leadership is an education and research nonprofit organization that has developed a demonstration aquaculture farm that includes scallop culture. They are focused on partnering with existing scallop growers and conducting research related to understanding the biological aspects of scallop culture to inform husbandry practices. The Gulf of Maine Research Institute based in Portland, Maine has commissioned two separate reports 1) to understand the market potential for farm-raised scallops and 2) to assess needs to support the growth of the scallop aquaculture industry (e.g., The Hale Group, LTD, 2016; Fitzgerald, 2021).

Farmers experimenting with scallop culture span the coast of Maine. Two of the four growers in Casco Bay have been working with CEI to test equipment and the Japanese method of ear hanging scallops. In the Penobscot Bay region, a farmers’ cooperative or co-op was established in 2016. The Maine Aquaculture Co-op (MAC), a formal network of farmers, interested individuals and others who support scallop aquaculture development, was formed to share best practices and lessons learned through experimentation, collective purchasing of gear and equipment from Asia, and to apply for grant funding as needed. For example, the MAC received funding from the Maine Aquaculture Hub to
purchase a net washing machine to reduce the labor associated with removing biofouling on lantern nets. In 2016, the MAC had approximately 8 members, including several actively experimenting with scallop aquaculture, some who were interested in starting to farm scallops, and others who wanted to support scallop aquaculture industry development. Now, MAC membership stands at 20 individuals with 10 actively farming at 8 different locations from Cape Elizabeth to Frenchman Bay and the other members supporting scallop aquaculture development through marketing, policy advocacy, grant writing and research.

Scallop farmers must secure a lease or license from Maine DMR to cultivate a species in coastal waters. Additionally, individuals must secure a spat collection license from Maine DMR in order to collect wild scallop seed or spat since scallop seed is not yet available for purchase from hatcheries; however, some individuals do sell seed they collect to other farmers. All farmers must also adhere to restrictions on selling product from their farms. If they farm scallops on a Limited Purpose Aquaculture license, they must have a Memorandum of Understanding with Maine DMR to do so. They must adhere to public health closures due to water quality issues after rainfall events and toxic phytoplankton blooms.

4.3.2. Development of Maine Scallop Aquaculture Industry

4.3.2.1. Experimentation phase for scallop aquaculture 1990s - 2012

Experimentation with sea scallop farming in Maine started in the mid-to-late 1990s. From 1999 through 2005, a cooperative research project involving scallop fishers, the Maine Department of Marine Resources, and extension staff worked to rebuild wild scallop populations by capturing scallop larvae or seed, growing them to a certain size and then releasing those individuals on scallop beds (Schick & Feindel, 2005). Ultimately, this project led to an understanding of seed collection techniques and initial grow-out methods, the first steps in the process for farming scallops. In the early 2000s, extension staff began to explore opportunities for developing the scallop aquaculture industry in Maine through
exchange trips to other places in the US and Canada where people had tried scallop aquaculture. In 2012, extension staff, researchers and prospective scallop farmers tested scallop growth in bottom trays and cage systems; an oyster aquaculture technology converted in this case for use with scallops (Morse, 2012). The use of these techniques to grow scallops in Maine was abandoned due to the risks of overcrowding of scallops.

This initial period of industry development is characterized by having few actors involved in the scallop aquaculture industry in Maine. In addition, networks and institutions supporting the industry’s development were minimal and industry development was reliant on the work being done by a small number of entrepreneurs and extension and nonprofit organization staff exploring the feasibility of starting scallop aquaculture. At this time, the focus of knowledge development and entrepreneurial activity was on wild seed collection, nursery stage and potential grow-out techniques. Functional performance of the emerging scallop aquaculture industry was limited, but developing in entrepreneurial activity (F1), knowledge development (F2) and some knowledge exchange between groups within Maine and with established industries elsewhere (F3). Very little to no activity was taking place in relation to market formation (F5), legitimation (F7), influence on the direction of search (F4), resource mobilization (F6), and development of external economies (F8).

4.3.2.2. Introduction of Suspended Culture 2012 – Present

Experimentation with different grow-out techniques continued and was aided by technology and knowledge transfer from the Japanese aquaculture industry to Maine. An established sister-state relationship between Maine and Japan facilitated delegations of individuals from Maine to travel to Japan and, in turn, host Japanese delegations in Maine. Extension and nonprofit staff and commercial fishers and farmers traveled multiple times between the 1990s and 2016, prompting a period of experimental efforts to adapt Japanese farming techniques to Maine’s environment and species of scallop. Since 2016, individuals in Maine have been experimenting with suspended culture, a technique
widely utilized in Japan’s industry (Morse, 2019). Suspended culture involves hanging pearl nets, lantern nets or ear hanging lines from a longline suspended between two moorings. Theoretically, this method required less space than bottom cages and adequately spaces out individual scallops to optimize growth.

Both the ear hanging method and managing biofouling on suspended lantern nets proved to be labor intensive and time-consuming; therefore, since 2018, nonprofit staff and farmers started experimenting with mechanizing the farming process, including the removal of biofouling. In 2021, seven to nine farmers were actively growing scallops (Fitzgerald, 2021) with approximately one to three of those selling their farmed product since 2019 (Schreiber, 2020). The product tends to be small to medium-sized scallops called “Princess” scallops as compared to the wild-caught product which are the adductor muscles from scallops with a shell height of at least four inches. During this period of scallop aquaculture industry development, entrepreneurial activity (F1) and knowledge development (F2) efforts continued with increased activity occurring related to knowledge exchange (F3) and initial efforts to establish a market for farmed product (F5).

4.3.3. Functional Performance of the Maine Scallop Aquaculture Industry

The most activity related to scallop aquaculture development in Maine has happened within the last 5 years (Figure 4.1). Based on the number of events occurring over the time period reviewed, the scallop aquaculture industry appears to be performing well in entrepreneurial activity (F1), knowledge development (F2), and knowledge exchange (F3) (Figure 4.1). Events related to the guidance of search (F4), resource mobilization (F6), and legitimation (F7) have also been consistent over time, but not always focused specifically on scallop aquaculture development and instead these events often include efforts to increase or support aquaculture activity within the state more broadly (Figure 4.1). Market formation (F5) and development of positive externalities (F8) have a limited number of events associated with them, but are increasing in frequency within the last few time periods (Figure 4.1).
Figure 4.1. Number of events by function over 5-year time periods from 1986 - 2020. Events include research projects, meetings, workshops, conference presentations and other activities related to scallop aquaculture development.
4.3.3.1. Strengths in the Maine Scallop Aquaculture Industry

The number of new entrants and the number of participants experimenting with the new technology over time indicate entrepreneurial activity is occurring (Hekkert et al., 2007). To date, entrepreneurial activity (F1) has driven scallop aquaculture development in Maine. Individuals interested in farming scallops have partnered with nonprofit organizations, extension staff and researchers to experiment with different stages of the farming process from collecting wild seed to testing various culture techniques for grow-out and more recently, to the sale of cultured scallops.

The number of active standard leases, experimental leases and Limited Purpose Aquaculture (LPAs) licenses that include scallops listed as a cultured species continues to increase each year (Figure 4.2; Figure 4.3). In 2021, seven to nine farms were actively growing scallops at farm locations from the Schoodic Peninsula to Casco Bay and one to three farmers sold product with one farmer entering their third season of sales (Fitzgerald, 2021).

In regards to experimentation with different types of technologies in use within the scallop aquaculture industry, initial research partnerships focused on collecting scallop seed from the wild to enhance wild scallop populations (Schick & Feindel, 2005). Once growing scallops to market size became a goal, a small group of farmers, researchers and extension staff started experimenting with growing the scallops in trays and cages (Morse, 2012). In 2016, Maine scallop farmers began experimenting with suspended culture techniques that were a direct technology transfer from Japan. In 2018, CEI was able to secure mechanized equipment used in the Japanese industry for farmers in Maine to experiment with; the machinery is expected to help farmers achieve a commercially viable scale of operation while minimizing labor costs (Fitzgerald, 2021).
Figure 4.2. Total number of active standard and experimental leases with sea scallops listed as a cultured species. Data includes lease information from 1987 to 2022. (Data source: Maine DMR data request, May 2022)

Figure 4.3 Total number of active Limited Purpose Aquaculture licenses (LPAs) with sea scallop as a listed cultured species from 2005 through 2022. (Data source: Maine DMR data request, May 2022)
Knowledge development (F2) can be measured by the number of research projects underway or that have been completed (Bergek et al., 2008). In the Maine scallop aquaculture industry, knowledge development is taking place as indicated by a number of research projects underway and this function has benefitted from two specific relationships: 1) over the last 20 years, nonprofit organization and extension staff have consistently partnered with farmers and secured funding to experiment with various stages of the farming process and 2) the existing sister-state relationship with Japan has facilitated technology and knowledge transfer from a country with a well-established scallop aquaculture industry to Maine, which has guided the direction of experimentation efforts in Maine.

Knowledge development activities are relatively evenly disbursed on the different stages of the farming process over time except for site selection parameters to identify the best locations for potentially farming scallops (Figure 4.4). This shows that knowledge development efforts have spanned all aspects of scallop farming (Figure 4.4).

![Figure 4.4. Percent of research projects by scallop farming stage that have been implemented between 1985 - 2020. The other category includes funding for infrastructure improvements that supports business incubators and hatcheries.](image)

The techniques for capturing wild scallop seed are relatively well understood; however, some respondents believe that hatchery technology is needed to achieve a larger scale of operation and
production (Fitzgerald, 2021). Hatcheries can increase the reliability of the seed supply within the industry and allow farmers to better plan their long-term operations and production. In the semi-structured interviews, three respondents identified the development of a hatchery as critical to the future growth of the scallop aquaculture industry in Maine, with one stating: “Once you have hatcheries, ...you can control when the seed is available to get into the growing system...[so you’re] not waiting for natural settlement to occur in the fall.” From 2007 through 2012, the Downeast Institute explored the potential to develop hatchery technology for seed production to enhance wild scallop populations; however, they were unable to identify the appropriate method to consistently produce millions of seed, which is the level of production needed to consistently supply a growing aquaculture industry (Downeast Institute, 2021).

Once seed has been secured, juvenile scallops can be kept in spat bags or transferred to pearl or lantern nets for the next stage of the grow out process or intermediate culture. Nonprofit and extension staff in partnership with farmers are working to determine the best husbandry practices and technology for grow out to market size. This work includes testing mechanized equipment for ear hanging scallops as well as for removing biofouling of ear hung scallops and lantern nets (Overton, 2016). Managing biofouling will continue to be an area where efficiencies in the farming process can be gained (Fitzgerald, 2021; Langston Noll & Davis, 2020).

Researchers and farmers continue to explore the scale of operation required to reach commercial viability and to develop a market for farmed product. In 2016, the Gulf of Maine Research Institute commissioned a report to understand the potential for shellfish aquaculture in the state, specifically the American oyster, blue mussels and sea scallops (The Hale Group, LTD., 2016). The Hale Group, LTD (2016) conducted a comprehensive market analysis for both the supply and demand side of shellfish with a focus on the potential for the Maine aquaculture industry. This report was meant to provide recommendations on strategies for the shellfish aquaculture industry to capitalize on
opportunities as well as help guide capital investment decisions over a 15-year planning horizon. They concluded that scallop aquaculture could expand significantly in Maine given the amount of coastal water suitable for growing scallops and the consumer perception that Maine scallops are a high-quality product (The Hale Group, LTD, 2016). In addition, national demand for scallops is high and Maine wild-caught scallops makeup less than 2% of total, national volume, but bring in the highest average price per meat pound. Given year-round demand, but seasonal supply, Maine farmed scallops could supplement the Maine wild fishery; however, the authors recommended investing in scallop aquaculture infrastructure to increase production capacity (The Hale Group, LTD, 2016).

In 2018, Coastal Enterprises, Inc. commissioned a report to analyze the market potential for selling Maine-cultured sea scallops (RBouvier Consulting, 2019). Relying on information collected from existing Maine farms and markets elsewhere as well as interview data with Maine farmers and chefs and a survey of restaurant owners, RBouvier Consulting conducted SWOT (Strengths-Weaknesses-Opportunities-Threats) and PESTEL (Political-Economic-Social-Technological-Environmental-Legal) analyses, concluding that the outlook for developing the Maine industry is promising. The industry would benefit from being able to provide product year-round, complimenting the season for the Maine wild fishery while also building on the strong brand for Maine seafood and the local food movement (RBouvier Consulting, 2019). However, challenges do exist including the upfront costs of the ear hanging or suspended culture method, susceptibility to economic recessions as a high-end, niche product, and climate change impacts (RBouvier Consulting, 2019).

In 2021, the Gulf of Maine Research Institute further delved into the challenges and opportunities for developing scallop aquaculture in Maine (Fitzgerald, 2021). Fitzgerald (2021) found similar potential for the growth of the scallop aquaculture industry, but flagged issues with biotoxins, co-existence between scallop aquaculture sites and other ocean users, and the state leasing process as
factors potentially limiting the growth of the industry. Overall, questions remain about the financial viability and the scale required to reach commercial level production and profitability (Fitzgerald, 2021).

Knowledge exchange and diffusion through networks (F3) is the exchange of information important to research and development as well as to market and policy formation (Hekkert et al., 2007). The exchange of information supports development of standards, goals and research agendas that align with the latest technological developments (Hekkert et al., 2007). At the international level, information exchange occurs on an annual basis, if not more frequently, as a result of the sister-state relationship between Maine and Japan; extension and nonprofit staff are the curators of these relationships and more recently, more established farmers are beginning to cultivate direct relationships with contacts in Japan. This relationship has allowed different pieces of equipment, designed and built in Japan, to be tested in Maine. These trials have been critical in helping Maine farmers understand the potential for mechanizing the farming process and reducing labor requirements. As one extension staff explained,

Everybody stands on one another’s shoulders. You learn from one another and you take another step forward. That’s just the way it happens….this Japan relationship is really good, because over a sustained time frame, we have learned about the ear hanging. We’ve learned about the pearl nets and the lantern nets, and the water quality, and the different kinds of things that you can make out of a scallop, which is really cool.

Within the state, formal information exchange between researchers, nonprofit and extension staff, and existing farmers has occurred on an annual basis formally during a session focused on scallop aquaculture development hosted during the Maine’s Fishermen’s Forum (Trotter, 2014; pers. obs., 2019). Additionally, extension and nonprofit staff as well as graduate students have presented about scallop-related research at annual meetings of the National Shellfish Association and the Northeast Aquaculture Conference and Exposition. In 2021, the Aquaculture Research Institute and the Hurricane
Island Center for Science and Leadership initiated the Scallop Research Collaborative, which brings together individuals from the commercial fishing, aquaculture, and research sectors (Dwyer, 2021).

The Maine Aquaculture Co-op (MAC) formed in 2016 to convene individuals who were farming scallops to exchange information and lessons learned and develop best practices (The Maine Aquaculture Co-op, n.d.). MAC started with approximately 10 members and as of 2021, membership has nearly doubled. Quarterly meetings involve farmers, extension staff and other researchers and the membership forms a network where new entrants into scallop aquaculture can approach more experienced farmers for advice.

The function of resource mobilization (F6) explores the amount and different types of human and financial capital available for the development of the Maine scallop aquaculture industry and complimentary goods and services (Hekkert et al. 2007). The performance of this function is difficult to measure and is often based on individual perception of the availability and accessibility of these resources and support systems (Hekkert et al. 2007; Negro et al. 2007). Human capital and the development of formal and informal networks have proven invaluable to supporting the emerging scallop aquaculture industry in Maine and new individuals continue to enter the industry or work to support its growth through research and development and other avenues. As one respondent mentioned:

... from about 2013/2014 through the last several years, there's a lot of other people who have come to the table and they are applying their expertise, and their questions, and their "what if" kind of effect, which is good and exciting, because to really make this happen it's gonna need more brains.

Additionally, nonprofit, extension, and university faculty and staff have mobilized grant funding from private foundations and federal agencies to support experimentation and development of the industry. However, a lack of capital investment, partially due to limited proof of commercial viability, creates a
barrier to growth. Financial institutions have limited options for supporting aquaculture operations. As one farmer explained:

[T]he last big area [in terms of challenges is] probably money.... for this industry to grow somehow, there’s going to have to be a lot of capital available. And my fear is that it’s not really, it’s not happening... It’s really hard to find people that are comfortable with aquaculture, that understand that it is different. You have to [have] very patient money.

In other words, financial institutions prefer seeing a return on their investment much sooner than the time it takes for aquaculture species to reach market size.

Initially, farmers sourced gear, including spat bags and lantern nets from Asia rather than relying on local vendors, because local marine supply stores did not yet stock the type of aquaculture equipment needed to farm scallops. However, this is slowly starting to change and over the last 10 years, marine supply stores have started to stock equipment related to scallop aquaculture, including spat bags, pearl nets and lantern nets (Fitzgerald, 2021). By making equipment needed in the scallop farming process readily available in Maine, individuals can more easily get started farming scallops. Maine--based companies do not yet produce the specialized equipment that mechanizes the farming process; these machines increase the efficiency of the suspended culture technique and reduce the labor inputs to the farming process. To date, CEI and Maine Sea Grant have purchased pieces of this equipment from Asia and have tested it in partnership with Maine farmers to understand how these pieces of equipment can be adapted to farming conditions in Maine. These experiments have not been without challenges. As extension staff mentioned:

You have to deal with customs [to get the specialized equipment to Maine]. You have to deal with freight. You have to deal with language [barriers], a different currency, and this [the farming process] all being brand new. It's gonna be a few times. Until we have a distributor here where can get off-the-shelf-stuff, it's gonna be a little bit tricky.
Beyond purchasing the equipment, the lack of a local knowledge about how to maintain the equipment also presents challenges. As one nonprofit staff noted:

If something breaks, who's going to fix it? We're basically sending e-mails to Japan and video [of the broken equipment]. We've attempted to introduce an engineer, a local engineer..., to sort of get that started with seeing the machinery and how it runs. But it's everything. There is not a manual that comes with it, so that's been a challenge. As we're learning, there are still things that are lost in translation...

Ultimately, the Maine scallop aquaculture industry would benefit from more firms entering the industry to support development of the inputs into the farming process.

As noted earlier, a lack of hatchery technology is considered a bottleneck for industry development. Hatchery-reared larvae would provide a consistent seed supply, stabilizing farm operations and business planning and reducing the reliance on natural population dynamics that tend to vary annually (Fitzgerald, 2021). Developing the hatchery technology could also provide an avenue to establish genetic variants that are disease resistant or sterile so energy consumed by the scallop goes towards growth rather than reproduction. Efforts to rear Atlantic sea scallop larvae in a hatchery setting in Maine have not yet been successful (Fitzgerald, 2021).

**4.3.3.2 Weaknesses in the Maine scallop aquaculture industry**

Influence on the direction of search (F4) identifies the societal level factors that affect technological innovation. The innovation process is influenced by beliefs in growth potential of the new technology (Bergek et al. 2008), societal preferences (Hekkert et al., 2007), customer or market preferences and government priorities which are evident through the types of incentives or regulatory pressures in place (Bergek et al., 2008). To determine the performance of this function, different targets established by governments or industries and the number of articles published in professional journals regarding specific technologies can be mapped over time (Hekkert et al., 2007). Specific to scallop
aquaculture, nonprofit organizations have commissioned consultants to explore different aspects of scallop aquaculture development (e.g., The Hale Group, LTD, 2016; RBouvier Consulting, 2018; Fitzgerald, 2021). Additionally, researchers have published three recent articles about scallop aquaculture related topics in Maine; two of which focus on growth rates of scallops in lantern nets that can inform farming practices in terms of site selection, stocking densities and thinning practices (Coleman et al., 2021b; Coleman et al., 2022). The third journal article focused on determining the bioeconomic potential of different scales of farming operations and different types of products such as whole scallops or meat-only (Coleman et al., 2021a). This study highlighted the barriers to scallop aquaculture development including high labor costs and the challenges to obtaining profitability when farming and selling whole scallops which require the farmers test their product for biotoxins before sale; the cost of these tests can be high and time consuming. Overall, Coleman et al. (2021a) recommended that mechanizing net culture operations, optimizing stocking density and increasing consumer demand for cultured scallop products could translate into a successful scallop aquaculture farm and industry.

Regarding the aquaculture sector more broadly, government entities in Maine have undertaken efforts to develop a comprehensive plan for aquaculture development within the state (i.e., Maine State Planning Office, 1990; Governor’s Task Force, 2004; Sadusky et al., 2022). Nonprofit organizations and Maine Sea Grant have undertaken efforts to promote scallop aquaculture by commissioning three reports assessing the potential of the industry (e.g., The Hale Group, LTD., 2016; RBouvier Consulting, 2019; Fitzgerald, 2021).

Assessing the performance of market formation (F5) involves tracking the implementation of favorable tax regimes, the creation of niche markets, or establishment of consumption quotas that can foster and grow consumer demand for an emerging technology, allowing the new product to be more competitive with existing products in the marketplace (Hekkert et al., 2007). Gardner Pinfold Consulting Economics Limited (2001) found that overall, fresh sea scallops tend to command the highest price out
of any scallops. Demand for scallops in the US is strong and is supplied by wild-caught scallops from the US and Canada as well as imports from wild-caught and farming industries elsewhere (Gardner Pinfold Consulting Economics Limited, 2001). The US fishery operates year-round while the Maine fishery is seasonal. The Maine wild fishery tends to command a slightly higher price due to the time of year the fishery is active and the day-trip nature of the fishery which results in a fresher, higher quality product. However, the Maine fishery only contributes 25% to the total national supply of the Atlantic sea scallop. Thus, while the product from the Maine fishery does influence the market price, it does not set the price.

Interviews suggest that those involved with scallop aquaculture are encouraged by the high value of the wild-caught sea scallop product. Atlantic sea scallop is a known entity in the seafood market and commands a high market value, which could translate into a valuable farmed product, if the farmed product is of similar quality. In addition, Maine’s strong brand for high quality seafood is considered an asset in growing demand for the farmed scallop product (Rbouvier Consulting, 2019). Individuals interviewed believe that the farmed product can provide high quality scallops on a year-round basis and will complement the seasonal production of sea scallops from the Maine wild-capture fishery, which is typically active from December through March. As an extension staff member stated:

Maine scallops currently command the highest landed value price of any scallops. So, to be able to offer them year-round as farmed or wild caught, that’s going [to] just enhance the brand. I mean, the seasonality of it is kind of wonderful but it’s also wonderful to be able to supply a really good product year-round.

To avoid direct competition with the meat-only wild fisheries for sea scallops and to get product to market sooner, farmers and distributors have started selling product that is smaller than the minimum legal size for wild-caught scallops (Fitzgerald, 2021). Initial reports from chefs for the smaller product are positive, although the timing of bringing product to market and the size do matter. Sales
have proven to be best when the farmed product does not compete directly with the height of sales for bay scallops or day-boat, wild-caught sea scallops. Additionally, the whole and roe-on products face barriers related to the regulatory framework for managing biotoxins. To sell these products, farmers need to conduct biotoxin testing in partnership with the Maine DMR, which can be costly and time consuming (Fitzgerald, 2021). These smaller roe-on and whole products are relatively new to consumers. To familiarize consumers with the farmed product, the Maine Aquaculture Co-op generated an electronic booklet of suggested recipes which members are distributing to legislators and potential customers (Coastal Enterprises, Inc., 2020). Market dynamics for the meat-only and the smaller, roe-on or whole products remain to be seen.

In the Maine scallop aquaculture industry, efforts to build the market for farmed product have slowly increased as farms in operation have started to generate product (Fitzgerald, 2021). However, this is a particular area where efforts should focus to help the farmed product gain traction within the wider scallop market. For market development efforts to be successful, it will be important to understand how the farmed adductor muscle or meat-only product will interact with the wild-capture fisheries for sea scallops, which includes product from the US and Canada and imports of similarly-sized species from Japan (Gardner Pinfold Consulting Economics Limited, 2001). Additionally, it is unclear how diversified products, such as scallop meats on the half shell, roe-on scallops and whole scallops will perform in the marketplace (Fitzgerald, 2021).

The creation of legitimacy or legitimation (F7) is the process by which the new product becomes socially accepted by key actors and policymakers, overcoming any resistance to change (Hekkert et al. 2007; Bergek et al. 2008; Esmailzadeh et al. 2020). The performance of this function is difficult to measure, but can be assessed by tracking the establishment of advocacy groups and their actions (Hekkert et al. 2007). In the Maine scallop aquaculture industry, two formal groups, the Maine Aquaculture Association (MAA) and the Maine Aquaculture Co-op (MAC), have the potential to advocate
for scallop aquaculture. Established in 1978, MAA represents shellfish, sea vegetables and finfish producers and advocates for the aquaculture industry at the state, federal and international levels (Maine Aquaculture Association, n.d.). The MAC formed to focus specifically on scallop aquaculture (The Maine Aquaculture Co-op, n.d.). While the MAC primarily organized to share information, it increasingly is involved in policy discussions to help support the growth of the scallop aquaculture industry in the state.

Additionally, other organizations and institutions, such as the University of Maine, Maine Sea Grant, Gulf of Maine Research Institute (GMRI), the Hurricane Island Center for Science and Leadership, and Coastal Enterprises, Inc (CEI) secure grant or other sources of funding to conduct research related to aquaculture likely playing a role in public perception of the aquaculture industry. GMRI has released a number of reports to help support the growth of the aquaculture sector in Maine, including a report on workforce development needs (Haines et al., 2020) and a separate report specifically on the scallop aquaculture industry needs (Fitzgerald, 2021). CEI and Maine Sea Grant have also generated reports and materials related to scallop aquaculture industry development (Rbouvier Consulting, 2019). Considering the Maine aquaculture industry more broadly, Maine has a strong brand for seafood and aquaculture products grown in the state are likely to benefit from brand recognition and reputation. The emerging scallop aquaculture industry will likely be able to capitalize on the existing brand and reputation of Maine seafood as the industry develops.

The function, development of positive externalities (F8), involves the entry of new firms that support the development of the emerging technology. These firms can help reduce uncertainty by addressing knowledge and supply chain gaps and increase the legitimization (F7) of the new technology (Bergek et al., 2008). As highlighted above, new individuals and firms are entering the scallop aquaculture industry and experimenting with growing the species on their permitted aquaculture sites; however, the numbers of firms involved still remains small. In addition, farmers and researchers still rely
on Japan and other countries in Asia for the purchase of the specialized equipment to mechanize the farming process and the cost of the equipment can be prohibitive. The scallop aquaculture industry in Maine would benefit from firms entering the industry to develop the inputs into the farming process (e.g., hatchery technology, mechanized equipment) and support the marketing and distribution of the farmed scallop product.

4.4. Discussion

Analyzing the innovation processes that underlie aquaculture development can facilitate the growth and sustainability of the sector (Joffre et al., 2017). Joffre et al. (2017) called for the application of innovation system approaches to identify the multi-dimensional aspects of complex aquaculture systems that influence the trajectory of the sector’s development. The Technological Innovation Systems (TIS) approach focuses on the development of an emerging technology and has been widely used in the transportation and energy sectors; however, few studies have applied this approach to aquaculture. The Maine aquaculture industry is growing and farming the Atlantic sea scallop is of increasing interest, but has yet to reach commercial viability. Given the relevance of the TIS approach in understanding development of an emerging technology and the need to apply systemic approaches to aquaculture, the TIS functional performance framework was selected to explore the case of the scallop aquaculture industry in Maine.

The Maine scallop aquaculture industry has robust entrepreneurial activity occurring (F1) and extensive work being done to improve knowledge development (F2) and knowledge exchange (F3). However, the market (F5) and positive externalities (F8) or the complimentary services remain underdeveloped. Scallop aquaculture growth in Maine could be facilitated by continuing to support entrepreneurial activities and knowledge development and exchange to continue to reduce uncertainties related to the farming process, complimentary services, and market development. In addition, the emerging industry could benefit from an increased focus on influencing government
policies and priorities to ensure alignment between those policies and the needs of the scallop aquaculture industry (F4) and developing the market for the farmed products (F5). Efforts are needed to increase the number of firms involved in supporting the industry development including gear and equipment manufacturers and maintenance as well as hatchery development and financial institutions willing to finance these operations. Doloreux et al. (2009) highlighted the importance of knowledge exchange through organized clusters that brought together producers, gear and equipment suppliers and others in a coordinated way to develop the positive economies necessary to support the growing aquaculture industry in Norway. Hu et al. (2019) identified this type of information exchange as an effective way for multiple aspects of the value chain to innovate together, reducing risk and transaction costs. Providing additional support for the Maine Aquaculture Co-op and the Scallop Research Collaborative, which are existing formal groups or networks of farmers, researchers, and firms already established in Maine could be incredibly valuable in increasing knowledge development and knowledge exchange and supporting entrepreneurial activity to continue to grow the industry. These efforts would also likely increase the legitimacy of the industry leading to more collective power to influence the government policy and priorities.

Kumar and Engle (2016) found that the salmon aquaculture industry benefitted from the use of automated, labor-saving technology and the technology proved to be a catalyst for shifting that industry from a formative phase of development into a growth phase. This phase shift increased the ease of technology diffusion (Kumar & Engle, 2016). If mechanizing the farming process proves critical to obtaining the appropriate scale of operation to achieve profitability in Maine, support should continue to be given to those organizations and farmers who are working to reduce the uncertainty related to using the equipment in Maine. Making this equipment more accessible and easier to use and repair in Maine would likely mean more individuals and businesses would get involved in aquaculture. CEI, in partnership with other organizations and some farmers, is working to test the equipment within the
Maine context and work with local mechanics to increase knowledge development in that supporting industry so that equipment can be built and maintained locally. In order for the industry to continue its growth trajectory, these efforts may need to be scaled up so more farmers can benefit.

A major barrier to entry into the scallop aquaculture industry will be the high capital investment required to purchase this equipment and to operate large-scale farms coupled with the lack of financial institutions willing to finance aquaculture operations. Baticados et al. (2014) found that low cost financing was critical to successful adoption of aquaculture largely due to the time lag between starting an operation and generating revenue from sales of the cultured species, because the process of bringing product to market can take a few years. Access to financing is important to business development. Financial institutions need to be familiar and comfortable with the new industry and technologies in use in order to lend capital (Theodorou et al., 2015). To facilitate the process of accessing financing, the scallop aquaculture industry could collect data about sector performance which would provide data needed for financial institutions to project sector performance and evaluate the potential of new or diversifying firms (Theodorou et al., 2015).

The market for farmed scallop product is not yet developed. Efforts going forward should work to understand the relationship between the farmed product and wild-caught scallops. In other cases, this interplay between wild and farmed industries had implications for the success of the farmed product. For example, in the UK, a scallop aquaculture industry was unable to develop because it could not compete with the wild fishery (Strand et al., 2016). Beyond the interaction between the wild and the farmed industry interactions, little has been done, in terms of policy action, to create a niche market or provide other incentives to encourage enough purchase, but this is likely because supply of the product has been limited. When production increases to a point where it is more readily available, groups like the Maine Aquaculture Co-op could work to increase consumer awareness in the market place either by working directly with restaurants, retailers, and consumers or through policy action. One avenue to
increase production would be to support entrepreneurial activity and increase the number of new entrants or existing firms producing scallops. These actions would help to build a consistent supply, which could translate into supporting market formation because product is more readily available.

In addition, effort needs to focus on increasing legitimacy so that new products brought to market can overcome the ‘liability of newness’ and compete with existing seafood products (Zimmerman & Zeitz, 2002; Bergek et al., 2008). Gaining increased legitimacy is critical for scallop aquaculture to be successful; yet, this can be a difficult process for an emerging industry. Bergek et al. (2008) discusses that increasing legitimacy in any emerging industry is a dynamic process and is the result of conscious actions by a variety of individuals and organizations. Additionally, it can take a considerable amount of time and can be slowed by competition from adversaries defending the institutional frameworks that reinforce the status quo (Bergek et al., 2008), which in the case of Maine scallop aquaculture could be commercial fishers defending the market for wild-caught Atlantic sea scallops. Organizations that have been involved with development of the scallop aquaculture industry could work to increase the legitimacy of the product in the market and in the policy arena by educating potential consumers and government officials about the farm-raised product specifically.

The TIS functional performance framework did present some challenges in that a number of the functions were difficult to measure or lacked clear metrics, which led to subjective interpretation of the results based on the interview and document data. Additionally, the framework was limited in assessing the external factors influencing scallop aquaculture development in Maine such as global seafood market dynamics or national efforts to fund aquaculture expansion. Ultimately, for the purpose of this research, the spatial and temporal boundaries for the analysis had to be defined and a portion of the data used in the analysis had to be searchable online to be included in the document database. Given these elements of the study boundaries, important events or information related to scallop aquaculture may have been missed.
Understanding innovation processes in aquaculture is critical to the development of a sustainable industry; however, a number of studies exclude the multi-dimensional aspects of aquaculture development, which are important to identifying appropriate interventions to encourage sustainable growth of aquaculture (Joffre et al., 2018). This case study is the first application of the Technological Innovation Systems functional performance framework to an emerging aquaculture industry. This framework proved useful in identifying particular areas of the scallop aquaculture industry that would benefit from intervention to further facilitate development. Future research could continue to apply the Technological Innovation Systems functional performance framework to other emerging aquaculture species in Maine to identify broader approaches necessary to support innovation within the aquaculture industry, specifically around establishing and growing industries for emerging species such as hard clams, razor clams and other seaweed species. The systems perspective provides an opportunity to understand factors that inhibit or promote adoption and diffusion of particular technologies which can facilitate the development of a more diverse aquaculture sector in Maine. More broadly, this study contributes to innovation systems literature and fills a gap of applying innovation systems theory to aquaculture development which has been identified as a need to encourage sustainable growth of a rapidly expanding food production system (Joffre et al., 2017; Joffre et al., 2018).
CHAPTER 5

CONCLUSION

This dissertation applied innovation theory to individual adoption of aquaculture by commercial fishers and an innovation systems approach to the development of an emerging aquaculture industry. Commercial fishers are an important stakeholder group in the debate about aquaculture expansion; aquaculture activity and commercial fishing can be in conflict, but there are instances where the two livelihoods coexist. Additionally, commercial fishers are potential adopters of aquaculture (Weeks, 1992; Tango-Lowy & Robertson, 2002; Jeffrey et al., 2021). In Maine, efforts are underway to facilitate fisher adoption through training programs and as a strategy to preserve working waterfronts and maritime heritage (e.g., Sadusky et al., 2022).

Findings from the 2018 mail survey reported here show that Maine lobster fishers have relatively neutral perceptions of aquaculture indicating some level of acceptance. The perceived rate of aquaculture growth and the perceived density of farms in the area in which individual’s fished contributed to their view of aquaculture with higher rates of aquaculture growth and density relating to more negative views. The management of aquaculture was also a significant predictor of one’s view of aquaculture. These factors could mean that as aquaculture activity increases or expands, the perception of aquaculture among lobster fishers may become more negative, especially if the government is viewed as not adequately managing this growing sector.

The lease hearing process provides an opportunity for fishers and farmers to establish relationships, connect face-to-face and reduce uncertainty about aquaculture (Johnson & Hanes, 2019; Hanes, 2018). Additionally, training programs, like Aquaculture in Shared Waters and the Aquaculture Business Development Program, provide the opportunity to educate potential farmers about the value of engaging local fishers and community members in developing their aquaculture plans. As aquaculture continues to grow, these opportunities for interaction will likely become more critical. Farmers in the
Damariscotta region were able to build community trust by organizing the Oyster Festival to celebrate oyster farming in the estuary (Hanes, 2018). Similar events pairing fishing and farming, such as the Maine Fishermen’s Forum, celebrate both industries and can potentially help build a connection and support for diversified working waterfront. These efforts are important to building comradery around Maine’s working waterfront and maritime tradition, which was identified as a priority in the Aquaculture Hub’s 2022 Aquaculture Roadmap (Sadusky et al., 2022).

In terms of fisher adoption of aquaculture, a majority of Maine lobster fishers surveyed did not agree with the statement that they would be employed in the marine aquaculture industry within the next 5 years. Respondents to the survey were older individuals who could be close to retirement and may be more entrenched in commercial fisheries; therefore, they are unlikely to consider diversifying or starting a new venture, such as adopting aquaculture. Younger individuals or those who participate in other commercial fisheries in Maine might be more interested in considering aquaculture given that a number of commercial fisheries are closed to new entrants. In addition, this survey was distributed in 2018 at a time when lobster fishers may not have yet seen a need to diversify; however, the future of the Maine lobster fishery remains uncertain given increasing rates of shell disease, increasing regulations to protect the critically endangered North Atlantic right whale and other large whales, and climate and market variability (Acheson & Acheson, 2020). Lobster fisher willingness to consider implementing aquaculture could change as some of these threats to the fishery intensify in the future. Efforts to facilitate fisher adoption, such as training programs like Aquaculture in Shared Waters should consider targeting individuals who participate in fisheries other than lobster or younger lobster fishers.

The majority of commercial fishers who are implementing aquaculture are doing so alongside their commercial fishing operation and they anticipate continuing to do both aquaculture and fishing. One barrier for commercial fishers to implementing aquaculture can be the economies of scale required to make aquaculture profitable where entering a well-established aquaculture industry can require a
high level of capital investment to start at the level of production needed to be competitive (Jeffrey et al., 2021). If practitioners and policymakers in Maine are interested in aquaculture as a diversification strategy for commercial fishers and those fishers who are currently adopting aim to continue doing both fishing and farming, efforts need to ensure that aquaculture and commercial fishing business models can support both activities happening simultaneously. One option is that the business model makes farming species typically only valuable in high volumes, such as kelp, profitable at smaller scales. Atlantic Sea Farms based in Biddeford, Maine has built its brand around partnering with commercial fishers to grow kelp, their primary product (Atlantic Sea Farms, n.d.). Atlantic Sea Farms provides technical assistance for fishers interested in starting their own kelp farms (Atlantic Sea Farms, n.d.). This strategy ensures that fishers have support going through the leasing process and learning how to farm as well as a market for the product they grow. In its current state, this approach seems to overcome the economies of scale issue in that the fisher-farmer can determine the size of farm they can maintain alongside their commercial fishing activity and through their partnership with Atlantic Sea Farms, they have a guaranteed customer for their product. This approach could potentially facilitate broader adoption among commercial fishers. Ultimately, fisher adoption of aquaculture requires consideration of social, cultural, and economic considerations and can be a complex process.

Future research should explore perceptions of aquaculture and willingness to adopt among other types of commercial fishers. In addition, studies of adoption could be broadened to include all new entrants into aquaculture to identify challenges and opportunities of aquaculture adoption generally. Interactions between commercial fishing and aquaculture should be explored as aquaculture activity increases, commercial fisheries continue to face uncertainty, and dynamics shift in coastal communities.

Maine’s aquaculture production is currently dominated by Atlantic salmon (Salmo salar), Eastern oysters (Crassostrea virginica), blue mussels (Mytilus edulis), and kelps (Saccharina latissima)
with a growing interest in other species including the Atlantic sea scallop (*Placopecten magellanicus*), various clam and seaweed species. A diverse aquaculture sector in terms of species produced may be more resilient to environmental and market variability (Bricknell et al., 2021). Applying an innovation systems approach, specifically the Technological Innovation Systems functional performance framework to the emerging scallop aquaculture industry in Maine helped identify factors important to the industry’s formation. The Maine scallop aquaculture industry is still in an emerging phase even after decades of experimental effort to establish the industry. Knowledge development and knowledge exchange as well as mobilization of human and capital resources has been working well and needs to continue being supported if the scallop aquaculture industry is to continue growing and shifting from an emerging phase to a more established phase. Additional effort and focus should be placed on developing the market for farmed scallop product as well as increasing the industry’s legitimacy. In terms of market development, understanding how the farmed products compete or complement the product from the wild scallop fishery will be important. The systems level perspective also put into context individual adoption by clarifying the various aspects and factors that need to align in order to support adoption and diffusion of aquaculture. This includes, but is not limited to, supportive policies that balance the interests of multiple users, investments in research, infrastructure, and other support systems that would more easily facilitate individual adoption of aquaculture, and support in developing markets for aquaculture product as well as understanding the interactions between wild-capture fisheries and aquaculture product. The context within which individuals are making adoption decisions is complex, multidimensional and is impacted by a number of external factors.

The TIS functional performance framework has been applied to emerging technologies in other sectors such as energy and transportation, but has only been applied to aquaculture in limited cases (Joffre et al., 2017; Joffre et al., 2018). In this case where the framework was applied to the emerging scallop aquaculture industry in Maine, it had several limitations, including that the terminology was
confusing and not directly applicable to the nuances of aquaculture industry development, and it excluded consideration of the ecological aspects of aquaculture development. One recommendation would be to apply a different framework, such as the Social-Ecological Systems Framework to incorporate ecological considerations into understanding the potential for an emerging aquaculture industry (Johnson et al., 2019). Future research could compare various frameworks for their utility in understanding aquaculture development or could compare aquaculture industry development for emerging species to see if there are similarities or differences across species where broad lessons can be derived for how aquaculture industries are established for emerging species.

Overall, aquaculture does provide an opportunity to diversify coastal economies and potentially support fishing-dependent livelihoods should commercial fisheries decline. Maine should continue to invest in providing training programs and support for those commercial fishers interested in adopting. In addition, the state should provide policy and other resources to develop aquaculture industries for emerging species to diversify the suite of potential species that can be cultivated to ensure a robust aquaculture sector can withstand or adapt to climate change impacts and other challenges.
BIBLIOGRAPHY


110


BIOGRAPHY OF THE AUTHOR

Caitlin Cleaver was born in Media, Pennsylvania. She was raised in Kennett Square, Pennsylvania and graduated from Unionville High School in 2002. She attended Colby College in Waterville, Maine graduating in 2006 with a Bachelor’s degree in Environmental Studies. She worked for the Natural Resources Council of Maine in Augusta, Maine doing North Woods conservation work before working for the Maine Department of Marine Resources on gathering information from lobster fishers to inform North Atlantic Right Whale regulations. In 2010, she received a Master’s in Public Administration in Environmental Science and Policy at the School of International and Public Affairs at Columbia University in New York, New York. She returned to Maine in June 2010 and enrolled in the dual Master’s degrees in Marine Biology and Marine Policy at The University of Maine. She graduated in May 2014.

From 2012 to 2014, while finishing her Masters degrees, Caitlin worked for the Island Institute focused on engaging coastal communities in regional ocean planning. In 2014, she was hired at the Hurricane Island Center for Science and Leadership as the Director of Science and Research where she led applied research projects in partnership with commercial fishers. In June 2015, Caitlin entered the Ecology and Environmental Science graduate program at The University of Maine while continuing to work for Hurricane Island. In 2018, Caitlin worked for one year as the Marine Sciences Division Lead at FB Environmental Associates before she started working at Bates College in August 2019 as the Director of the Bates-Morse Mountain Conservation Area and Shortridge Coastal Center. She is a candidate for a Doctor of Philosophy degree in Ecology and Environmental Sciences from The University of Maine in December 2022.