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Social and Ecological Factors Affecting the Adoption of Aquaculture

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SOCIAL AND ECOLOGICAL FACTORS AFFECTING THE ADOPTION OF AQUACULTURE

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Thesis Co-Advisors: Dr. Teresa Johnson and Dr. Paul Rawson

An Abstract of the Thesis Presented
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Commercial fishermen in Maine are increasingly dependent upon the American lobster fishery, and this reliance on a single species poses a threat to working waterfronts. Aquaculture represents a potential opportunity for commercial fishermen to diversify their income. Literature on the adoption of innovation suggests that factors such as age, education level, fishing experience, diversification, and leadership are important predictors of early adoption of innovation. However, few studies have examined whether such factors affect the adoption of aquaculture by commercial fishermen. Our marine policy research studied fishermen enrolled in two pilot shellfish and seaweed aquaculture classes held in 2013 in Harpswell and Corea, Maine. Those enrolled in the classes can be considered early adopters of innovation. To better understand these early adopters and their perceptions of aquaculture as a means of income, we conducted a total of 33 semi-structured interviews before and after the course with fishermen who did and did not finish the course. Those who had broader experience and more years of experience, as well as those having demonstrated some form of leadership in fisheries cooperatives, were more likely to adopt. Potential barriers to the adoption of aquaculture were mostly related to risks associated with an uncertain return on investment. The results from this

study will inform the structure of future aquaculture training courses as well as highlighting additional avenues of research on the adoption of aquaculture by commercial fishermen.

Those starting aquaculture farms face many challenges, among them parasites such as the blister worm, *Polydora websteri*. This polychaete burrows into shells of several commercially important shellfish species, including the eastern oyster. As the oyster industry has grown, so has the impact of this worm. Oysters served on the half shell are not only less attractive when infested by worms, but mud and detritus can leak out during shucking and create off-flavors. Farmers are concerned about their reputation if blister worm-infested oysters are sent to market. Various kinds of chemical, fresh water, and brine baths have been used to treat blister worm infestations, but none has reliably eliminated worms in established burrows. The Bagaduce River Oyster Company (BROC) has developed the only known effective method of killing the worms without causing damage to the oysters. They place their oysters in cold storage for three weeks or more during the winter months – a method which is generally not harmful to the oyster but kills the adult blister worm. This treatment, however, is labor intensive and can result in lost production time. Our marine biology research explored whether periodic air-drying and pressure washing could reduce the settlement of larval *P. websteri* and block blister worm infestations before they occur. Oysters were air-dried for 4 h or 24 h, or air-dried and washed, every other week. Ten to twenty oysters were sampled from each treatment bimonthly from May through October 2014 and examined for the presence of newly constructed worm burrows. Additionally, plankton tows were taken on each side of the oyster farm to track the abundance of blister worm larvae in the plankton. Air-drying

alone resulted in a substantial decrease in the formation of new blister worm burrows in experimental oysters. Although washing resulted in additional decreases in the number of new burrows, the impact of washing was not statistically significant. Our results suggest that regular air-drying and washing of oysters can reduce the impact of *P. websteri* at oyster farms in Maine that employ surface culture and reduces the need for complex treatments to rid oysters of blister worm infestations.

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CHAPTER 1

INTRODUCTION

As global demand for seafood continues to grow, production from capture fisheries is leveling off at about 90 million tons per year (FAO 2014). Aquaculture production is on the increase, and now provides almost half of the total global seafood supply. In Maine, aquaculture production is growing as well. For example, the Maine Department of Marine Resources (DMR 2016a) reports that the shellfish aquaculture industry in Maine has grown 8-10% in the past decade with mussels and oysters being the primary species currently under culture.

Aquaculture is often discussed in the context of promoting and protecting working waterfronts. Maine is well known for its iconic commercial lobster fishery. Although the lobster catch has increased in recent years, there is concern that many working waterfront communities are becoming more and more dependent upon this single species. This poses a threat to these coastal communities because few other economic opportunities exist in these areas (Alden 2011), and it is uncertain how the commercial lobster fishermen would fare in the event of a downturn in lobster catch.

Maine is one of the top producers of farmed marine seafood in the United States (NOAA Fisheries, 2016). Oysters are the most valuable shellfish species cultured in the state, and oyster culture in Maine has been increasing since 2005 (DMR 2016b). Shellfish and seaweed aquaculture are seen as potential opportunities for commercial lobstermen in coastal communities to diversify their income. However, entry into this industry can be difficult, and even established farmers face challenges. Environmental conditions can vary constantly on an oyster farm, there are very high standards with respect to oysters' appearance, and there is demand for oysters year-round although their primary growing season occurs during the warmer part of the year.

To better understand the factors affecting adoption of aquaculture by fishermen, we studied a pilot aquaculture class offered to commercial lobstermen in two working waterfront communities in Maine (Chapter 2). The *Aquaculture in Shared Waters* (AQSW) course covered all aspects of setting up an aquaculture operation, and included field trips to working aquaculture facilities so that participants could have a better idea of what would be involved. We adopted a qualitative research approach that relied primarily on participant observation and semi-structured interviews. Class participants were interviewed before and after the course in order to better understand who they are and their perceptions about aquaculture as a business. We asked about their age, education, number of years fishing commercially, and dependence on income from fishing. The cost of starting an aquaculture business and the potentially extensive requirements of the leasing process were the potential barriers mentioned most often.

One roadblock that can impact not only new oyster culture operations but established ones as well is financial loss due to disease and pest species. The oyster industry in Maine markets its product primarily to higher-end, white-linen restaurants. The presentation of an oyster when served on the half-shell in such restaurants is very important in this market, and anything that detracts from the visual appeal of the oysters is taken very seriously by oyster farmers (Leach, pers. comm.). One thing that could mar the appearance of an oyster being served on the half-shell is the blister worm, *Polydora websteri*. A member of the family Spionidae, this polychaete burrows into the oyster's shell, creating a mud "blister" which can be unsightly when the oyster is shucked. In a worst-case scenario, if a blister is inadvertently opened while an oyster is being shucked, the customer will experience off-flavors when mud and detritus from the worm burrow are released. Although this worm has a nearly global distribution (Read 2010), there is currently only anecdotal information on how widespread the impact of blister worm infestations is (Rheault, pers. comm.).

Various chemical and saline dips and baths have been used in attempts to rid oysters of adult blister worms, but none has been reliably and consistently successful (Dunphy *et al.* 2005, Gallo-Garcia *et al.* 2004). The Bagaduce River Oyster Company (BROC) in Maine has developed a treatment that kills the adult worms, but it is labor intensive and can result in lost production time. We discuss in Chapter 3 how working closely with this farm, we tested whether combinations of air-drying and washing of oysters could reduce infestations by limiting the initial establishment of blister worm burrows. Air-drying was achieved by culturing oysters in a "flip-cage" system in which oysters were regularly air-dried for 4 to 24 h and in some treatments the air-drying was accompanied by regular washing to remove mud and detritus from the outside of the oyster shell. Both types of treatments were designed to reduce the opportunity for blister worm larvae to settle on the oysters, instead of trying to kill the adult worms, with the idea that during the larval or recent post-settlement stages the worm might be more vulnerable to environmental stress. Our results suggest that regular air-drying and washing of oysters can reduce the impact of *P. websteri* at oyster farms in Maine that employ surface culture and reduces the need for complex treatments to rid oysters of blister worm infestations.

CHAPTER 2

ADOPTION OF SHELLFISH AND SEAWEED AQUACULTURE BY COMMERCIAL FISHERMEN

2.1. Introduction

The lobster fishery is the most valuable commercial fishery in Maine, representing 81% of landed value in the state (DMR 2016a). On the one hand, lobster catches in Maine have increased in recent years, reaching 122 million pounds and $499 million in 2015 (DMR 2016a). On the other hand, Maine communities are becoming more and more dependent upon the lobster fishery, and this over-reliance on a single species poses a threat to fishing communities and working waterfronts (Steneck *et al.* 2011, Henry and Johnson 2014) because these communities have few other economic opportunities (Alden 2011). If there were to be a downturn in this fishery, it is unclear how commercial fishermen would weather this challenge.

The adoption of aquaculture is considered one option for commercial fishermen to supplement their income and protect working waterfronts (Idlebrook 2013, Tango-Lowy and Robertson 2002). But fishermen may be reluctant to shift from fishing to aquaculture because they see it as similar to a shift from hunting to farming (Griffith and Dyer 1996). Weeks (1992) noted that it is easier for commercial fishermen to shift to aquaculture if existing social patterns are not disrupted in the process. Rubino and Stoffle (1990) argue that in order for aquaculture to be successful, the local community must take part in the design and implementation of the aquaculture project, and the community must realize direct benefits as a result. Although the socioeconomic benefits of aquaculture are recognized, the general public and stakeholders still have concerns regarding its environmental impact (Mazur and Curtis 2008). Nevertheless, fishermen in Maine appear to be adopting or at least considering it (Arnold 2012, Idlebrook 2013).

With working waterfronts in an increasingly precarious position and aquaculture as a possible solution, we need to improve our understanding of the factors affecting the adoption of aquaculture by commercial fishermen. To study the adoption of this innovation by commercial fishermen, we examined participation in a shellfish and seaweed aquaculture training course held in 2013, referred to as the Aquaculture in Shared Waters project. Viewing these fishermen as "potential adopters" of aquaculture, we investigated the characteristics of the class participants and their perceptions related to the adoption of aquaculture.

2.2. Adoption of Innovation Literature

Rogers (2003) created a typology of adopters of innovation based on a scale of "innovativeness," and described five categories of adopters related to the average time of adoption of an innovation within a community (Fig. 2.1). Rogers studied the adoption of a variety of innovations, from boiling water to the adoption of cell phones. "Innovators" are described as individuals who are able to work under conditions of high uncertainty and risk, and who are willing to accept occasional setbacks. These individuals tend to play a gate-keeping role in their communities, and often are somewhat outside the local system with its associated constraints. Innovators are the first to adopt an innovation, but represent a small percentage (2.5%) of all adopters.

"Early adopters" are defined as individuals in a community who serve as role models and trigger change in their communities. These early adopters assign their "stamp

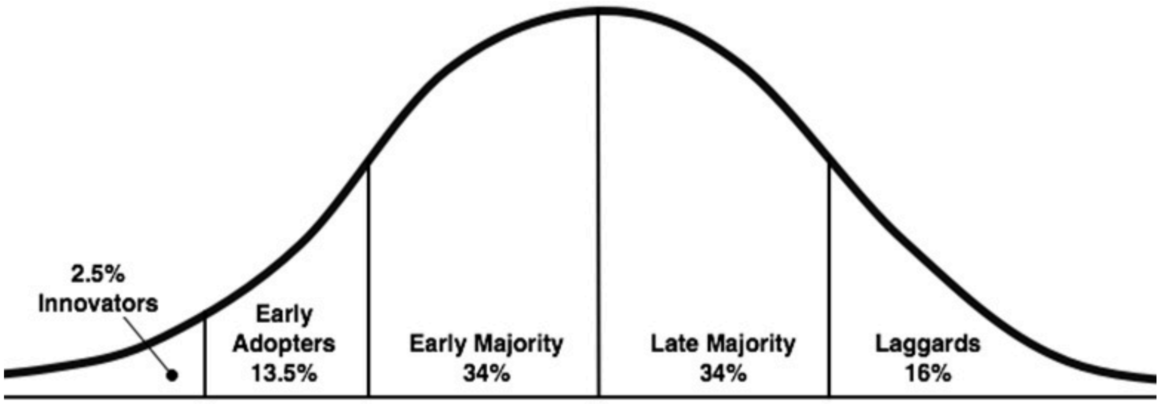

Figure 2.1. Diffusion of Innovations. From Rogers' *Diffusion of Innovations* (2003).

of approval" to an idea when they adopt it. They are more integrated into the social system than the innovators, and possess the greatest leadership in a community with respect to their opinions about an innovation. Rogers characterizes early adopters as more rational and able to work with abstractions than later adopters, meaning that they are efficient at discovering the most effective way to reach a given goal. They do not need to observe the innovation in action in order to appreciate its usefulness. Early adopters represent about 13.5% of total adopters.

The "early majority" are those who adopt innovations slightly before the average individual in a system. These people tend not to hold "opinion leadership" positions in their communities like the early adopters do, but they interact with others in the system on a frequent basis. They often spend more time deliberating about whether to adopt an innovation before moving forward with it. The "early majority" represents approximately 1/3 of the adopters in a system.

Rogers' "late majority" group will tend to adopt an innovation slightly later than the average member of a local system. Peer pressure likely contributes to the decisions of the members of this group, and they maintain a skeptical attitude. The "late majority" also represents about 1/3 of the total adopters.

Finally, Rogers refers to "laggards" as the most traditional group of all those who adopt an innovation. Similar to the innovators, the laggards are somewhat isolated from their social system. They are described as suspicious of change and resistant to innovation. This group represents about 16% of the total adopters. Diederen *et al.* (2003) further categorize "laggards" as either adopters of mature technologies ("late adopters") or "non-adopters." The term "late adopter" refers to those who adopted an innovation but were not part of the first 25% of potential users of the innovation. Non-adopters are those who ended up not introducing any new kind of technology. At the most general level, Rogers (2003) explains that an individual's social status is often positively correlated with his or her level of innovativeness. Individuals who are striving to reach a higher social status have been shown to be more likely to adopt innovation, perhaps even using the adoption of innovation as a means of achieving this status.

Numerous studies have looked at the adoption of aquaculture, although not specifically by commercial fishermen. Income has been found to be an important indicator of willingness to adopt aquaculture or new aquaculture-related innovations. Studies have shown that those with greater financial assets tend to be more likely to adopt aquaculture (Agbamu and Orhorhoro 2007, Bosma *et al.* 2012, Miyata and Manatunge 2004). For example, in a study of the adoption of concrete ponds and polyculture systems in Delta State, Nigeria, Agbamu and Orhorhoro (2007) found that income level showed the strongest correlation with adoption. Among Louisiana crawfish farmers, Nyaupane and Gillespie (2011) found that the percentage of household income coming from farming was a significant predictor of the adoption of best management practices.

Access to information and familiarity or knowledge of an innovation have been found to correlate with the adoption of innovation (Nyaupane and Gillespie 2011, Bosma *et al.* 2012). One study of a fish culture training program in Nigeria (Aphunu and Ajayi 2010) recommended that an assessment of the trainees' needs be conducted before the start of such training activities, so that the training could be structured appropriately. In the same study, the authors identified a need for the development of practical skills related to the innovation over theoretical knowledge. Adequate communication with fishery extension agents has also been shown to be an important factor in the adoption decision (Agbamu and Orhorhoro 2007). Bosma *et al.* (2012) showed a correlation between farmers' knowledge of rice-fish farming systems and their level of adoption. Nyaupane and Gillespie (2011) found that the lack of familiarity with an innovation ranked as the second most important reason that best management practices were not adopted. Miyata and Manatunge (2004) studied Indonesian farmers' decisions to adopt floating net aquaculture after their farms were relocated as the result of the construction of a dam, and concluded that "learning from others" was the most important factor in the adoption decision. This is in line with those who have suggested that greater access to accurate information concerning aquaculture could strengthen the aquaculture industry in the United States (Chu *et al.* 2010).

Self-identification as an individual with a tendency to innovate also appears to impact the adoption decision. Nyaupane and Gillespie (2011) showed that producers who self-identified as early adopters were more likely to adopt best management practices in the Louisiana crawfish industry than those who saw themselves as late adopters. Additionally, they found that those who saw themselves as risk averse were less likely to adopt best management practices than those who did not.

Commercial fishermen are well known as adopters of innovation and technology (Acheson and Reidman 1982, Dewees and Hawkes 1988, Levine and McCay 1987). A significant inverse relationship appears to exist between age and adoption of innovation in the context of commercial fishing (Acheson and Reidman 1982, Dewees and Hawkes 1988): that is, we would expect younger fishermen to be more likely to adopt innovations compared to older fishermen. Acheson and Reidman (1982) found that localized kinship played an important role in the adoption of innovation in the New England finfish industry, as the level of openness and amount of accurate information dramatically increased if the fishermen were closely related. In addition to kinship, those who are fishing for the same species, using the same gear, and in the same approximate area turn out to be the best source of information for one another (Wilson and Acheson 1980) – an example of peer learning. At least in the New England finfish industry, membership in a political organization correlates positively with the adoption of innovation, in part because information concerning innovations is exchanged at meetings of these organizations. Membership in these organizations may also influence the political environment in order to ensure members' continued success in the industry (Acheson and Reidman 1982). Education level is associated with increased adoption as well (Acheson and Reidman 1982, Dewees and Hawkes 1988). Dewees and Hawkes (1988) found that education was especially important when considering the adoption of innovations that are perceived to be complex, such as electronic fish-finding equipment for mid-water trawlers. However, Acheson and Reidman (1982) did not find that a particular group of fishermen consistently adopted innovations before others, mostly because the needs of each potential adopter were so different.

Only a few studies have looked specifically at the adoption of aquaculture by commercial fishermen (Weeks 1992, Tango-Lowy and Robertson 2002). Most relevant to this study, Tango-Lowy and Robertson (2002) conducted a survey of New England inshore groundfish fishermen to assess their attitudes towards the adoption of open ocean aquaculture. Participants in this study were given information concerning the University of New Hampshire's Open Ocean Aquaculture Demonstration Project which involved net pens for summer flounder and blue mussel culture using a system of submerged longlines. After being provided with this information, nearly a third of the fishermen surveyed indicated that they would consider adoption of open ocean aquaculture. Slightly more than a third of these individuals indicated that they would not consider adoption of this innovation, and slightly more than a third answered that they were unsure whether they would consider it or not. This study found that fishermen who had less commercial fishing experience (i.e., were less "entrenched") and those who participated in more fisheries (i.e., were more diversified) were more likely to consider adopting aquaculture. The variable "entrenchment" was defined as the number of days spent fishing commercially and the amount of money that had been spent on fishing gear.

Our study examined the variation in fishermen participation in Aquaculture in Shared Waters, a shellfish and seaweed aquaculture training course, and whether participants demonstrated characteristics of innovators. Based on the literature, we predicted that age, education level, diversification, and dependence on fishing would be important factors in whether participants adopted aquaculture. We investigated whether entrenchment, defined as fishing commercially for more than 40 years, was correlated with participant decisions to adopt aquaculture. We also predicted that an individual's willingness to adopt was likely to be influenced by their perceptions or misconceptions about aquaculture.

2.3. Aquaculture in Shared Waters Course Description

In the spring of 2013, University of Maine researchers and Maine Sea Grant and University of Maine Cooperative Extension associates, in collaboration with other aquaculture experts in Maine, offered an 11-week pilot course to train lobstermen in shellfish and seaweed aquaculture. This course was called the Aquaculture in Shared Waters (AQSW) project. University of Maine social scientist Dr. Teresa Johnson was the PI of the project, and oversaw the research and assessment components of the course. The research team was tasked with (1) conducting social science research on the fishermen's experience during and after the course and (2) providing an assessment of the course to the instructors, with the intention of improving future aquaculture courses targeting commercial fishermen. Dana Morse, an extension associate with the Maine Sea Grant and the University of Maine Cooperative Extension and the co-PI of the project, led the instructional component of the course, along with experts from the Maine Aquaculture Association, the Maine Aquaculture Innovation Center, and Coastal Enterprises, Inc. The Island Institute was another project partner that assisted with outreach efforts in the communities.

Initially we reached out to many different communities – including some island communities – to find out where there were the facilities and interest to make a course like this successful. We ended up targeting two lobster co-ops, and worked through the co-op managers to reach the lobstermen who were members of each co-op. The course was offered to fishermen associated with the Interstate Lobster Co-op in Harpswell, Maine and to those associated with the Corea Lobster Co-op in Corea, Maine (Fig. 2.2).

The AQSW course covered aquaculture techniques, the biology of shellfish and seaweed, sales and marketing, financing and financial management, small business management, farm management and biosecurity, site selection, and the aquaculture lease process. Each class met once a week for about 3-4 hours, with a morning classroom session and an afternoon session that consisted of either classroom work or a field trip. The course focused on shellfish and seaweed aquaculture because these have the highest potential to fit easily into existing commercial fishing operations and are not as time intensive as growing finfish. Additionally, commercial fishermen already have much of

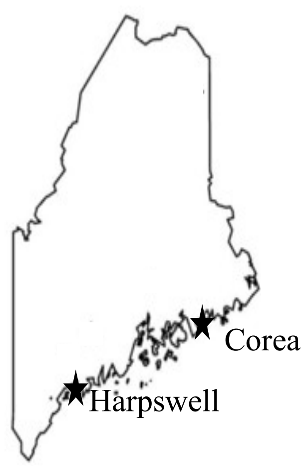

Figure 2.2. Map of Maine Showing Locations of Harpswell and Corea.

the equipment necessary for shellfish and seaweed aquaculture. Kelp aquaculture is relatively new to the United States, although it is a $5 billion industry worldwide (Bell

2014). In Maine, three species of kelp are commercially important: sugar kelp, winged kelp, and horsetail kelp (Island Institute, 2015). Kelp is one of the fastest-growing plants in the world – able to grow 12 feet in 6 months (Schmitt, 2015) – so fishermen should be able to sell their crops within the same year that they are seeded. Husbandry of kelp is minimal, requiring seeding in the fall, maintenance of lines, checking for damage during the winter, thinning harvests during March and April, and final harvest during April or May. Aquaculture of seaweed should complement commercial lobstermen's operations well because the majority of the growing season for seaweed occurs during the winter months, at the time when the lobster fishing season slows down. Shellfish aquaculture in Maine (mostly oysters and mussels) has grown at about 8-10% per year during the past decade (DMR 2016a). Preliminary estimates indicate that 2.1 million pounds of oysters generating $1.5 million (DMR 2016b) and 1 million pounds of mussels generating $800,000 (DMR 2016c) were harvested in 2012.

Several opportunities are available for individuals who are interested in getting started in aquaculture. The DMR offers three types of leases: a limited-purpose lease, a standard lease, and an emergency shellfish lease (DMR 2016d). Standard leases offer the longest term of up to 10 years, and require the most extensive review of any of the aquaculture leases. A pre-application meeting, a scoping session, and a public hearing are conducted as part of the review of the standard leases, and all adjacent riparian landowners, municipalities, and interested government agencies are notified of the lease application and may offer their opinions at the hearing. Standard leases may cover up to 100 acres, and may be renewed or transferred. This type of lease may be issued for shellfish, finfish, or seaweed, and may be for either bottom or suspended culture.

Experimental leases may cover up to 2 acres and may last up to 3 years. These leases do not require as extensive a review as the standard leases, and they may only be renewed if they are for the purpose of scientific research. A limited-purpose aquaculture license may cover an area of up to 400 square feet, and allows the holder to raise mussels, oysters, soft-shell clams, hen clams, or quahogs for one year. Emergency shellfish leases allow existing shellfish leaseholders to temporarily relocate their stock away from an existing lease site in the event of a health or safety threat to the stock. This type of license is granted for up to six months.

2.4. Methods

In this exploratory study, we adopted a qualitative research approach that relied primarily on participant observation and semi-structured interviews. Participation by fishermen in the research was encouraged, but not required as part of acceptance into the course. We aimed to interview participants before and after the course although in many instances this proved difficult. We interviewed some of the class participants who had adopted aquaculture in some form a year after the course ended.

Participant observation occurred at six class meetings and four follow-up meetings with the instructors and other fishermen. In addition to notes taken during the class, observations and conversations with fishermen offered an opportunity for us to talk informally with the participants about their interests and concerns regarding adopting aquaculture. During the final class, participants presented “proposals” of aquaculture projects to the course instructors for their review; with the permission of all participants, we audio-recorded and transcribed the presentations and the discussion that followed.

Following the course, instructors and other project leaders held a debriefing meeting. We took detailed notes at this meeting and sought the instructors' perceptions of who in the class had participated the most, who was likely to move forward with aquaculture, and whether any of the participants had been in contact since the course ended. The instructors ranked participants in the course into categories reflecting their perceptions about participants' level of engagement in the class, and these rankings were used to prioritize attempts to contact fishermen for follow-up interviews. A follow-up meeting was held with the Corea group a year after the course with three fishermen in attendance. Again, with permission, we audio-recorded this meeting and took detailed notes. In the fall of 2015, two community meetings were held to discuss the potential for holding additional aquaculture classes and to offer fishermen who had taken the class a chance to talk about their projects. We attended these meetings as well and took detailed notes.

Initially, a total of 29 fishermen signed up for the course. The two co-op managers were excluded from our analysis because they attended the aquaculture course in more of a facilitative role than with the intent to start their own aquaculture projects. Two other people who were interviewed were also excluded from the analysis because they were not commercial lobstermen. Four of those who signed up were not interviewed and did not make it to any classes. Twenty-one fishermen were ultimately interviewed and included in the analysis. Fifteen of these fishermen attended at least one class, while six fishermen signed up, but never attended any classes. We conducted a total of 33 semi-structured interviews. Interviews ranged from 5 minutes to 75 minutes, with an average interview length of about 30 minutes. The shortest interviews were conducted with individuals who had signed up for the course, but did not attend any classes. All interviews were audio-recorded with permission and transcribed. Interviews occurred before (n=19) and after (n=14) the course, and were conducted with individuals who finished the course and gave a presentation (n=7), those who attended some of the classes but did not give a presentation (n=8), and those who did not attend any of the classes (n=6; Table 2.1). We also interviewed the two co-op managers to gather more specific information about each co-op (Table 2.1).

Table 2.1: Summary of Interviews Conducted.

Category	Before	After	Totals
Participants Interviewed	**15**	**13**	**28 (12 were interviewed twice, 1 3x)**
No Shows Interviewed	**4**	**4**	**8 (2 were interviewed twice)**
Total Interviews	**19**	**17**	**36 (14 were interviewed twice, 1 3x)**

- **29 people initially signed up for the class**
- **4 were excluded from the analysis (co-op managers & non-lobstermen)**
- **4 were not interviewed and did not attend any of the classes**
- **21 people were ultimately included in the analysis**
- **3 interviews were conducted a year after the course finished**

Prior to the start of the course, we asked participants about their motivation for getting involved in aquaculture, whether they had any prior experience with aquaculture, and whether they knew other fishermen who had tried aquaculture. Other interview questions included how long they had been fishing commercially, what fisheries they were involved in, and what percentage of their total household income came from fishing. They were asked about the highest grade level in school that they had completed, whether they would consider themselves leaders or innovators in their fishing community, and what type of aquaculture they were thinking of pursuing. Interviews conducted after the class was finished included questions about how the course could be improved, as well as questions about what kind of aquaculture project participants were envisioning, and what concerns they had about aquaculture.

We uploaded the interview transcripts into QSR NVivo 10 for qualitative analysis. The researchers read all interview transcripts several times to identify emerging themes. Themes were related to the adoption of aquaculture and included perceptions of opportunities for fishermen provided by aquaculture, perceived impacts of aquaculture, ideas for innovation, perceived conflicts between aquaculture and fishing, as well as potential barriers and concerns related to aquaculture. In addition, attribute data were entered into Excel for further analysis. Our research complied with the University Policy and Procedures for the Protection of Human Subjects of Research and was approved by the University of Maine's Institutional Review Board for the Protection of Human Subjects (Application #: 2012-09-14).

2.5. Results

We divided class participants into three categories based on levels of adoption: innovators, potential early adopters, and no shows. Participants were divided into these categories based on similar characteristics, which we describe below.

2.5.1. Course Participant Attributes

We categorized all of those who finished the course, gave final presentations and have since taken steps towards starting their aquaculture project to be "innovators" (n=4). Their actions are consistent with these individuals having "adopted" aquaculture, even though we don't know if they will be successful in the long term. One of our innovators has obtained a Limited-Purpose Aquaculture (LPA) license to grow oysters.[1] Of the four innovators, three indicated that they would like to try to grow more than one species. One innovator expressed interest in growing mussels, scallops, and seaweed; at the follow-up meeting, this individual indicated that he had set up a limited liability company (LLC), and planned to use the LLC to apply for his aquaculture lease. Another innovator told us he would like to grow seaweed and oysters, and a third indicated interest in growing scallops and seaweed. The fourth innovator expressed interest in growing oysters.

Our second category, "potential early adopters" (n=11), includes those participants who attended at least one class, but have not taken steps towards creating an aquaculture business, at least to our knowledge. These individuals may still be interested in the possibility of "adopting aquaculture" down the road, but we do not expect they will adopt it in the immediate future. In interviews, several of the fishermen cited scheduling conflicts as the reason they did not attend all classes and give a final presentation. One fisherman had a previously scheduled international trip that took place in the middle of the class and, after returning, felt that he might not be able to catch up. Two others from this group ended up having scheduling conflicts with their commercial fishing obligations, and one had several unexpected health issues come up with family members.

[1] This type of license allows an area of up to 400 square feet to be used for the culture of certain species of shellfish, algae, or sea urchins.

After the class was finished, we interviewed seven potential early adopters: three expressed interest in growing both oysters and seaweed, two were interested in growing seaweed, and two were interested in trying to grow oysters.

One of the fishermen we classified as a "potential early adopter" ended up attending just one class. He explained that he was very caught up in the excitement of the opportunity of the class during his early conversations with the extension agent. But when he came to the first class, received the big binder which would be full by the end of the course, and realized that each class was going to last for several hours, he said that he felt overwhelmed, having not been in school for many years. He then decided not to continue with the course. Even though this fisherman may be considered to have rejected aquaculture (at least in the context of this course), we kept him in our analysis as a potential early adopter because he expressed more interest at first than some others, including those fishermen later categorized as no shows. He tested out the class, but didn't feel it was a good fit for him. He told us that he was still interested in aquaculture, but just couldn't fit the class in.

Finally, we grouped participants into a category called "no shows" (n=6); these represent the individuals who had initially expressed an interest in the class, but did not attend any classes. For this group, we have no evidence to suggest that they will or will not adopt aquaculture. Most of these "no shows" were unable to attend because they had conflicts with other work or responsibilities. Five had work-related scheduling conflicts that prevented them from taking the class. One fisherman was attending college and had a class that conflicted with the course.

Most of the class participants who completed the course and gave final presentations at the end were planning to apply for limited purpose aquaculture leases. One innovator who planned to grow sugar kelp indicated that his main concern is coming up with a means of drying the product so it would be ready for sale to the buyers in the area.[2] Another innovator who plans to try to grow scallops, mussels and seaweed indicated that he plans to build a dryer for the seaweed and charge others to use it.

The individuals who signed up for the class ranged in age from 20 to 60, with a mean age of 40 years. All innovators were at least 36 years old. The majority of those who signed up for the class (58%) had no more than a high school education. Slightly more than half (57%) of the innovators, half of the potential early adopters, and 75% of the no shows who were interviewed had no more than a high school education (Table 2.2). Twenty-five percent of the individuals in each of these three groups had some college-level education. The majority of those who signed up for the class (67%) had been fishing commercially for at least 20 years (Table 2.2). All of the fishermen categorized as innovators had fished commercially for at least 20 years. Approximately half of the potential early adopters and 1/3 of the no shows had fished for less than 20 years (Table 2.2). Over half of those who signed up for the class (61%) reported that a high percentage (>67%) of their household income came from fishing (Table 2.2). Half of the innovators, 70% of the potential early adopters, and half of the no shows reported a high percentage of their income coming from fishing. Twenty-five percent of the

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[2] With regard to the concern raised about the need for a central drying facility for preparing seaweed for sale, a discussion of this need is already underway among stakeholders in the area, and evidently the Maine Technical Institute has already begun work on this problem.

Category	Innovators	Potential Early Adopters	No Shows
Age			
20-35 years old	0	5	4
36-50 years old	1	4	0
Over 50 years old	3	2	1
Education			
8th Grade	0	1	1
High School	4	3	2
Some College	2	3	1
Bachelor's Degree	1	1	0
Years of Commercial Fishing Experience			
0-20 years	0	5	2
21-30 years	1	3	3
31-40 years	1	3	0
41-50 years	2	0	1
Dependence on Fishing			
Low (0-33%)	0	1	1
Medium (34-66%)	2	2	1
High (67-100%)	2	7	2
Diversification			
yes	2	1	1
no	2	10	5
Knowledge of Aquaculture			
yes	3	0	2
no	1	11	3
Self-Identification as Leader			
yes	0	1	2
no	4	10	2
Participation in Fisheries Management			
yes	2	3	1
no	2	8	3
Leadership in Co-op			
yes	3	5	0
no	1	6	4

Table 2.2. Characteristics of Individuals Who Signed Up for the Class.

fishermen interviewed described themselves in their interviews as innovators or leaders. One person who identified himself as an innovator or leader in the fishing community during his interview did not demonstrate leadership or innovative qualities in the context of this course. Another individual answered the question of whether he would consider himself an innovator or leader by saying:

> If you're a leader, you get way too much flak for leading, and you've got – you say your opinion, and you've got a whole bunch of little Indians behind you, disagreeing with you, and even if they said opposite two weeks earlier, so… no, the leadership role in lobster fishing's not a good place to be.

Although few of the fishermen in our program described themselves as innovators or leaders, they did exhibit leadership. For example, most of the class participants who were co-op members either hold or have held leadership positions in their co-ops. The majority (75%) of our innovators and 45% of the potential early adopters held leadership positions in their co-ops, but none of the no shows did. Although many held leadership positions in their co-ops, the majority (68%) indicated that they do not participate in fisheries management. About 25% of those who were asked whether they participated in fisheries management (n=18) indicated that they attended meetings, but did not serve on any councils or committees. Half of our innovators, 27% of potential early adopters, and 25% of no shows indicated that they participated in fisheries management. One potential early adopter was on the original Zone Councils, and had served as the co-chair of the Lobster Advisory Council. Seventy-five percent of the class participants did not have knowledge of aquaculture. Broken down by category, 75% of our innovators, none of the potential early adopters, and 40% of our no shows reported prior knowledge of aquaculture. One of our innovators said: “[I] took quite a few courses down in Eastport back when – that was when aquaculture was really popular, and it was currently the University of Maine in Franklin, I was first hired there. I was the hatchery manager when I left. I’ve done a lot with it.” The majority of class participants reported at least some prior interest in aquaculture, and 75% reported knowledge of others who had tried aquaculture. A potential early adopter said:

> Well, I have friends that, a lot like me, so that education, I guess is the key – they don’t know about it, but – we all read National Fisherman, and there’s always articles in there about different people in different parts of the country doing it. I’m sure they read the same ones I do. Was it Great Eastern Mussels – been doing it for years, growing their own mussels, and they’re quite a big, booming business, so…_guess it might be the way of the future, I don’t know.

Over half of the fishermen in the class (68%) held federal fishing permits, and most of these federal permits were for lobster. Nearly 70% of these fishermen relied on a diversified fishing portfolio (defined as participating in more than two fisheries) in the past. About half (52%) are diversified currently, with most (74%) fishing only for lobster.

2.5.2. Perceptions of Barriers

We believe that everyone that signed up for the class did so because they felt there might be an opportunity for them to diversify through aquaculture. We know that many came to the class with prior expectations and perceptions. We found differences between how fishermen viewed potential barriers to aquaculture before and after the course.

Before the class started, fishermen were asked what they saw as the main barriers or obstacles that might prevent them from starting an aquaculture operation. Over half of those interviewed saw cost as an obstacle (Fig. 2.3). Leasing/permitting, general uncertainty, and siting were also seen as obstacles by the greatest number of participants in the class. One fisherman explained his concerns this way:

> For me, it's lack of capital, I guess. I think I can deal with the permitting process and site selections, that kind of stuff, and then the long lead time too, of course, if you're raising oysters, you're talking 3 years before you get any money back, mussels – you're only 18 months or two years, but it's still a long time to put out the money, and plus, then you're not positive you're going to get a crop – you might get raided by eider ducks or whatever.

As the above quote indicates, fishermen recognize that there is a risk to investing their time and capital in aquaculture.

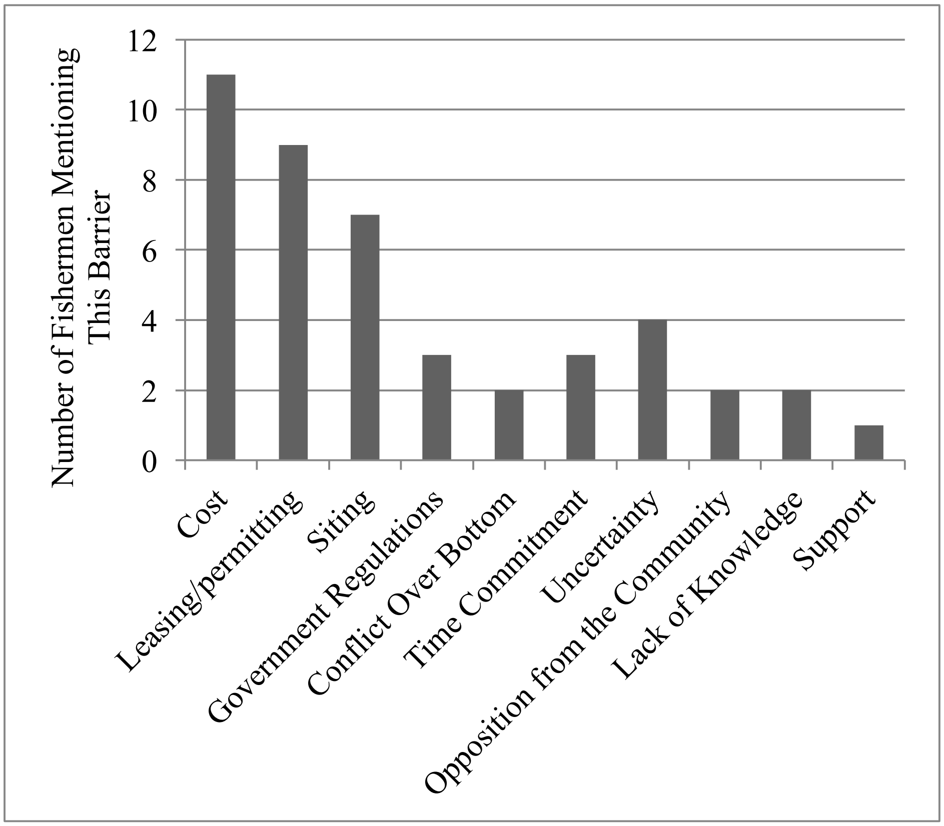

Figure 2.3. Participant Perceptions Before the Class. Number of class participants mentioning various potential barriers to starting up an aquaculture project in interviews conducted prior to the class (n=19).

Prior to the class, almost half of the fishermen interviewed (n=9) were concerned about being able to get a lease. Similarly, site selection and "conflict over bottom" were seen as challenges. "Conflict over bottom" refers to the conflict that may arise if other lobstermen would like to use the proposed lease area for their lobster traps. For this reason, lease applicants often try to locate their leases in an area where not many other lobstermen usually set traps. If conflicts do arise, one possible result is damage to the aquaculture gear. One fisherman described his concerns with site selection and conflict over bottom as follows:

> Location would be a big challenge, because of potential gear conflict… would be something that I'd be concerned about. I mean, there doesn't even seem to be room – I mean last year – no, the year before last – an edge that we fish below Halfway Rock – it's busy there, and somebody, from Biddeford I think, put some spat bags out, which they probably assumed was a good location for it, but even – whoever did it probably thought they were in the middle of the ocean, and nobody was around, but – yeah, we kept hooking those spat bags, and eventually, somebody else hooked them, and they ended up being moved quite a ways off to the side. So I don't know how that person – well, actually, I actually hooked some of them this spring – that was just kind of ghost gear then, you know what I mean? So that kind of opened my eyes up as to location – you think you're good, but there's always somebody trying to do something there.

Another fisherman described his concern with regard to siting this way: "… it always seems to cause a big stink when somebody wants to lease a piece of bottom, or a piece of ocean, to do this."

Opposition from the community may become a concern for new aquaculture leaseholders in the event that the proposed lease area is also used by others for purposes such as recreational boating, swimming, and fishing. Additionally, landowners whose property looks out over the proposed lease site may react negatively to viewing aquaculture gear (Hempe 2014, UNC Institute for the Environment 2015). In the aquaculture class, emphasis was placed on the importance of communicating plans to set up an aquaculture facility with others who may use the area in question. Depending upon the type of aquaculture lease being applied for, a hearing may or may not take place as part of the approval process. If an aquaculture lease hearing conducted by the DMR does take place, individuals who are not in favor of the lease being granted ("intervenors,") are offered the opportunity to testify regarding their concerns. The lease applicant is also given the opportunity to testify at the hearing.

Prior to the class, the time commitment involved in starting an aquaculture project was mentioned by interviewees as a potential barrier. Other perceived barriers mentioned by fishermen before the class included administrative concerns such as government regulations and the paperwork burden. A lack of knowledge and lack of support from the state to start an aquaculture venture were also noted as potential barriers. Additionally, participants mentioned barriers outside their control, such as predators and diseases, which were included in the "siting" category.

After the class, when participants were asked whether they anticipated any challenges to starting an aquaculture operation, concerns about cost and leasing/permitting again dominated their responses (Fig. 2.4). Uncertain markets emerged as a new potential barrier, while opposition from the community was not mentioned in the responses to this question. Other potential barriers the fishermen acknowledged included siting, government regulations, poaching, the time commitment, and uncertainty. In particular, the innovators mentioned conflict over bottom, siting, cost, government regulations, uncertain markets, and poaching as potential barriers in response to this question. Of the potential early adopters, 40% saw leasing as an obstacle, and half

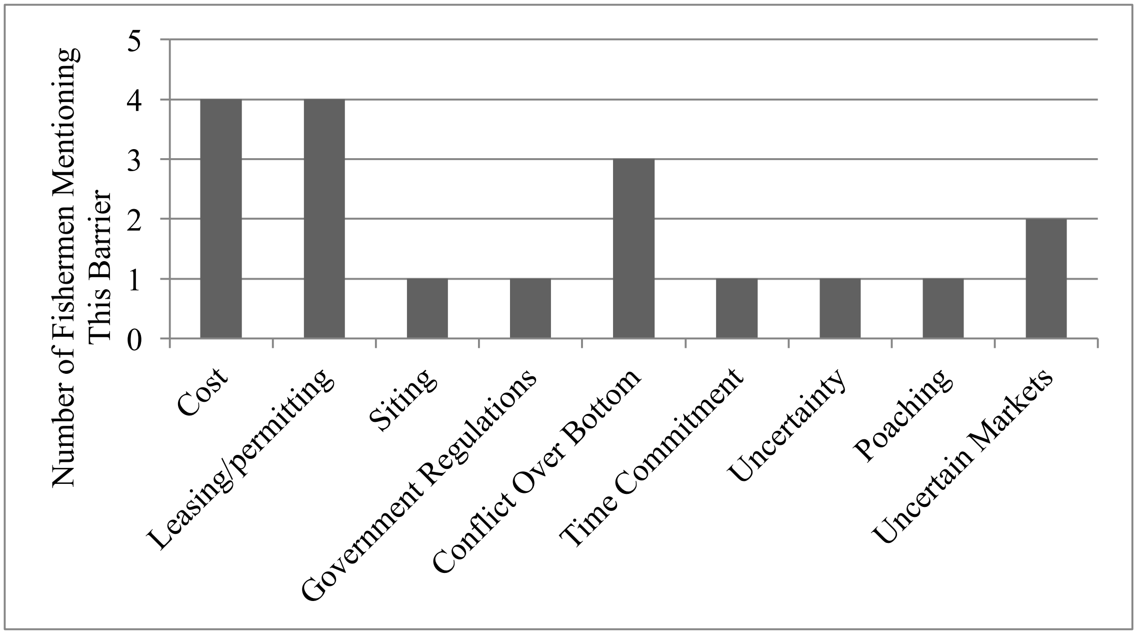

Figure 2.4. Participant Perceptions After the Class: Open-Ended. Number of fishermen mentioning a potential barrier in interviews conducted after the class was finished (n=10). The researchers asked whether participants anticipated any challenges to starting an aquaculture operation.

mentioned cost. Following the course, we also asked participants whether they were concerned about various obstacles that were identified during the pre-course interviews (Fig. 2.5). In this part of the interview, barriers were specifically identified and participants were asked whether the potential barrier was of concern to them or not. Concerns associated with poaching and getting a lease were the perceived barriers acknowledged by the largest number of class participants (8/10). The majority of class participants (7/10) were also concerned about government regulations, the paperwork burden, and a lack of knowledge. One fisherman commented with regard to government regulations: “I’m always concerned about those... what will they come up with next?”

Another said: "Yeah, too many of those – which is good and bad, I mean – if we just had *sensible* government regulations, but maybe that's asking too much... " When asked

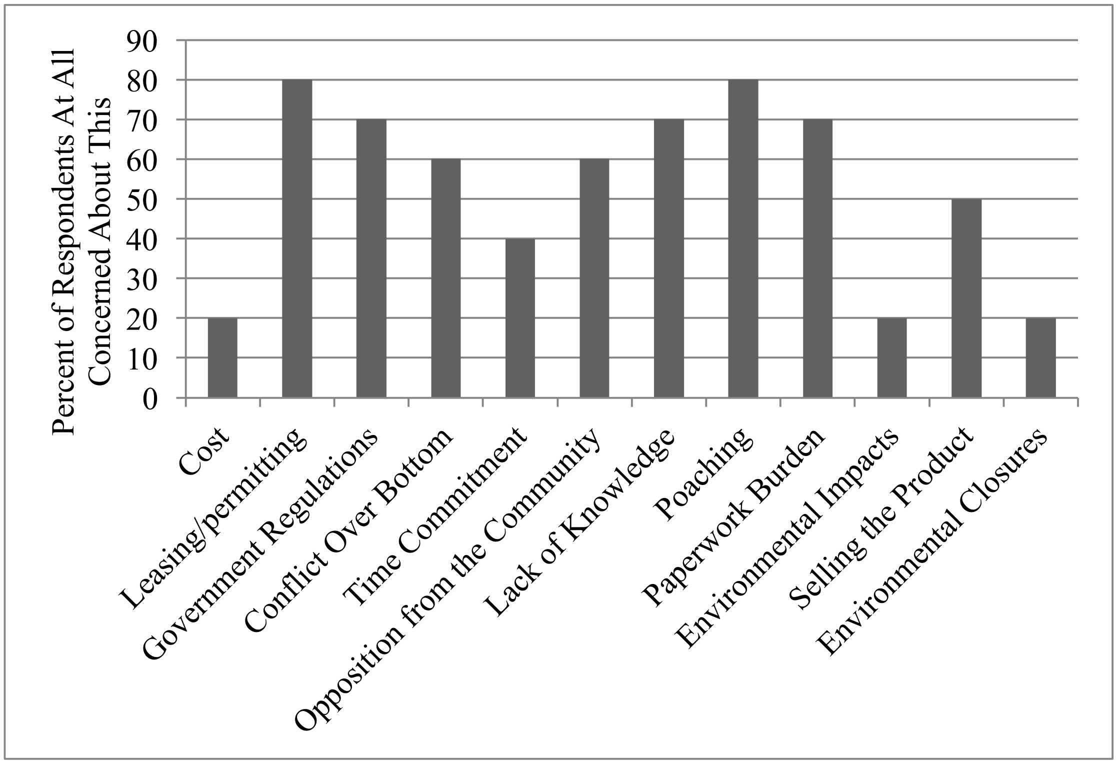

Figure 2.5. Participant Perceptions After the Class. Percent of class participants acknowledging various potential barriers to starting up an aquaculture project in interviews conducted after the class was finished (n=10). The interviewer mentioned each barrier by name, and then asked the participants if they were concerned about it.

about whether he was concerned about the paperwork burden, one fisherman answered: "Well, I think you'll find fishermen hate paperwork." Conflict over bottom and opposition from the community were barriers acknowledged by the majority of the class participants (6/10). Uncertain markets and the ability to sell their product were a concern for half of the participants, while the time commitment involved was seen as a barrier by less than half (4/10). Half of the class participants who indicated they were interested in growing kelp noted a concern with uncertain markets. The cost of running the business, environmental closures, and environmental impacts were also perceived barriers. The cost of running the business and the time commitment involved remained areas of concern following the class. Elements outside of the participants' control such as environmental closures, uncertain markets, and the ability to sell the product were new concerns that were mentioned once the class was completed. When asked about what concerns he had about aquaculture, one fisherman who was planning to grow seaweed said:

> Oh, markets I think is the biggest thing. We really, from what I could tell in the class, [don't have] really defined markets for it right now. I would hate to have – get a lot of product and not be able to get rid of it, get stuck with it – it would be like lobsters, a lot of product and no money.

The fishermen learned about uncertain markets for kelp aquaculture in Maine in the class. One individual who attended some of the classes expressed his concern regarding the time commitment required for setting up a new aquaculture business as follows:

> Well, I thought the part on the oysters sounds real interesting, but the more you hear on classes and stuff, and reading the pamphlets and stuff… it's a lot more work than I was anticipating it was going to be, a lot more tedious little things, I think, than [I thought] it was going to involve. It's not as simple as throwing them in a box and letting them grow, and going to sell them, that's for sure.

In the interviews following the course, one individual who had indicated that he planned to grow seaweed and oysters indicated that he would not be able to start this project for three to five years, because his children are in school right now and he needed to focus all his energy on his commercial fishing operation in order to make sure those bills are paid:

> I don't have the money to start up any business right now – any funds I have I need to keep in my business, and I have two kids in school right now – it's just hard to find any extra time or money to put towards something new.

In the interviews, we did not ask directly about risk aversion. However, one of the innovators who plans to work with scallops, seaweed, and mussels cautioned at one point: "Now, mind – I'm just seeing if it's going to work – I ain't going to jump right in."

Prior to the class, three primary obstacles (cost, leasing, and siting) were seen by 1/3 of the participants as barriers that might prevent them from starting an aquaculture operation. The rest of the perceived barriers were mentioned by less than 1/4 of the participants. After the course was finished, a similar pattern emerged when researchers asked an open-ended question about potential barriers. When the researchers specified a barrier and then asked whether participants were concerned about it, there was a more even distribution of perceived obstacles among course participants. Several potential barriers (opposition from the community, lack of knowledge, the time commitment, conflict over bottom, and government regulations) were mentioned by less than 25% of participants before the class, but were acknowledged by at least 40% of participants when the barrier was specified after the class. Also some of the perceived barriers that were new after the class finished (such as uncertain markets and the ability to sell the product) were topics the course had covered. The paperwork burden, environmental impacts, and environmental closures were acknowledged when the researchers mentioned the barrier, but not otherwise.

The class provided a considerable amount of time for the participants to become familiar with aquaculture; additionally, the class instructors encouraged the participants to contact them with questions at any time, including once the class was finished. Many of the fishermen who participated in the course emphasized the impact of the field trips on their interest in trying aquaculture. These fishermen are “hands-on” people, and they absorb information more easily by trying to do something than by hearing about it while sitting in a classroom. In debriefing meetings following the class, class facilitators suggested that it might be beneficial to include more field trips closer to the beginning of the class, so that participants would be more engaged by the time they need to make their choices regarding the type of aquaculture they would like to try. When the aquaculture course was repeated in 2015, it was structured differently to accommodate these suggestions. Another need expressed by one of the fishermen in the class was that the text on the slides for the PowerPoint presentations be made larger since he experienced difficulty reading the slides after looking down at his notes for an extended period.

2.5.3. Innovator Profiles

Below we profile 2 innovators, i.e., individuals who finished the class, gave final presentations, and have made substantial progress towards the development of aquaculture businesses.

2.5.3.1. Innovator 1

One of the class participants who plans to grow oysters has built research gear for several state agencies and other organizations,[3] and has a history of innovating. He has been responsible for several inventions in the industry, among them alterations to groundfish nets so that they could be used for cod fish or flat fish depending upon the height they were positioned off the bottom. Another project involved building metal oyster tables for artisanal oyster growing. He indicated that he has done some public speaking as part of his work in research. This fisherman was the most diversified of any of the class participants; in addition to his permits to fish for scallops and sea urchins, he has individual federal fishing permits for lobster, shrimp and groundfish, and associated with his federal groundfish permit, he can fish for monkfish, squid, butterfish, and dogfish. When asked which fishery was the most valuable to him, he answered:

> Some years, most of my money was made shrimping, some years most of it was made groundfishing – the most money I ever made in a year was

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[3] The organizations this fisherman has built research gear for include the Massachusetts Division of Marine Fisheries, the Maine Department of Marine Resources, the University of New Hampshire, the University of Maine, New Hampshire Sea Grant, the Damariscotta River Association, and the Northeast Consortium.

> doing research – and there's been years that I've made half my year in say, lobstering, so… we go where the money is.

This fisherman is very involved in fisheries management, and has been on several advisory committees. He has served on a shrimp advisory committee, was involved in setting up the Maine and New Hampshire in-shore trawl survey and the Cod survey, and serves on the enforcement board of his catch share sector as well as on the Board of Directors of his fishermen's association. He indicated that he attends about 20 fisheries management meetings per year.

When asked whether he had spoken with others in his community about their interest in aquaculture, he replied:

> Yeah – quite a bit. I tried to get a bunch of the young fellows interested a few years ago in setting out these spat bags to collect juvenile scallops, to see if we could get an area closed off for the state… so we could just put them there for like three years and then when they opened it back up again, try to give the people who've – put the scallops there first dibs, you know? I thought it would be a good experiment, because they can't prove, yet, that collecting juvenile scallops and putting them somewhere actually enhances the fishery – I've talked to several of these young fellows about growing seaweed or getting into aquaculture – it's just because they're looking for something else to do, and I think that's something they can do.

He stated at the final course meeting that he plans to apply for a full 10-year aquaculture lease, and use longlines for his oysters. He presented a three-year projection of earnings and debts at the final class meeting. He stated that one of his concerns is poaching: "I'm a little worried about poachers, but – what cameras achieve nowadays – my son tells me you could have one set up to take a picture every thirty seconds and send it to your cell phone for like 15 dollars a month."

2.5.3.2. Innovator 2

One of the fishermen who planned to grow kelp and oysters obtained his limited purpose aquaculture license for oysters in May 2014. This individual also has a lunch stand on his wharf, where he sells some of the lobsters that he traps. He plans to sell his farmed oysters at this stand as well. He has a history of innovating – he began selling crab claws at the lunch stand after seeing the price they commanded in Florida when he visited there with his wife. In an effort to encourage his son to apply to work for the census one year, he applied as well, and ended up working as the crew leader. He talked about this in his interview:

> Back in 2010, I did the Census, and when I called for the results, I got talking to the guy, and he – I think that's how you get your jobs, is the connections you make, a lot of times, I mean, it's who you know, or you happen to stumble into something – it's not just, you're not getting pulled out of a hat for it most of the time, so, we got talking, and – so anyway, I ended up as a crew leader, and had a *great* time with that, and *really* enjoyed it, didn't spring fish – met great people, did two different crews in

> different places, and so – it sort of broke the cycle of spring fishing, going spring fishing and not making any money.

There are several different species of seaweed near the site where he plans to grow his oysters, and he dried some sugar kelp and brought it to the aquaculture class for everyone to sample. His family has lived in the area for 200 years – he said that they were the first white people to live there. He has been a member of his co-op for 35 years (more than all of the rest of the fishermen in this analysis) and has served on its board. During his interview, this fisherman encouraged the course facilitators to include more business training in the class:

> I don't know much about the business end of things – I think that's part of some of the training we need is some sort of basic business skills, because we don't – well, we don't do that. And I was hoping, I was actually hoping more of the fishermen would do this course, but the way we're set up here, and the way that the fishermen – it's just the way we do it – is we go to haul, we come in, and we drop our lobsters over there, and of course we all belong to the co-op, but that's it, and then the truck comes, and they take all the lobsters away, and those people that take the lobsters away, they might be just truckers, or they might be the buyers themselves – they're the ones making the money. We're getting paid the bottom dollar, and then they're going – they're taking it to another step, and doing the marketing, and the grading of them, and stuff, and so they're making,

> probably, when you get right down to it, more on them than we are, because our expenses are high – I mean, it's very expensive to go to haul. So, I think it'd be good if fishermen were educated in that part of it.

This fisherman asked whether several of the other class participants had ended up finishing the course, and explained what other factors might have kept them from finishing. He seemed to be very aware of the challenges his fellow fishermen might be experiencing, and eager to present others in the community in a positive light.

We interviewed this fisherman again in August 2015. At that point, he had two LPAs for oysters, and about 3,000 oysters that were almost ready to sell. He told us he'd had no idea how popular the oysters would be; when he brought his first load of oysters in to serve at his lunch stand, they were gone in 15 minutes. One challenge he encountered with his first crop of oysters was predation by green crabs, which climb into the bags when they are small, and grow along with (and eat) the oysters.

He tried growing kelp, but there was worse ice than usual and his spot was iced out, so he plans to try again. He did build a kelp drying shed, which was a need identified by the group during the class. He hopes to get certified as organic.

He expressed interest in applying for grants but not the low-interest loans that were discussed in the class, because of his age. His biggest concern with doing aquaculture in the future is having the market to sell the product.

2.6. Discussion

Many of our findings about individuals who act as innovators in the adoption of aquaculture matched our expectations based on what has previously been reported in the literature. Although many of our findings are consistent with the literature, our results diverge in some cases, especially when considering the categories in detail. Leadership, experience, and diversification may indicate a greater willingness to adopt aquaculture, while younger, less diversified and experienced fishermen may experience challenges or demonstrate less willingness to adopt aquaculture.

In some cases, characteristics of our innovators diverged from those identified in previous findings as indicating a tendency to innovate. The majority of the innovators in this study had no more than a high school education, participated in fisheries management, demonstrated leadership qualities, were diversified in the past, and reported at least a moderate amount of their household income coming from fishing. Fishermen in our innovators group were also all over age 35, while those in the potential early adopter and no show groups had a wider variety of ages. Perceived potential barriers appear to relate to the risks associated with an uncertain return on investment such as costs, siting, uncertain markets, the time commitment, and the government burden.

In contrast with previous findings that education level correlates with adoption of innovation (Agbamu and Orhorhoro 2007, Nyaupane and Gillespie 2011, Bosma *et al.* 2012, Acheson and Reidman 1982, Dewees and Hawkes 1988), the majority of the innovators in our study did not have more than a high school education, while over half of the potential early adopters had more than a high school education. According to the Gulf of Maine Research Institute (2008), the majority (80%) of average, active lobstermen in New England have a high school diploma or GED, so it appears that our study population is representative in this respect. However, all of the individuals in our innovators group had received some form of specialized training,[4] while only 50% of the potential early adopters and no shows groups had such training. The Aquaculture in Shared Waters course could also be considered specialized training. Perhaps, then, specialized training or training along with education level is a better predictor of willingness to adopt aquaculture than education level alone. More research is needed in order to determine whether specialized training by itself correlates with adoption of innovation.

Nyaupane and Gillespie (2011) observed a positive relationship between self-identification as an early adopter and the likelihood of adopting innovations in aquaculture. Very few of our class participants stated that they considered themselves to be leaders or innovators in their community even though they exhibited leadership qualities during the class. We believe it is possible that the individuals in our groups who demonstrated leadership qualities may not have felt comfortable assigning themselves the title of “leader” or “innovator.” However, the majority of the individuals in our “innovators” group held leadership positions in their co-ops, while the percentage of leadership positions held was much lower among potential early adopters and no show groups. A common characteristic for the innovators we profiled was that they advocate aquaculture in their communities and actively try to get others involved. These could be considered leadership qualities in the context of their communities. Rogers (2003) considers individuals like this to be “innovation champions”, charismatic people who are

[4] The specialized training reported in the interviews was varied, from boat safety to Master Dive License training.

particularly skilled in persuasion and in handling people. He notes that, all other things being equal, if an innovation has a champion, it is more likely to be adopted than if it does not.

The percentage of household income obtained from farming some aquatic species is a significant predictor of adoption of innovation (Agbamu and Orhorhoro 2007, Nyaupane and Gillespie 2011). We found a similar pattern among the commercial fishermen in our class. The majority of our class participants reported a high percentage of their income coming from fishing. Individuals in our "innovators" group all reported at least a moderate amount of their household income coming from fishing, while a small percentage of the "potential early adopter" and "no show" groups reported low dependence upon fishing. If individuals are very dependent on fishing, it is likely that they are not as diversified outside of fishing. Those dependent on fishing are more likely to be interested in trying aquaculture in order to stay working on the waterfront and they already have a lot of knowledge about the area. For example, they are familiar with coastal currents, what traffic exists in the area, and what species will grow.

Rogers (2003) acknowledges the importance of "near peers" in the process of adoption innovation. Although most of our class participants did not have prior experience with aquaculture, most did report knowledge of others who had tried aquaculture. A greater percentage of the innovators in our study had prior experience with aquaculture than those in the potential early adopters or no show groups. Additionally, three out of four of our innovators share the same wharf, and the increased level of communication that they have with each other may have afforded them an advantage in the context of this class. At the follow-up meeting, one of these fishermen commented on how the shared wharf put them “that much further ahead.” Future research should examine whether an increase in the level of communication between fishermen in a community increases the chance that they will adopt innovation. In this particular case, participants in the aquaculture class were recruited through two existing cooperatives. These cooperatives already represent examples of commercial lobstermen working together to strengthen their working waterfront. If future aquaculture courses are offered, a new research question should be whether individuals who are not already part of cooperatives are more or less likely to adopt this innovation.

Previous research has generally found that the likelihood that individuals will adopt innovation is inversely related to their age (Acheson and Reidman 1982, Dewees and Hawkes 1988). In contrast, the innovators in our study were all over age 35, while many of the potential early adopters and no shows were younger. This is not surprising given the aging nature of the fishing industry, and is consistent with the findings of a Gulf of Maine Research Institute study (2008) that found the average lobsterman in New England is 50 years old. However, this divergence from earlier findings raises the question whether experienced fishermen in this community are more likely to innovate than experienced fishermen in other waterfront communities.

Acheson and Reidman (1982) found that political organizations were important in strengthening fishermen’s position in the industry and increasing their propensity toward adoption of innovation. Our research was consistent with these findings. Individuals in our innovators group participated more in fisheries management than those in either of the other groups. On the other hand, the co-ops themselves can be considered political organizations. If so, then all of our class participants could be categorized as early adopters of innovation. Further, there were at least two innovators who had a history of success with previous innovations, which may indicate a tendency to adopt innovations more readily than others. This seems to represent a divergence from the findings of Acheson and Reidman (1982).

In contrast with the findings of Robertson (2001) and Tango-Lowy and Robertson (2002), all of our innovators had at least 20 years of commercial fishing experience, and half of them had over 40 years. Although "entrenchment" reduced the likelihood of innovation, Tango-Lowy and Robertson (2002) found that diversification increased the chance of adoption. Based on our metric where "diversification" was defined as a fisherman participating in at least two commercial fisheries, we found that the majority of those who expressed interest in the class and were interviewed had been diversified in the past, but most were not participating in multiple fisheries at the time of the class. However, all of the individuals in our innovators group had diversified in the past, and half of the individuals in this group were still diversified at the time of the class, consistent with Tango-Lowy and Robertson's (2002) findings. It is possible that if individuals are already participating in several fisheries, they may be more willing to try new projects. Participants in Tango-Lowy and Robertson's study (2002) completed a survey after they were provided with information about aquaculture projects. Our research focused instead on whether participants took steps towards starting their own aquaculture projects after being provided with information about aquaculture.

Perceived barriers may limit fishermen's interest and therefore are a critical consideration when evaluating what might prevent a commercial fisherman from adopting the innovation of aquaculture. Additional barriers may exist, but the perceived barriers mentioned in the interviews likely represent the preconceptions and concerns that come to mind first for the course participants. In the interviews before the course, leasing or permitting, siting, and the cost of running the business were the concerns most frequently mentioned. Following the aquaculture course, different concerns were mentioned that were associated with topics covered in the course: uncertain markets and conflict over bottom; thus, the perceived barriers changed after the course. Although there were still some perceived barriers, participants left the course armed with more information about what starting an aquaculture project would involve.

There may have been some characteristics of our recruitment process or the communities where we worked that were unique to our study so that our findings may not be generalizable to other communities. For example, three of the innovators in Corea worked on the same wharf and shared information. Although more people signed up in the Harpswell area than in Corea, more people in Corea actually finished the course than in Harpswell. There is the possibility that if we had used a different recruiting process or worked with different communities that our results would have been different. For example, when the Aquaculture in Shared Waters course was run again in 2015, it targeted clammers instead of lobstermen. After the 2015 class, three individuals started new farms, one individual expanded an existing farm, and four other individuals took steps towards starting new aquaculture operations. In addition, a municipal demonstration farm was set up in the Brunswick, Maine area in association with the 2015 class to provide an example for the community and to stimulate interest in aquaculture.

Few studies have focused on the characteristics of innovators and the adoption of aquaculture, and those studies did not consider perceived barriers to starting an aquaculture operation. Identifying and discussing people's perceptions will inform the design of future classes. The Aquaculture in Shared Waters course has likely changed participants' perceptions and provided those participants with a familiarity with aquaculture. Additionally, the class provided networking opportunities that will allow participants to connect with people who can help them start aquaculture projects well into the future. Future research could expand the study population to include more commercial fishermen from throughout the New England region and beyond. Additionally, a longer-term study could explore the transition from fishing to farming and would improve our understanding of the feasibility of the adoption of this type of innovation. Aquaculture has been proposed as a way to preserve working waterfronts, and courses like Aquaculture in Shared Waters will continue to be a powerful tool to help people in Maine's coastal communities.

CHAPTER 3

PREVENTATIVE TREATMENTS FOR BLISTER WORM (A PEST SPECIES) IN THE EASTERN OYSTER

3.1. Introduction

Aquaculture is an important and growing industry in Maine. Sales of aquaculture products in the state are dominated by cultured Atlantic salmon. However, there are substantial sales of farmed shellfish, including eastern oysters (*Crassostrea virginica*), in Maine as well. The culture of eastern oysters began on the Damariscotta River, but has expanded and oysters are now cultured on multiple rivers in the state. Oyster culture has been on the increase since the year 2005 (DMR 2016b), and in terms of dollar value, oysters are the top aquacultured shellfish species in the state. Despite the growth, the oyster industry is still mostly composed of small owner-operator farms.

The advent of hatchery technologies for oyster seed production has fueled some of this growth. There are different perspectives on what constitutes complete domestication of a “livestock”. Duarte *et al.* (2007) argue that domestication includes a closed production cycle, where the cultured animals’ food is produced on site (within the farm), and the cultured species reproduce and carry out their entire life cycle within the confines of the farm. Under this definition, oysters would not be considered a domesticated species, but shellfish hatcheries have allowed the industry to close the life cycle and facilitated the development of genetic lines (Allen *et al.* 1993, Rawson *et al.* 2010). Even so, oysters are grown in the natural environment and farmers have little control over the food that is provided to their oysters. These farmers also exert little control over environmental conditions including temperature, salinity and exposure to pest species.

One of the pest species that has proven difficult to control is the blister worm, *Polydora websteri*, which creates unsightly mud “blisters” by burrowing into an oyster’s shell (Fig. 3.1). The majority of oysters grown in Maine and the rest of the northeastern United States end up served on the half-shell in white-linen restaurants. This is a lucrative market with a heavy reliance on the oysters’ appearance, and any factor that mars it, such as the blister worm, is taken very seriously by the industry (Leach, pers. comm.).

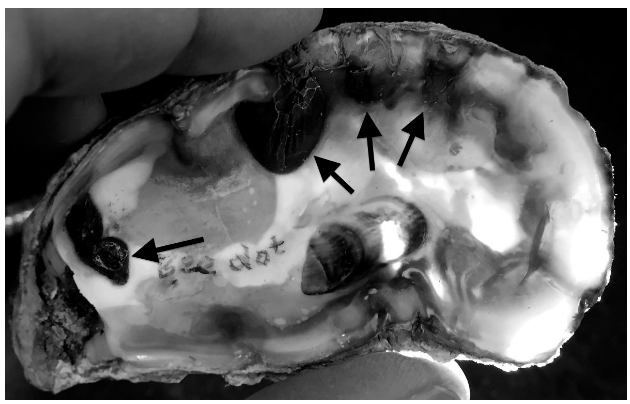

Figure 3.1. Mud Blisters in Oyster Shell. Each blister (see arrows) contains a single adult blister worm. Worms deposit fecal material, mud, and detritus on the walls of their burrow, creating a dark “blister” on the inside of the oyster’s shell.

Polydora websteri is one of several closely related polychaete species in the family Spionidae and one of several polychaete species that burrow into the shells of bivalves. Natural historians noted *P. websteri* and its habit of burrowing into shells as early as the 1880s (Carazzi 1893) and early 1900s (Leloup 1937). Although reports suggest that this polychaete has a nearly global distribution, recent attention has focused on the blister worm's impact on oyster culture operations in Australia as well as along the Gulf and Atlantic Coasts of the United States (Nell 2007). In Maine, as the oyster industry has grown, the incidence of blister worms has also increased.

Haigler (1969) and Zottoli and Carriker (1974) suggest that *P. websteri* uses chemical secretions to dissolve shell material. Burrows often start at the shell margin and have a characteristic u-shape (Zottoli and Carriker 1974) extending inward as the worm grows (Fig. 3.2). Burrows may also start at other places on the shell – for instance, they are often found along growth lines in the shell. If a *P. websteri* burrow extends inward to the shell cavity, the oyster responds by adding additional layers of shell material (nacre) on the inner surface. The worm then continues to extend its burrow, the oyster puts down new layers of shell, and they engage in a sort of "tug of war" (Nell 2007).

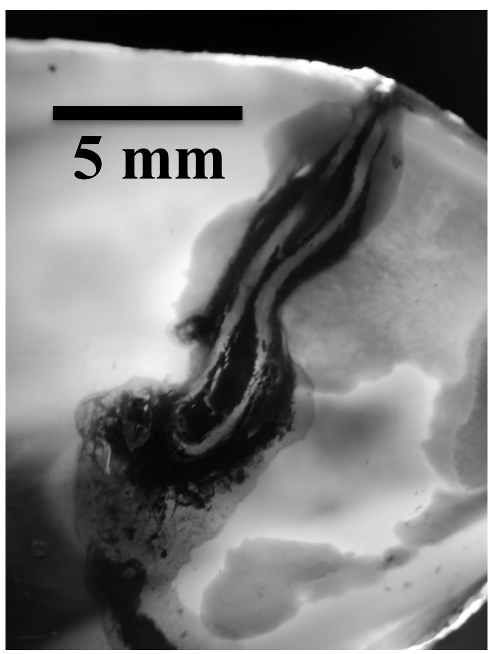

Figure 3.2. Adult Blister Worm Burrow. An adult blister worm burrow in the cup valve of an oyster. The burrow starts at the margin of the shell (upper right in this photo).

Blister worms deposit fecal material, detritus, and mud along the walls of the burrow which creates a dark "blister" on the inside of the oyster's shell. Adult blister worms (e.g., Fig. 3.3) can reach up to 20 mm in length and they feed either on materials found on the shell's surface or on detritus or phytoplankton from the water column. Food is captured using anterior ciliated structures called palps; particles captured on the cilia are transported down a central food groove to the mouth where they are ingested.

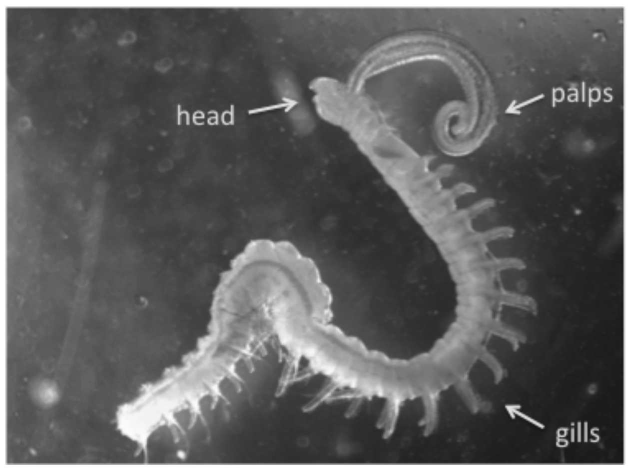

Figure 3.3. Adult Blister Worm. Although missing some of its posterior sections including the tail, an adult blister worm is shown in this photo with the head, feeding palps, and gills identified.

Light infestations of blister worm may result in one to a few visible burrows per oyster (e.g., Fig.3.1) while in heavy infestations oysters may have dozens of worm burrows in each valve. It is unknown whether such severe blister worm infestations weaken the shell or are associated with increased mortality in oysters. However, oysters routinely put down new shell (Nell 2007), and so suggestions that a heavy infestation of blister worms causes a decrease in the oyster's energy reserves are anecdotal. It has also been suggested that burrows under the adductor muscle cause the shell to gape and kill the host; however, this too is not well substantiated.

What is clear is that *P. websteri* burrows make the interior of oysters' shells unattractive. In addition, if the burrows are broken open during the shucking process, consumers may experience off flavors if mud and detritus leak out. In heavy infestations of blister worm, farmers have discarded whole crops as a result of this pest with a financial impact to a farm of hundreds of thousands of dollars (R. Rheault, J. Leach, pers. comm.). Few farmers have resorted to such extreme measures, but they are understandably concerned about their reputation and loss of market share in the event of an infestation.

Substantial research has sought to find treatments that could be applied to oysters to rid them of existing infestations of adult blister worms. For example, chemical treatments have included dipping oysters in a solution of copper sulfate, 2% formaldehyde, chlorine, phenol, marine diterpenes from algae, tetrachloroethylene, and 0.2% calcium hydroxide (hydrated lime) as well as bleach, iodine, and acetic acid (Dunphy *et al.* 2005, Gallo-Garcia *et al.* 2004, Nel *et al.* 1996). Most of these chemical treatments have not consistently rid oysters of these worms, and even if they succeeded at eliminating established worms, they would render the oysters unsaleable. Other reports suggest that submerging oysters in either freshwater or salt-saturated solutions may kill adult worms (Nel *et al.* 1996, Dunphy *et al.* 2005). Hooper (2001) treated bottom-cultured oysters by exposing them to the air for 48 h, immersing them in a salt-saturated solution for 15 min, and then air drying them for an additional 2 h before replanting the oysters on the bottom. Littlewood *et al.* (1992) suggested that an extended period of air drying significantly reduced blister worm infestation, while Nel *et al.* (1996) proposed that dipping oysters in heated seawater may be a remedy for blister worm. Hooper's approach agreed with the suggestion by Littlewood *et al.* (1992) that air drying may significantly increase worm mortality.

Some growers have suggested that bottom culture of oysters may reduce blister worm infestations (Morse, pers. comm.). It is important to note that blister worms can live in sediments if shells are not available. Perhaps if a thin film of sediment covers bottom-cultured oysters it could inhibit worm settlement or possibly suffocate worms that have already settled. However, no systematic test has been performed to confirm this. Additionally, blister worms have been observed in oysters grown on the bottom at some locations on the Damariscotta River, so it appears that more work needs to be done to establish whether and under what circumstances bottom culture may confer an advantage.

The foregoing reports suggest that the proposed treatments have worked at least once, but these successes have typically not been repeated. Part of the problem may be that once a burrow has been constructed, a blister worm is protected from environmental changes. For example, Brown (2012) found that worms in burrows were much less impacted by low salinity conditions compared to worms outside of burrows. The only approach that has repeatedly treated blister worm infestations successfully without hurting the oysters is temporarily holding the oysters in cold storage on land during the winter (J. Leach, unpublished data). In this approach, the oysters are placed in large plastic totes and kept at 38°F (3°C) for 3-4 weeks. During this time, the oysters hermitize (close their shells) and their metabolism slows. In contrast, worm burrows are open at the shell surface and dry out, which kills the adult worms. After the 3-4 weeks in cold storage on land, the oysters are placed back into the water at the culture site and allowed sufficient time to deposit new nacre over the blisters that now contain dead worms. This method is labor intensive, and should only be employed during the colder part of the year when the oysters' glycogen reserves are high and they have acclimated to winter water temperatures. When this treatment has been attempted at other times of year, oyster mortality was much higher (Leach, pers. comm.).

Given the difficulties in application and inconsistent results associated with treatments for ridding oysters of established adult worms, our research focused on treatments aimed at eliminating the initial settlement of worms. Blister worms have a complex "indirect" life cycle that includes a dispersive larval stage. Initial stages of reproduction in *P. websteri* are not well known. In the congener, *P. cornuta*, which often occurs in the same estuaries as *P. websteri*, Rice and Rice (2009) found that males deposit spermatophores in the burrows of female worms, and females of *P. cornuta* use stored sperm to fertilize eggs. Although fertilization has not been observed in *P. websteri*, it is known that female blister worms deposit fertilized eggs in egg cases along the burrow walls "like beads in a string" (Blake 1969; Fig. 3.4).

Blake (1969) reported that larvae hatch from their egg cases when they reach 3-4 segments in length (Fig. 3.5), and typically spend a month or more feeding on plankton in the water column as planktotrophic larvae (larvae that obtain their food from the plankton). The length of the planktonic stage depends upon the water temperature; Blake (1969) found that *P. websteri* larvae reached a length of 14 setigers in 60 days at 10°C and in 40 days at 15°C. When the larvae reach a length of 17 setigers, they are then ready to settle on oysters. However, Haigler (1969) reported finding larger larvae in

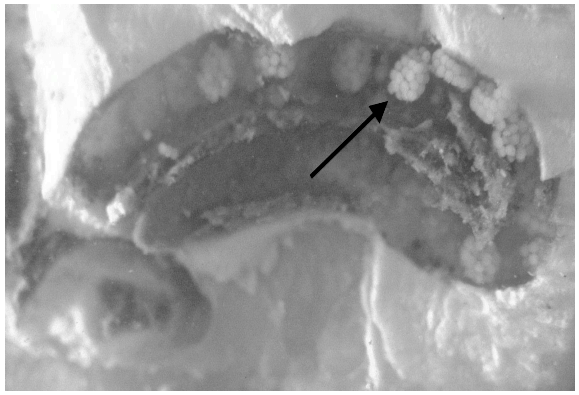

Figure 3.4. *Polydora websteri* Egg Cases. Individual egg cases lining the u-shaped burrow of a single large ~ 20 mm female blister worm. Each case may contain upwards of 50 eggs or more.

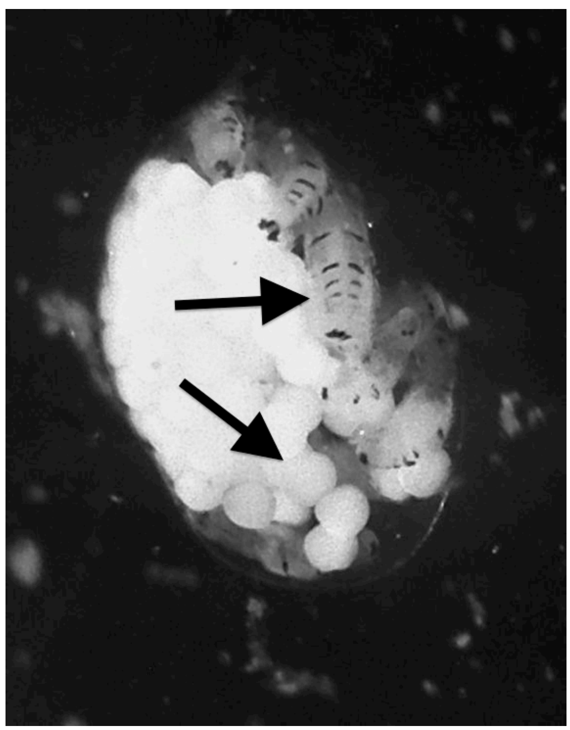

Figure 3.5. *Polydora websteri* Egg Case with Larvae. Three-setiger *P. websteri* larvae are visible together with undeveloped eggs in a single egg case. The photo shows the dark bars on each segment.

burrows, and suggested they may adelphophagic (feeding on nurse eggs provided by the parent) and perhaps spend less time in the plankton. The consumption of non-developing by developing larvae may impact the rate of larval development and the timing of larval settlement (Rice and Rice 2009). Rice and Rice (2009) found that in *P. cornuta*, not all of the developing larvae fed on the unfertilized eggs even if these were available. If *P. websteri* larvae are adelphophagic they may require less time for dispersal, and so are vulnerable to predators for shorter times. Regardless of the early patterns of development, blister worm larvae eventually leave the adult burrow and once they settle on an oyster, they create a burrow that usually begins at the margin of the shell (Fig. 3.6). Given the exposure of the initial tube at the edge of the shell, the immediate post-settlement stage of *P. websteri* may be more susceptible to stressful environmental conditions.

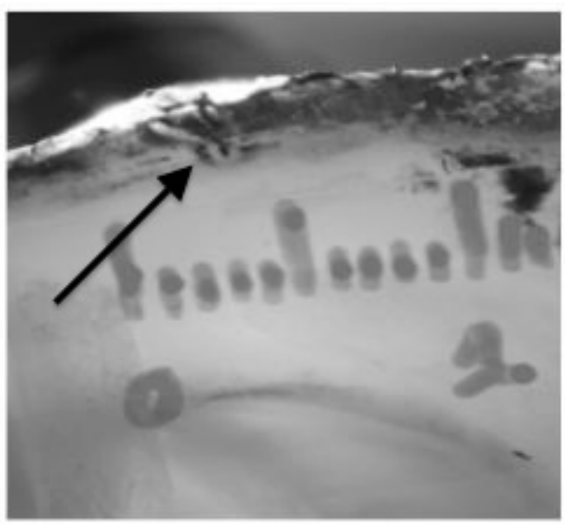

Figure 3.6. New Blister Worm Burrow. New blister worm burrow starting from the margin of the shell. Photo credit: Ian Ellis.

Littlewood *et al.* (1992) and Zottoli and Carriker (1974) felt that a regular period of air drying during each tidal cycle could reduce or eliminate blister worm infestations. For intertidal oysters, it is possible that regular drying reduces blister worm settlement. However, many Maine farms have subtidal leases, and often at these lease sites the oysters are cultured in surface bags or cages. Such bags or cages are turned periodically to control fouling organisms, but the oysters themselves are continuously submerged. Recent advances in cage design such as the Oyster-Gro or Oyster Ranch systems have made it possible for growers to "flip" the cages to provide regular air drying time for their oysters to reduce fouling. Such air-drying may also be beneficial with respect to blister worm if periods of drying reduce worm settlement or survival of recently settled worms.

The goal of our research was to test treatment options for reducing blister worm settlement that coincide with seasonal variation in the timing of larval settlement. Our hypothesis was that the early post-settlement worms would be most vulnerable when still on the shell surface, prior to excavating into the shell. The results of previous research by Blake (1969) and a project conducted at the Bagaduce River Oyster Company (BROC) by students at Old Town High School (Old Town, ME; unpublished data) suggest that egg cases and gravid female blister worms occur in oysters in central Maine during the period from April through September each year. The students observed that the average size of the blister worms decreases as the summer progresses and new recruits settle on oysters. They also found that the proportion of oysters with at least one worm with coelomic eggs, egg clusters in a burrow, or egg clusters with larvae was highest in June and decreased with each subsequent month. Similarly, the proportion of blister worms either with coelomic eggs or with egg clusters in their burrow peaked in July and dramatically declined by September.

The timing of our research was based on this information. If oysters could be treated during the early post-settlement stages of the worm's life cycle (e.g., from June to October) before the worm had a chance to create a deep, protective burrow, we predicted that the treatments would be more effective than if applied once the adult worms had already become established. Our intent was to disrupt worm settlement using an environmentally friendly treatment, and we focused on methods that would fit within an oyster farm's normal production cycle. A related aspect of the research was to document whether the abundance of larvae was correlated with the appearance of new burrows in the oysters. Our reasoning was that if we identify discrete periods of larval abundance and settlement, then further refinements in application and timing of treatments can be designed to make them more effective.

The specific objectives of our research were to 1) test whether periodic air drying of oysters reduces settlement by blister worms and appearance of new burrows, 2) determine whether the duration of air drying of the oyster hosts impacted worm settlement, and 3) examine whether washing of oysters in addition to air drying them results in further reductions or elimination of newly settled worms.

3.2. Methods

Our research on treatments for controlling blister worm was conducted at the Bagaduce River Oyster Company (BROC) in Brooksville, Maine (Fig. 3.7). This farm frequently experiences problems with blister worm. The Bagaduce River receives little freshwater input and experiences strong tidal surges, resulting in a tidally dominated estuary with relatively high salinity. The water flow is restricted at the Route 175 bridge creating a reversing tidal falls and resulting in water temperatures and levels of productivity that are higher at the farm upriver of the bridge than they are downriver in the adjoining bay. The farm grows oysters using surface culture with oysters held inside floating bags. Oysters grow very quickly at the BROC, with some reaching a shell length

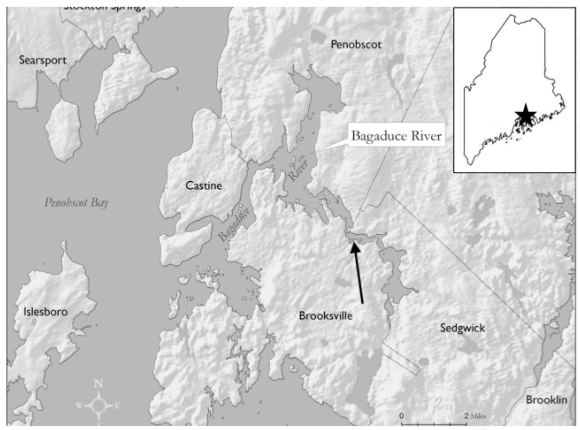

Figure 3.7. Location of the Study Site. The BROC provided access to their site located just upriver of the Maine Route 175 bridge over the Bagaduce River to Brooksville.

of 4 inches within one growing season, although oysters at other locations in Maine often take 2 years to reach market size of 2.5 inches.

In our research, oysters were deployed in one of five treatments: controls (Con), air dried for 4 h every 2 weeks (AD4), air dried for 24 h every 2 weeks (AD24), air dried for 4 h and washed every 2 weeks (AD4W), and air dried for 24 h and washed every 2 weeks (AD24W). On May 27, 2014, oysters with an average shell length of 35 mm were stocked in industry standard ADPI plastic mesh bags at an initial density of 250 per bag. Each bag measured approximately 84 cm x 46 cm x 13 cm. Two control bags were deployed on the surface in the manner typically employed at the BROC. These bags were rotated periodically to reduce fouling, but otherwise the oysters were submerged throughout the experiment. The remaining 16 bags were distributed among four Oyster Ranch cages. These cages measure approximately 104 cm x 104 cm, and each housed 4 bags of oysters. The bags in each cage received one of the experimental treatments. Each bag was tagged for unique identification and to facilitate repeated sampling. The bags were haphazardly assigned to positions within the cages. Washing of oysters, where appropriate, was achieved by “sudsing,” in which the bag of oysters was lifted out of the water, plunged back into the water, and lifted out again, repeating this process four or five times. “Sudsing” dulls the sharp edges of the oyster shells, reduces fouling, and breaks oysters apart if they have started to attach to each other and form doubles.

We visited the BROC site approximately biweekly from May 27, 2014 through November 8, 2014, during the time when the blister worms were reproductive. At each visit, we haphazardly sampled five oysters from each of the oyster bags and brought them back to the University of Maine at Orono. Oysters were shucked, meats removed, and the shells dried. After drying, the shells were backlit with a microscope light, allowing us to view the size and distribution of established adult burrows as well as any new burrows (see Fig. 3.6). We recorded the presence of adult burrows (from previous seasons) and new burrows (from the same summer season in which the oysters were sampled). To prevent overcrowding due to rapid growth, oyster density in each bag was reduced periodically during the experiment. This was accomplished by removing about half of the oysters in each of the bags before replacing them in their respective cages. Oysters that were removed were transferred into other bags on the farm and were no longer part of the experiment.

Each time we visited the study site, we took two plankton tows, one on either side of the oyster farm. Larval polychaetes collected in the plankton tows were counted, photographed, and measured. There are several species of polychaete that have larvae in the plankton at the same time as *P. websteri*, and distinguishing between the species microscopically is difficult. Additional work during the summer and fall of 2014 focused on the development of a polymerase chain reaction (PCR) assay to confirm the identity of the Spionid polychaete larvae discovered in the plankton at the BROC.

We calculated the mean number of burrows in each sampled oyster at each time point, as well as the cumulative number of burrows among all sampled oysters in each treatment over the whole season. A one-way analysis of variance (ANOVA) with treatment as the main factor was used to evaluate whether there was a significant difference in the mean number of cumulative burrows among treatments. Significance among individual means was determined by pair-wise comparison with a Bonferroni correction for multiple comparisons that kept the experiment-wide $P < 0.05$. Finally, we examined whether there were differences in the frequency of oysters with new burrows in each of the treatments. Significance of any differences in frequency was assessed by a chi-square test of independence: $p < 0.05$.

3.3. Results

The experimental treatments used in this study had a measurable impact on the establishment of new blister worm burrows in eastern oysters. We observed substantial variation in the mean number of new burrows per oyster among sampled oysters, both among treatments and over time (Fig. 3.8). There were few new burrows established

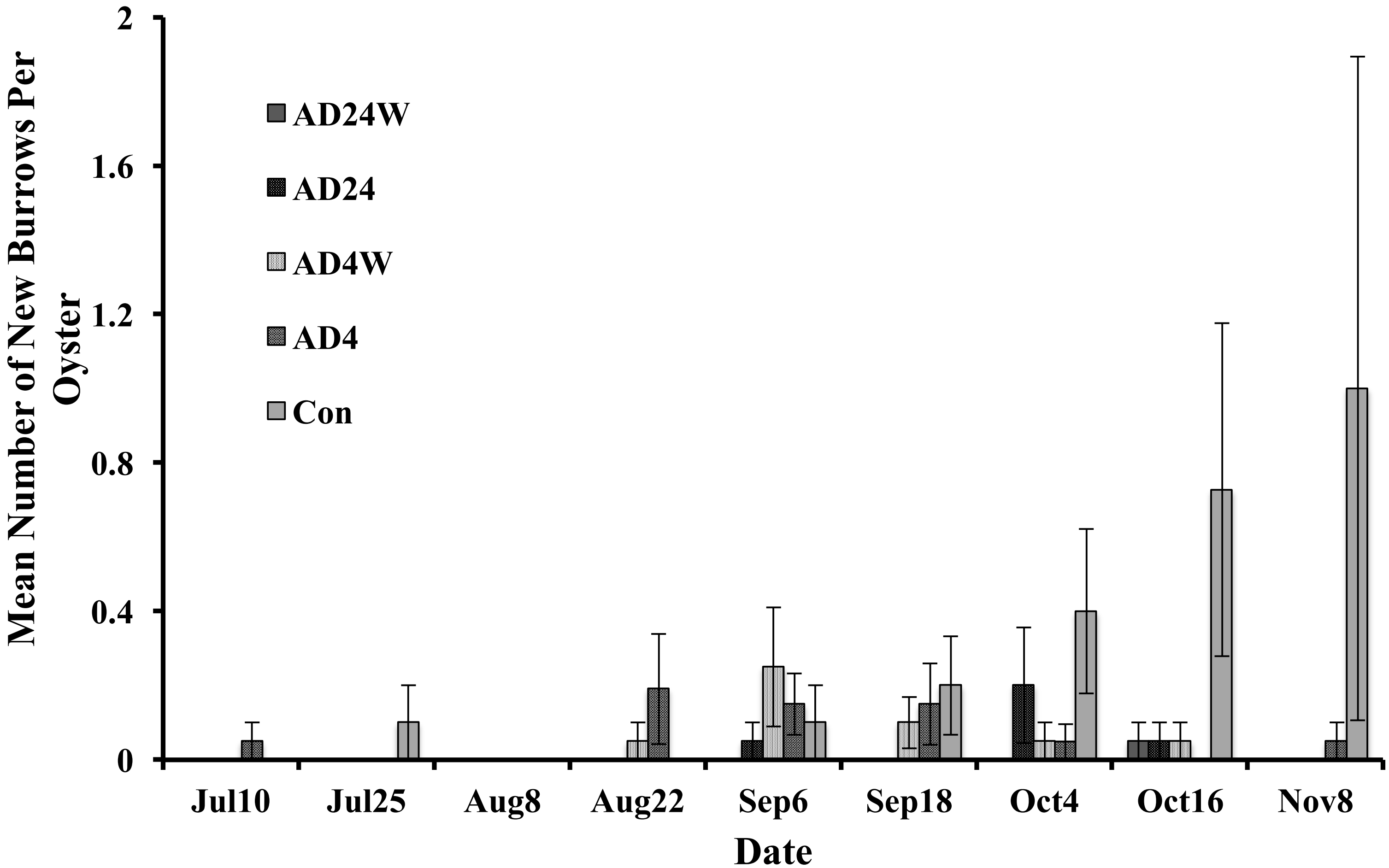

Figure 3.8. Mean Number of New Burrows Per Oyster. Mean number of new burrows per oyster for oysters sampled in each treatment at each time point. Con = control treatments, AD4 = air dried for 4 h without washing, AD4W = air dried for 4 h and washed, AD24 = air dried for 24 h with no washing, and AD24W = air dried for 24 h and washed. Error bars indicate mean ± standard error.

during July and August, but by September 6, new burrows were observed in all treatment groups. More importantly, by November there were 10-fold more burrows in control treatments as compared to the oysters in the AD4 group. The position of the bags in each Oyster Ranch cage had no effect on the number of new burrows per oyster (data not shown).

The same data were used to estimate the cumulative number of new worms per oyster over the whole season (Fig. 3.9). A one-way analysis of variance indicates that there were significant differences in the mean cumulative number of worm burrows among oysters in the five treatments we applied (F ratio = 17.95, d.f. = 4,13, $p < 0.001$). The average oyster in the control bags was colonized by approximately 2.5 worms over

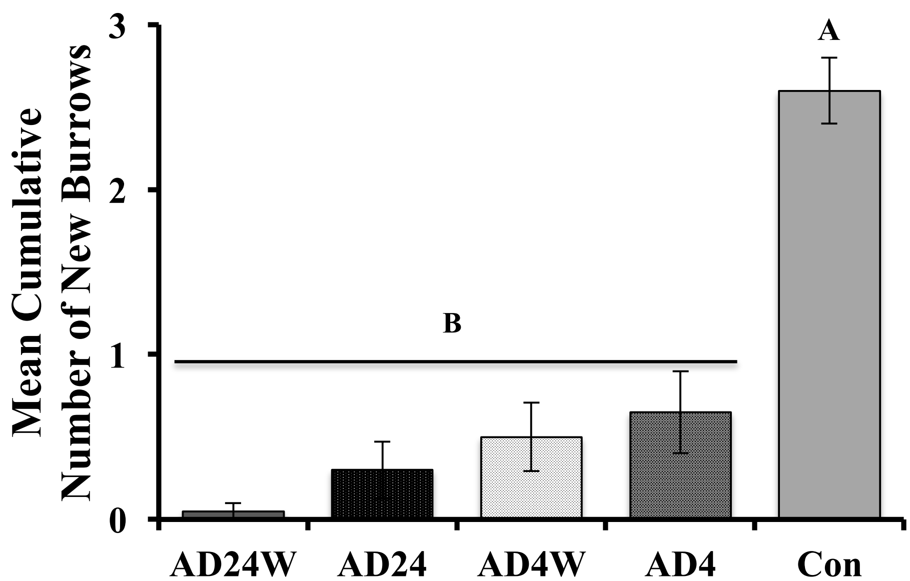

Figure 3.9. Mean Cumulative Number of New Burrows. The mean cumulative number of new burrows per oyster in controls dramatically exceeded the mean in all other treatments. Con = control treatments, AD4 = air dried for 4 h with no washing, AD4W = air dried for 4 h and washed, AD24 = air dried for 24 h with no washing, and AD24W = air dried for 24 h and washed. Letters indicate analysis of variance with Bonferroni correction for multiple pairwise comparisons: overall $P < 0.05$. Error bars indicate the mean ± one standard error.

the sampling period of July to November 2014. This "load" of new worms in the controls was over 4-fold higher than that seen in any of the drying and washing treatments, an increase that post-hoc pairwise-comparisons indicated was statistically significant. The cumulative number of burrows per oyster decreased in oysters exposed for 24 versus 4 h, while washing resulted in even further decreases in the number of blister worm burrows in the oysters. Thus, air-drying for 24 h with washing resulted in the greatest reduction in cumulative new burrows. However, pair-wise comparisons indicated that the differences among the drying and washing treatments were not statistically significant.

Treatments were considered effective if there was a reduction not only in the number of new burrows but also in the number of oysters impacted. To assess the latter, we examined the proportion of oysters in each treatment with blisters. The proportion of oysters that had at least one worm was significantly higher in the control bags (Fig. 3.10) than in any of the treatment groups. Additionally, there were three times as many oysters with blisters in the control bags as there were in the treatments. Air-drying for 24 h without washing resulted in the fewest oysters impacted by new worm burrows. Significantly more oysters in controls had new burrows compared with those in all other treatments, and those in the AD24W treatments had a significantly lower proportion of oysters impacted (chi-square, $p < 0.05$).

We observed distinct seasonality in larval abundance among the plankton tows taken between May and November 2014 (Fig. 3.11). The number of polychaete larvae present in the plankton decreased dramatically after May. The number of larvae per tow

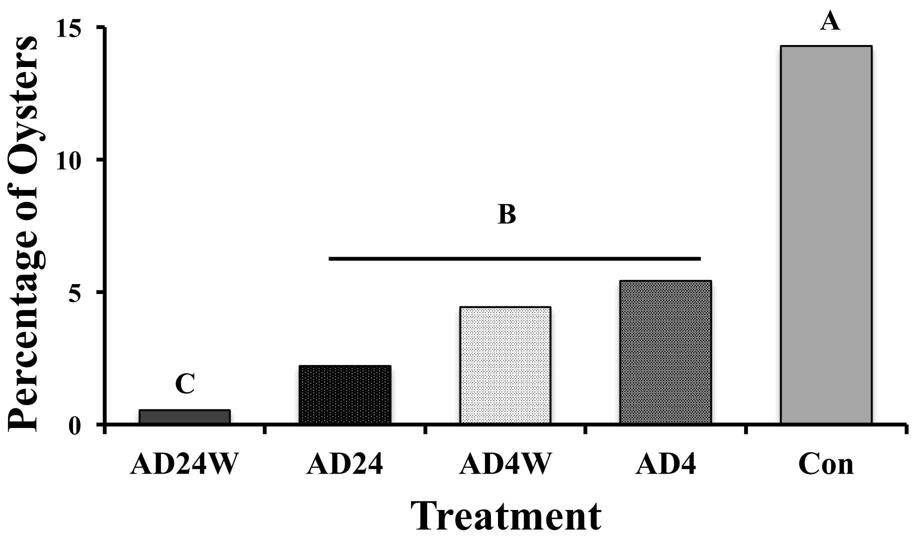

Figure 3.10. Proportion of Oysters with New Burrows. There were substantial differences in the proportion of oysters with new burrows among all oysters sampled in each group. Con = control treatments, AD4 = air dried for 4 h with no washing, AD4W = air dried for 4 h and washed, AD24 = air dried for 24 h with no washing, and AD24W = air dried for 24 h and washed. Letters indicate groups are significantly different as determined by a chi-square test of independence; $p < 0.05$.

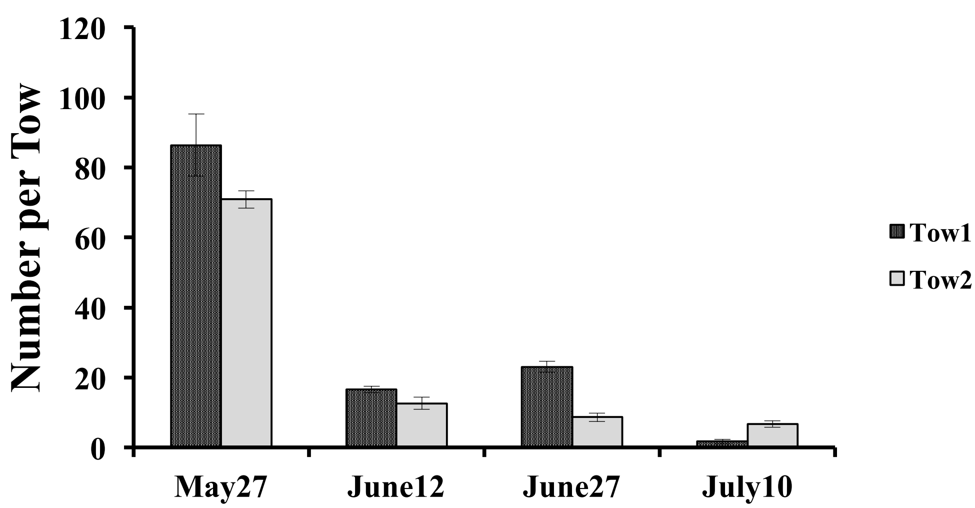

Figure 3.11. Relative Number of Polychaete Larvae per Tow. Relative number of Polydora-like polychaete larvae collected in each plankton tow from May 27 through July 10, 2014. Only a portion of the plankton tow was sampled in each case. Number of larvae dropped 8-fold by June, then well below 10 larvae per tow, and stayed that way for the remainder of the year – so August, September, October, and November are not included in this graph.

dropped 8-fold by June, to well below 10 larvae per tow, and remained low through tows taken in August, September, October, and November (data not shown).

Larval size distribution also varied considerably over the course of the summer (Fig. 3.12). From May 27 to June 12, the average larval size doubled. On May 27, the majority of the larvae collected were 0.2 mm in size, and on June 12, the majority of the larvae collected were 0.4 mm in size. By June 27, average larval size decreased to 0.2 mm. There were similar numbers of larvae at the end of June, suggesting there was a new cohort of larvae. However, we didn't recover enough larvae to continue the size frequency analysis after that point in the season.

3.4. Discussion

The treatments used in this experiment were successful at reducing the settlement of blister worm on eastern oysters at the BROC in 2014. Our findings are consistent with the view of Littlewood *et al.* (1992), as the number of new blister worm burrows appears to have been significantly reduced by periods of air-drying. We also found that the number of new burrows was further decreased by washing. Drying the oysters for 4 h appeared to be somewhat effective, and we saw incremental reductions in blister worm burrows when oysters were washed in addition to being air dried, although these changes were not statistically significant. We did not include washing-only treatments, so it is impossible to separate the effects of washing from air-drying in our results. However, air-drying oysters for 24 h every 2 weeks appears to be effective with or without washing.

Over time, oysters in floating bags become covered with many types of sessile organisms, a condition known as "fouling." Walton and colleagues (2013) argue that off-

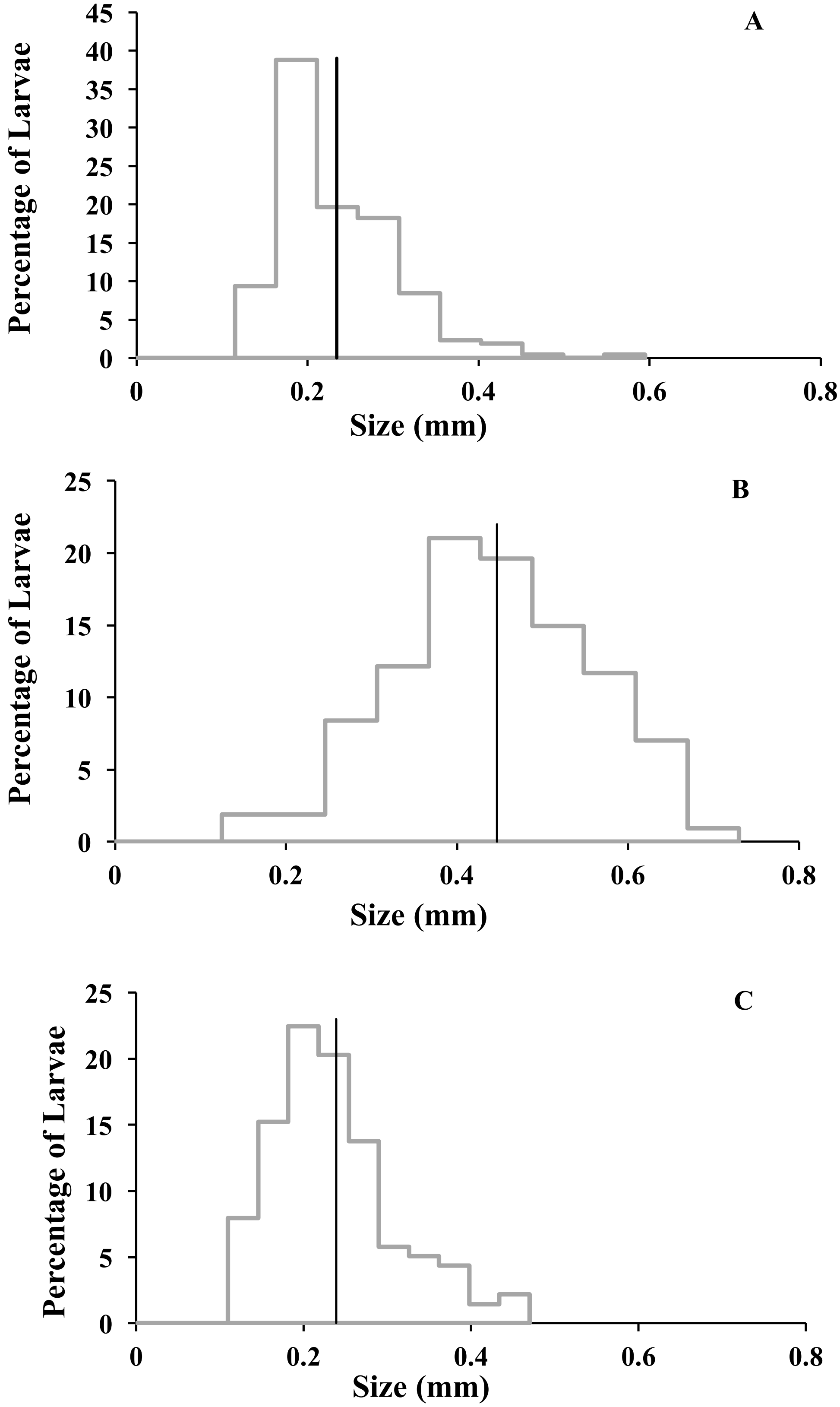

Figure 3.12. Size Distribution of Polychaete Larvae. The size distribution of polychaete larvae varied among tows taken on A) May 27, 2014; B) June 12, 2014; and C) June 27, 2014.

bottom oyster culture limits fouling, even in warm water locations such as the Gulf of Mexico. However, in a productive environment, fouling will rapidly occur on oyster cages and other equipment suspended at the surface. Miyazaki (2008) found that fouling in suspended oyster culture reduces flow around oysters and slows their growth. The reduced flow around oysters may also lead to the increased settlement of blister worm. The treatments we applied for controlling blister worm may also help with the control of other types of fouling organisms. The reduction in fouling organisms as a result of the treatments used in this experiment might not only reduce blister worm settlement but can reduce overall fouling and facilitate faster growth of the oysters.

Our sample size was very small in the 2014 experiment, and we also had concerns about pseudoreplication. There may have been cage-specific effects on the bags that were included in each cage; a robust experimental design would include multiple cages receiving each treatment. However, our experimental design was constrained by the number of cages available, the logistics of sampling and analyzing (90 oysters per sampling trip), and the space provided by the farm. Future research should include additional replication, including conducting the research at additional sites as well as measuring the effect of treatments on oyster growth and survival.

Variation in humidity, winds, and temperature might change the effectiveness of the treatments we applied. The surface of each oyster within a bag is likely to experience the greatest degree of drying on warm, windy days with low humidity. The drying and washing treatments were applied after we sampled oysters during each visit. We visited the study site when we could coordinate visits with farm personnel and when the weather permitted. Although we tried to choose days when it was not raining, we did not specifically pick the warmest, least humid, or driest days to visit the site. In future experiments, effort should be made to purposely select the best days for drying whether they coincide with sampling dates or not. The efficiency of drying is also likely impacted by the density of oysters within each bag. Under guidance from BROC personnel, we maintained oyster density so as to not overload each bag, but did not systematically control density to determine the impact of density on blister worm settlement. Applying the treatments used in this experiment on consistently warmer or drier days and further manipulation of oyster density within each bag might lead to even more pronounced decreases in blister worm infestation.

Our initial project design included pressure washing of oysters to remove mud and detritus from the surface in conjunction with air drying. However, the BROC did not have a pressure washer available during this project. Although we initially saw the missing pressure washer as a drawback, we applied “sudsing” of oysters as an alternative. Sudsing may not remove as much of the accumulated material on the surface of the oyster as pressure washing, but has the added advantage of tumbling the oysters and has a noticeable impact on the shape of the oysters and the formation of doubles. In addition, many growers may not have pressure washers, but all growers with floating cages should be able to “suds” their oysters.

Oysters are an intertidal species, and as such are likely to have adaptations that increase growth and survival in a habitat that includes repeated air exposure. Thus, we expected that oysters would tolerate some degree of exposure and that periodic drying would not impact survival in the different treatments that we applied. Anecdotally, we found only a few dead oysters among all of the treatments, but we did not explicitly quantify the treatment-specific variation in survival. Future experiments should quantify not only differences in worm settlement, but also the growth and survival of the oysters associated with each of the various treatments, since oyster growth and survival are critical to productivity on a farm.

We sampled the plankton in tows taken adjacent to the farm site at the BROC each time we visited the site. Initially, we had hoped to use the key in Blake (1969) to identify *P. websteri* larvae; however, we found it difficult to microscopically identify polychaete larvae that might be *P. websteri*. A DNA-based assay was designed to differentiate between the larvae of *P. websteri* and *P. cornuta.* Although there were large numbers of *Polydora*-like larvae in the tows taken from May to July, the majority of the larvae recovered during this period were determined by the DNA assay to be *P. cornuta* (data not shown). By the time blister worm settlement increased in the oysters deployed in our experiment, the number of *Polydora*-like larvae in the plankton had decreased substantially. Thus, there was no obvious correlation between the abundance of larvae in our plankton tows and blister worm settlement. We would have expected an increase in planktonic larvae during September and October to supply the larvae that settled on the oysters in the experiment. Our observations suggest that we may have been taking plankton tows in the wrong location to collect *P. websteri* larvae. On the other hand, a heavy infestation of blister worm is considered to be about 10 burrows or more per oyster. The cumulative number of burrows per oyster was only about 2.5 in this project, suggesting that blister worm settlement was light during the period from June to November 2014. Thus, perhaps the abundance of *P. websteri* larvae was quite low during 2014. Future research should examine larval abundance and oysters from additional oyster farms in subsequent years to see whether these treatments are as effective at other sites as they were at the BROC, and whether the same treatment differences occur using these treatments in a heavy infestation year.

We hypothesized that applying air-drying and washing treatments would reduce the settlement of larval blister worm and the establishment of new blister worm burrows in eastern oysters, and be more effective than treating already established oyster worm burrows. While it may not be possible to “break the cycle” of infestation and completely rid farms of *P. websteri*, the treatments employed in this experiment show promise in greatly reducing blister worm load in surface cultured oysters. Farmers we have spoken with are showing interest in applying the types of treatments we used at even shorter intervals, such as once per week. More frequent application may be even more effective in inhibiting worm settlement. The treatments employed in this experiment represent methods that can be included in the normal production cycle and will not result in increased labor or lost production time. These treatments do not introduce any chemicals into the oyster or the ecosystem and do not include extreme temperature swings that could stress the oysters. If similar results are realized in subsequent years and at other locations, the research will benefit growers throughout the Northeast.

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