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# Aquaculturists' Perceptions of Integrated Multi-Trophic Aquaculture (IMTA)

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# AQUACULTURISTS' PERCEPTIONS OF INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA)

BY

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**ABSTRACT**

Integrated Multi-Trophic Aquaculture (IMTA) has been proposed as a potential strategy to reduce negative impacts of traditional monoculture and improve the domestic seafood trade market in the US. Views from the aquaculture industry on incentives for IMTA adoption and continuation are crucial for understanding the likelihood of IMTA reaching a commercial scale; however, studies on aquaculturists' perceptions of IMTA are limited.

The objectives of this study are: 1) to explore different methods of IMTA being used in the US by aquaculturists; 2) to determine how US aquaculturists' perceptions of IMTA affect the adoption and continuation of IMTA; and 3) to identify perceived economic, environmental, and social considerations that mediate commercialization of IMTA in the US. This qualitative study used semi-structured interviews to explore perceptions of eight US aquaculturists in Maine, Connecticut, and Washington state who have been introduced to and involved in IMTA pilot projects or research. All of the interviews were coded using NVivo 10 qualitative analysis software to identify and organize key themes in the data.

Respondents identified perceived economic benefits as the major driving force for their initial adoption of IMTA; however, based on the interviews in this study, IMTA did not offer adequate financial returns for the majority of aquaculturists to continue using the method. Only two aquaculturists out of eight continued (or plan to continue) using IMTA after the initial trial period. In addition, respondents identified more economic considerations than environmental or social considerations. Product diversification was mentioned by the greatest number of respondents, and was

considered a very promising aspect of IMTA. Furthermore, findings indicate that the use of IMTA as a marketing strategy to reach not only more, but also higher paying, customers might not be effective because there is no policy on the distinct requirements necessary to identify an IMTA facility. Findings from this study can be used to inform efforts to more effectively engage aquaculturists in IMTA.

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# INTRODUCTION

## 1.1 Significance of study

In 1999, the Department of Commerce (henceforth DOC) developed an aquaculture policy with the goal of raising the value of domestic aquaculture from a $900 million industry to $5 billion by 2025 (NMFS 1999). A major objective expressed in the policy was the reduction of the then $6 billion seafood trade deficit, which is expected to increase the number of jobs, enhance depleted wild fish stocks, and increase seafood exports to $2.5 billion (NMFS 1999). Yet, twelve years later, the US seafood trade deficit had increased to $11.2 billion, and in 2011 the US was importing about 91% of its seafood (by value)[1], half of which was from foreign aquaculture sources (National Ocean Council 2013; Kite-Powell et al 2013).

Every fall, NOAA puts out a report on fisheries statistics titled, "Fisheries of the United States". This report describes the recreational catch and commercial fisheries landings and values in the US (among other things), and includes the calculated percentage of imported/exported seafood (National Marine Fisheries Service 2015). In 2014 and 2015, the US was the second largest single market for fish imports in the

[1] It is important to note that this value is not completely accurate because it does not take into consideration the products that are exported by the US to other counties for processing and then imported back into the country (FAO 2016). However, the seafood demand in the US is increasing, and the nation is importing a substantially higher amount of seafood then it is exporting. Overall, this means that the US is almost entirely dependent on fishery imports from other countries, and since roughly half of the world seafood production comes from aquaculture, the US is highly dependent on aquaculture as well.

world (FAO 2016). The report also identifies the US as the third largest marine capture producer (out of the top 25), but the 17th (of 25) largest producer of farmed species in 2014. Out of the top 10 exporters and importers of fish and fishery products, the US is the 5th largest exporter ($6.14 billion) and *the* largest importer by far ($20.3 billion). In addition, the US' calculated APR (average annual percentage growth rate for 2004-2014) for exports and imports is 4.8% and 5.4% respectively, meaning that the US imports are not only greater than exports, but that the rate of growth for imports is rising faster than exports as well. Globally, however, the production of marine fisheries have been in decline since 1996, while aquaculture has been increasing substantially during that time.[2] In order to become a more prominent competitor in the world seafood market and reverse the US seafood trade deficit, the DOC continues to promote an increase in aquaculture while maintaining the sustainability principles reaffirmed by NOAA in its 2011 Aquaculture Policy (NOAA 2011).

Traditional monoculture aquaculture has been criticized for negatively impacting water quality, having high risks associated with growing one species, and increasing concentrations of pests and disease, ultimately leading to a negative public perception of the industry (PEW Ocean Commission 2003). Integrated Multi-Trophic Aquaculture (henceforth IMTA) has been proposed as one potential strategy to reduce negative impacts of traditional monoculture, and increase the domestic seafood trade market in the US, and has gained the interest of some US aquaculturists and scientists (Thomas 2010).

[2] See footnote 1.

While IMTA has great potential as an ecosystem approach to aquaculture, and advances the United States' goal of achieving sustainable seafood resources, commercial development has been slow; as of 2010, only pilot studies of IMTA were present in the US (Thomas 2010). The cause of the slow development in the US as well as in other countries (Chile, South Africa, Spain, Portugal, France, Norway, Sweden, Finland, and the United Kingdom) is not well defined, but some suggest it may be attributed to lack of funding, lack of financial incentives, an undiversified market for cultured organisms, and difficulty of educating the public and regulators about the complex topic (Thomas, 2010; Soto 2009; Alexander et al 2015).

If IMTA can provide a feasible alternative to the perceived disruptive monoculture methods, understanding how to better promote its use is needed. Specifically in the US, the need for industry acceptance of IMTA, and the amount of effort the aquaculture industry is willing to put into developing it, are critical factors affecting the success of this method (Thomas 2010). Studies on the perceptions aquaculturists have about IMTA are limited, yet, industry input is crucial to understanding the likelihood of IMTA reaching a commercial scale.

This study explores perceptions of US aquaculturists who have been introduced to, and been involved with, IMTA pilot projects or research. Data gathered will help to fill gaps in knowledge about potential benefits and challenges to commercialization of IMTA in the US, stemming specifically from industry level adoption, followed by continuation or abandonment. The objectives of this study are: 1) to explore different methods of IMTA being used in the US by aquaculturists; 2) to determine how aquaculturists' perceptions of IMTA affect the adoption and continuation of IMTA in the US; 3) to identify perceived economic, environmental, and social considerations that may benefit or limit the commercialization of IMTA in the US according to aquaculturists currently or previously involved in IMTA pilot projects and research.

# CHAPTER 2

# BACKGROUND

## 2.1 Aquaculture in the US

Aquaculture in the United States began in the early 1800s as a method to improve freshwater finfish stocks (Parker 1989). Aquaculture, also known as fish or shellfish farming, is described by the National Oceanic and Atmospheric Association (NOAA) as the process of breeding, harvesting, and rearing freshwater or marine aquatic animal or plant species for consumption or ecological restorative purposes. According to the National Aquaculture Sector Overview (NASO) of the Food and Agriculture Organization of the United Nations (FAO), the majority of aquaculture methodologies in the US were adopted from European techniques where aquaculture had already been practiced for centuries (Olin 2011). At the time of its adoption, species like catfish, carp, trout and other popular sportfish were already in decline in the US because of overfishing and habitat alteration (Parker 1989). Over time, federal and state agencies like the United States Commission of Fish and Fisheries (created in 1871) were developed to help restore and maintain fish as a resource. Although initially focused on improving and restocking freshwater fisheries like trout and carp, aquaculture in the US has grown to include a wide variety of species ranging from finfish to crustaceans, mollusks, and in more recent years aquatic plant species (United States National Agricultural Statistics Service 2013).

Currently, the United States produces around 18 major species through aquaculture, and in 2013 the industry was responsible for $1.38 billion in revenue (freshwater and marine combined) (National Marine Fisheries Service 2015). As the US and world populations continue to increase, some commercially important species remain overfished (NOAA 2016). Aquaculture has become a necessary addition to wild harvest fisheries, and has been vital in taking pressure off wild fish stocks, while still meeting an increasing demand for seafood (Moffitt 2014). While wild harvest fisheries have begun to level off, the aquaculture industry continues to grow on both a world scale and throughout the US, and will play an increasingly important role in supporting capture fisheries in the coming years (National Marine Fisheries Service 2015, Moffitt 2014).

Although the US aquaculture industry is growing, the US still imports ~91% of its seafood; half of which is presumed to be from international aquaculture facilities (Kite-Powell et al. 2013). In the US, freshwater aquaculture has historically been the major aquaculture producer with marine aquaculture making up ~37% of the total aquaculture production value (miscellaneous species omitted) (breakdown of marine aquaculture species: ~70% marine mollusks (clams, mussels, and oysters), ~4% crustaceans (shrimp), ~26% finfish (salmon)) (Moffitt 2014). In recent years, however, the growth in freshwater aquaculture has been relatively stagnant and experts anticipate that any new growth in the aquaculture industry will primarily come from raising marine finfish species (Marine Aquaculture Task Force 2007).

Aquaculture, like many agricultural practices, is typically set up as a monoculture system meaning only one species is grown in a confined area. Similar to agriculture, intensively growing a single species at one time can have negative effects on the surrounding environment, overall product quality, economic value, and societal support of the industry. Finfish and crustacean (shrimp) aquaculture have been especially affected by this because of their requirement for a much higher initial energy input. At a large scale, these industries have been shown to create environmental damage including, but not limited to: biological pollution from escaped fish (which compete and interbreed with wild stocks), increased spread of disease and parasites, use of large quantities of wild-caught fish used in feed ingredients, organic pollution and eutrophication brought about from nutrient loading caused by discharge of fish wastes and uneaten feed, chemical pollution including antibiotics and pesticides (which can be discharged into the water column and could cause harm to non-targeted species), and habitat modification depending on the location or style of aquaculture (accidental entanglement, or intentional harassment) (Figure 1) (Goldburg 2001; Naylor et al. 2003, PEW Ocean Commission 2003). The extensive damage from some of these farms (both domestically and abroad) has led to public and regulator opposition to intensive aquaculture (Center for Food and Safety 2016). A major concern to those who live near the aquaculture sites is the potential for reduced water quality and, over time, a negative attitude toward fish farming and aquaculture in general has developed (Knapp and Rubino 2016).

Over the years, the aquaculture industry has worked to address these limitations. Automated feeding and video monitoring systems have helped reduce excess feed entering the environment, and increased system efficiency. In addition, other organisms that exist at lower trophic levels, like shellfish (throughout this thesis the term ‘shellfish’ will refer to mollusk species only, and in the case of lobster and shrimp, the term ‘crustacean’ will be used) and seaweeds, do not require added inputs like feed or antibiotics, and therefore, pose less of a problem in monoculture settings. Finally, alternative aquaculture methods like offshore aquaculture and IMTA are slowly achieving greater industry interest, showing that aquaculture may be a sustainable alternative to continued overfishing of wild stocks, or a supplement to sustainably-managed ones.

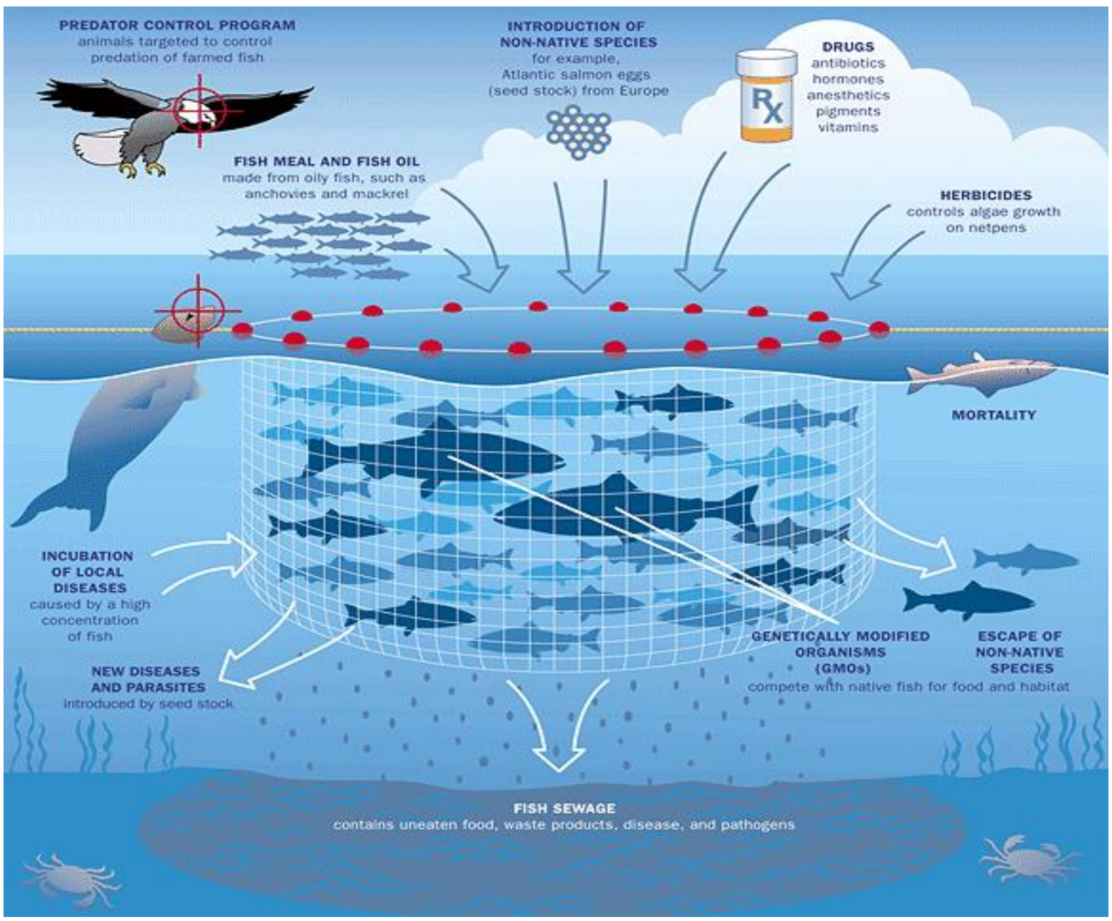


**Figure 1. Visual depicting some of the environmental risks of marine aquaculture. Illustration by John Michael Yanson. Many of these risks apply to freshwater aquaculture, and other cultured species (PEW Ocean Commission, 2003)**

## 2.2 Integrated Multi-Trophic Aquaculture

The term 'Integrated Multi-Trophic Aquaculture' (IMTA) was coined in 2004 during an aquaculture workshop in New Brunswick, Canada by Jack Taylor (Fisheries and Oceans Canada) and Dr. Thierry Chopin (University of New Brunswick) (Chopin 2013). IMTA utilizes nitrogen sequestering species, like shellfish and/or seaweeds, to take up excess particulate and dissolved wastes expelled by finfish (or shrimp) in an aquaculture setting. This method attempts to replicate a natural ecosystem where the energy output of one trophic level is transferred to the next, lower level. In doing so, waste previously deposited in the water as lost profit can be captured and transformed into another sellable product.

While the actual term is less than 20 years old, in countries like China where aquaculture has a much longer history, the concept of IMTA has been around for millennia, and is closely modeled after an ancient technique known as polyculture. A common example of polyculture is the practice of culturing multiple species of carp together on one farm. This process allows farmers to take advantage of the different niches carp are adapted to (Parker 1989). These integrated ecosystems often included an agriculture aspect as well like the ancient mulberry dike-polyculture systems used in South and Southeast Asia described by Ruddle and colleagues (1983). Polyculture is considered a form of integrated aquaculture, but does not *require* that more than one trophic level be used (although they often are). The term IMTA, is more specific requiring two or more species at different trophic levels to be grown simultaneously in close proximity to each other. This system exemplifies a natural ecosystem function, and allows the farmer to get more use out of the same amount of food and energy put into a monoculture system. IMTA includes a wide variety of techniques, species, locations, and number of incorporated trophic levels, but has a final goal to "ecologically engineer aquaculture systems for increased environmental sustainability; economic stability through improved output, lower costs, product diversification, risk reduction and job creation; and societal acceptability" (Chopin 2013, p. 16) (Figure 2).

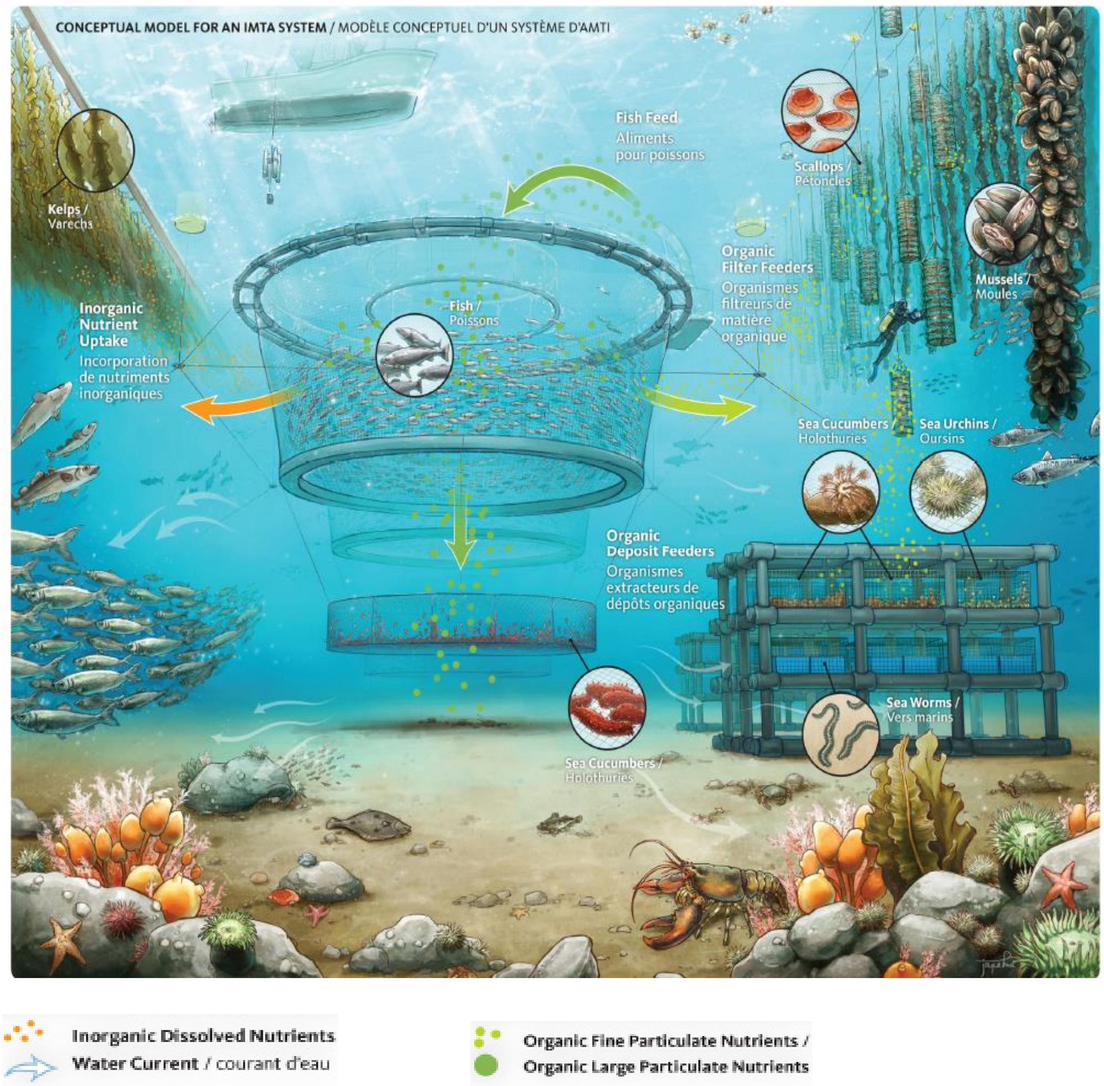


**Figure 2. Visual depiction of IMTA showing potential species grown together at the different trophic levels. Illustration by Joyce Hui (Aquaculture Science Branch, 2013)**

Although IMTA is not species-specific, many definitions typically identify finfish as the highest trophic level organism, or strictly state that "IMTA is the culturing of fed finfish in combination with other species that filter waste particulates and dissolved nutrients, thereby reducing organic discharge and expanding the economic base of a farming operation” (Price et al 2015, p.165). The focus of IMTA has been on IMTA’s potential ability to improve water quality surrounding finfish aquaculture.

Typically, shellfish are placed in the middle trophic level of a full IMTA system. However, arrangements placing shellfish at the highest trophic level are being developed in areas without finfish aquaculture industries. For example, in 2012, at Woods Hole Marine Biological Laboratory, *Gracilaria tikvahiae* and Eastern oysters (*Crassostrea virginica*) were grown together in a bio-extraction project (Gallagher 2012), and in 2013 seaweed and ribbed mussels (*Geukensia demissa*) were grown together in an attempt to improve the water quality in Long Island Sound (Tedesco 2013). Growing shellfish and seaweed together is less popular worldwide than a complete IMTA system because of the reduced incentive to improve the conditions brought about by the aquaculture system itself. Research has shown, however, that these lower trophic IMTA systems can still have a positive impact on the water quality, especially near commercial facilities, and can still act as an additional revenue for the facility (Soto 2009).

The initial use of shellfish in IMTA systems in the US was to treat wastewater from intensive shrimp aquaculture (Soto 2009). Today, there are a number of different shellfish species used in IMTA. Species are selected because of their ecosystem function, habitat appropriateness, established husbandry practices, economic value, high potential for development, biomitigation ability, and consumer acceptance (Soto, 2009). There have been a few instances in the US where shellfish were used in IMTA systems as a risk mitigation factor rather than for nutrient capture and retention. In these cases, the shellfish species were included as either the top trophic species (ex. the Japanese Northern (Ezo) abalone, *Haliotis discus hannai*), or grown with another species (lobster) (ex. the Eastern Oyster, *Crassostrea virginica*) (Soto, 2009).

In 2009, the Fisheries and Aquaculture Department of the FAO put together a report on the current global state of IMTA. The study included marine (brackish and saline) land-based, coastal, and offshore systems, and were separated based on the climatic zones (temperate, tropical, and Mediterranean Sea) (Soto 2009). Within the temperate environment, the incorporated study by Barrington, Chopin, and Robinson (2009) identified 8 countries including the US that had used IMTA near or at commercial scale (Canada, Chile, China, Ireland, South Africa, the United Kingdom of Great Britain and Northern Ireland), and three with ongoing research (France, Portugal, and Spain). In the tropics, the included study by Troell (2009) indicated that most IMTA operations were located in ponds, and that only 16% (of the 100 peer reviewed articles) focused on integration of species in open waters. In the tropical climate region, there were 19 countries including the US that had used a form if integrated marine aquaculture, six of which had used open water IMTA systems (Vietnam, Philippines, China, Solomon Islands, Micronesia, and Venezuela). In addition, China, Japan, and South Korea were identified as counties having a long history with coastal marine IMTA where finfish, shellfish and seaweed species were used (Troell 2009). Finally, the Mediterranean Sea range included five countries

(Greece, Turkey, Israel, Croatia, and Italy) that had used IMTA systems at experimental or commercial scales (Angel and Freeman 2009).

These countries, among others have been working in different ways to develop and implement different levels of IMTA at commercial scale. For example, the National Sciences and Engineering Research Council of Canada (NSERC) provides funding to the Canadian IMTA Network (CIMTAN) which supports combined efforts from scientists, universities, industry, and federal locations from 6 provinces in Canada. This network works to develop best practices for IMTA use in order to maximize its ecological as well as its economic benefits. A similar program in Scotland, launched in 2012, called Increasing Industrial Resource Efficiency in European Mariculture (IDREEM) and funded by the European Union's seventh framework (FP7) Program, works to support the use of IMTA in European Aquaculture by helping aquaculture business and research institutions come together to tackle constraints related to economic, environmental, technical, social, and regulatory issues surrounding IMTA.

## 2.3 Understanding Perceptions of IMTA

At the first IMTA conference in the US in 2010, scientific experts, researchers, and aquaculturists identified three main factors affecting aquaculture commercialization: concern about coastal zone use for food production rather than for other uses, lack of social acceptance/political viability, and the absent regulatory framework needed to allow aquaculture (including IMTA) to develop responsibly (Thomas 2010). IMTA has been identified as a strategy to improve public acceptance of aquaculture because of its potential environmental benefits. Although public perceptions of IMTA (and aquaculture in general) are considered important to the success of the industry, they are often not studied (Barrington et al 2010).

A strengths, weaknesses, opportunities, and threats (SWOT) analysis survey of participants at the 2010 conference highlighted participants' perceptions of ecological, economic, and social impacts (Figure 3). Many impacts were directly related to farmer capabilities and operational technology needed to conduct IMTA. The analysis showed that the environmental benefit or service provided by IMTA was considered a strength, while the overall lack of understanding of environmental impacts was identified as weakness. In terms of economic impacts, the ability for IMTA to establish a 'sustainable image' and therefore obtain public acceptance was considered a strength, while complexity (in marketing, operations, juveniles, business planning, and the regulatory sector) was seen as one of the largest weaknesses. Finally, when analyzing the social impact factors, stakeholders did not identify any major strengths, although some lesser ones were identified (Figure 1). The major weakness was considered the complexity of IMTA, however the study was not specific about the details of the complexity (Thomas 2010).

Outside of the US, there have been a few of studies investigating the acceptance of IMTA by stakeholders with previous knowledge and experience with IMTA (e.g. Alexander et al 2016; Perdikaris et al 2016). For example, a qualitative study in Europe highlighted twelve different stakeholder-perceived-benefits of IMTA from six different countries, and found that IMTA was seen as a viable way "to improve the negative image of the aquaculture production", and although concerns were brought

**Table 1. IMTA Ecological Impacts SWOT Analysis**

| STRENGTHS | WEAKNESSES |
|---|---|
| • nutrient recycling (especially in closed systems)<br>• reduced demand for feed from pelagic marine fisheries and terrestrial crops<br>• greater emphasis on quantifying ecological effects<br>• increased farm productivity<br>• increased farm crop diversity<br>• application to a variety of environments (e.g., land-based or marine-based), alleviating impacts on coastal zones when sited inland | • lack of thorough understanding of environmental impacts<br>• currently emphasizes only high value products and thus less likely to contribute to world food needs (except seaweeds)<br>• converts more resilient food webs to more vulnerable food chains<br>• shifts nutrients flows in the environment to reduce natural production |
| **OPPORTUNITIES** | **THREATS** |
| • more data-driven decision making in aquaculture development<br>• remediation of anthropogenic eutrophication<br>• if IMTA increases domestic production, decreased environmental costs (e.g., transportation) of imported seafoods<br>• aquaculture research platform<br>• potentially greater profitability compared to existing aquaculture systems<br>• produce products (such as seaweed-based biofuels) that would reduce environmental impacts of fossil fuels<br>• specialized markets for IMTA products<br>• grower collaboration | • larger scale applications may have greater environmental impact and thus less social license<br>• potentially lower profitability compared with existing aquaculture systems (in the short term)<br>• not enough public funding (i.e., political will) for developing a network of demonstration and research sites to examine the feasibility of IMTA |

**Table 2. IMTA Economic Impacts SWOT Analysis**

| STRENGTHS | WEAKNESSES |
|---|---|
| • efficiency: nutrient uses, coastal space<br>• marketing advantages<br>• new image: differentiated coastal aquaculture<br>• diversified products = risk production<br>• operational efficiencies: labor, operational rates, leasing<br>• ecosystem services revenue opportunities | • complexity: marketing, operations, juveniles, business planning<br>• risks: structural, disease, operations, seed supply<br>• site-specific criteria (because of multiple species): salinity, current, temperature<br>• greater capital costs for start-up<br>• regulatory complexity |
| **OPPORTUNITIES** | **THREATS** |
| • markets: pricing, raise high-value product, packaging, niche opportunities<br>• "sustainable" image<br>• ecosystem services, potential revenue<br>• development platform: new products, aquaculture innovations, feed, macroalgae, research<br>• use IMTA as launching platform for national aquaculture vision<br>• accelerated innovation potential<br>• adaptability (e.g., climate change)<br>• new partners | • social acceptance, public perception<br>• natural threats: disease, parasites, storms<br>• disappointment of expectations: failures could reflect badly on entire effort<br>• market threats: overproduction, price cycles<br>• competition from monoculture<br>• cheap imitation of IMTA<br>• greater regulatory requirements<br>• new competing users |

**Table 3. IMTA Social Impacts SWOT Analysis**

| STRENGTHS | WEAKNESSES |
|---|---|
| • strong brand/green business<br>• species diversification<br>• opportunities for business (niche)<br>• visual perception of aquaculture operations<br>• educational opportunities<br>• ecologically sound<br>• healthful food (protein, Omega-3)<br>• scalable operation<br>• young industry—new model<br>• commerce/jobs/living wages<br>• rewarding enterprise<br>• scientific discovery<br>• preserve working waterfront<br>• improve environmental condition<br>• provide ecosystem services<br>• year-round production, multiple species<br>• lease revenues<br>• good stewardship | • visual perception of aquaculture operations<br>• fear of unknown<br>• poor examples/failures could color overall perception<br>• young industry<br>• complexity<br>• conflict of use (e.g., water, space)<br>• lack of critical mass<br>• capital intensity-scale<br>• potential to downgrade monoculture<br>• maybe greater privatization of public resources<br>• economic viability<br>• greater wildlife impacts and public perception thereof |
| **OPPORTUNITIES** | **THREATS** |
| • social awareness<br>• local buying<br>• niches<br>• increase healthy food supply<br>• initiate partnerships<br>• education pathway<br>• optimize nutrient loads<br>• service industry jobs<br>• eco-food tourism<br>• regulatory design<br>• control environment (marketability)<br>• improve technology<br>• opportunity to culture new ecologically responsible species | • competition in market<br>• environmental degradation<br>• shoreline development<br>• user conflicts/space<br>• financing<br>• regulation or lack thereof<br>• negative response to the label, "farm-raised"<br>• uncontrolled messages (e.g., on the Internet)<br>• misinformation<br>• lack of marine spatial planning |

**Figure 3. SWOT analysis results from the 2010 IMTA workshop (Thomas 2010).**

up, most stakeholders felt that they "could be addressed by research studies, education, and changes to legislation" (Alexander et al 2016, pg. 105). In a study conducted in Greece, IMTA was unfamiliar to a large portion of the freshwater and marine farmers, and when farmers were asked their opinions on multi-trophic aquaculture, only ~30% of individuals stated that they had positive perceptions towards its utilization. The results of the study did not specify whether the lack of knowledge about the technology was the reason behind the low volume of positive perceptions (Perdikaris et al 2016).

Findings from these studies provide insights about IMTA, however, few studies specifically examine *aquaculturists'* perspectives on IMTA, and the few that do, do not differentiate what the farmers think from what other stakeholders think (e.g.,Thomas 2010; Alexander et al 2016), nor do they delve deeply into why aquaculturists have particular perceptions about IMTA (e.g., Perdikaris et al 2016).

## 2.4 Perceptions of the industry toward the adoption of IMTA methods

The value of understanding how industry perceptions of new ideas affect adoption rates is especially important to technology advancements like IMTA. The evaluation of an individual's willingness to adopt new technologies and resulting community support and continued implementation (i.e. diffusion of innovation (Rogers 1984)) have been studied in a variety of sectors. For example, Roger's model has been applied to agriculture, to better understand the transition and adoption to more environmentally-sound farming methods, like organic agriculture (Padel 2001). In the case of organic farming, it was suggested that understanding the rate of adoption of these methods was valuable to policy and regulation development (Padel 2001; Lapple and Rensburg 2011). Similar research on industry perceptions of IMTA would likely contribute to the development of strategies to increase the adoption, consideration, and improvement of the current system of implementation.

To better understand aquaculturists' perspectives of IMTA, this study addresses the following research questions:

1) What different species and methods of IMTA are being used by US aquaculturists?

2) How do aquaculturists' perceptions of IMTA affect the initial adoption and later continuation of IMTA?

3) What do the aquaculturists involved in IMTA pilot projects believe are the economic, environmental, and social factors that benefit and/or limit the commercialization of IMTA?

# CHAPTER 3

# METHODOLOGY

## 3.1 Data Collection

In-person and telephone semi-structured interviews were conducted with individuals in Maine, Connecticut, and Washington state who had experience with IMTA practices. Telephone interviews were only conducted when it was not possible to meet in-person with the respondent. Participation was limited to aquaculturists over the age of 18 who had previously used the IMTA method on their farms, or to aquaculturists who planned to use the IMTA method in the near future (within the year). It was not necessary for the participants to be utilizing IMTA at the time the interviews took place. The initial scope of this research was intended to reach aquaculturists in Maine who had participated in IMTA pilot projects; however, the scope was expanded to aquaculturists in other states in order to obtain a larger sample.

This research focuses on aquaculturists' views because industry support and willingness to utilize IMTA methods are critical for adoption of the method on aquaculture farms. These culturists are the primary drivers and decision makers when it comes to adopting new aquaculture methods. Therefore, evaluating industry support of IMTA is crucial to understanding the future of this method in the US. Finally, there are very few studies, if any, which have focused on aquaculturists' perceptions of IMTA, and this research attempts to help fill these research gaps.

Two sampling methods were used to identify potential interview respondents: purposive and snowball sampling. Purposive sampling is a process in which individuals are actively selected for a sample based on predetermined qualifying criteria (Guest 2013; Patton 2002; Robson 2011). A list of individuals who participated in IMTA pilot projects in Maine were obtained from a final report of a pilot study by Morse and Redmond (2014). Purposive sampling was chosen because of the study's small sample size, and has been useful for gaining insights into, and increasing the understanding of individuals' views, rather than generalizing to a population (Onwuegbuzie and Leech 2007). The second sampling method was the snowball, or chain referral sampling method. Snowball sampling is a method in which a researcher obtains additional respondents through contact information given by other respondents (Noy 2008; Guest 2013; Patton 2002). This method was used as an auxiliary means to obtain new contacts after the purposive sample was depleted (Noy 2008). IMTA participants exhibit a sampling difficulty known as low social visibility, or difficult to reach or 'hidden' populations (Biernacki and Waldorf 1981; Atkinson and Flint 2001). This low visibility stems from the limited number of individuals taking part in this method of aquaculture.

A total of 13 individuals were initially contacted via telephone, email, or both depending on available contact information using an IRB approved recruitment script explaining the purpose of the study, and asking for their voluntary participation (Appendix A). The use of phone and email techniques were used to potentially increase response rate from contacted individuals.

Eight interviews were conducted. Five were completed in person, and three by telephone. The interviews lasted between 20 minutes and 1 hour and included twelve main questions broken into three sections: farm demographics, project involvement, and perceptions of IMTA. (Appendix B).

3.2 Interview methods

In-person interviews were selected because they allow clarification of any confusion directly with the individual, and can be used to direct conversation more effectively by observing non-verbal responses like facial expressions or body language (Robson 2011). In addition, in-person interviews allow the interviewer to establish rapport with the respondent through eye contact allowing for a better personal connection (Guest 2013). Rapport was also established before the interview by returning the respondents emails and calls promptly, accommodating their scheduling needs, and maintaining an "open, friendly, responsive tone [in] all pre-interview interactions" (Guest 2013, pg. 145). In some cases, telephone interviews were conducted for locations that were either too far away, or for schedules that did not work for meeting in-person. Before conducting any interviews, pilot surveys were conducted to help identify any potentially confusing or leading questions.

Semi-structured interviews were used to allow for more specific detail, clarity, and flexibility during data collection. This flexibility included the use of follow-up questions for clarification or deeper investigation during the interview creating a more complete response. This was especially helpful during this research because of the complex and variable definition of IMTA. Flexibility also allowed me ask the prepared questions in varied order to prevent disrupting the natural flow of the conversation. Structured interviews were considered, however, this type of interview would not be able to easily address an individual's reasoning behind an answer.

## 3.3 Data analysis

Digital recordings were transcribed and a thematic analysis was conducted. Thematic analysis was chosen because of the flexibility it has in determining themes and prevalence (Braun and Clarke 2006). All of the interviews were coded using NVivo 10 qualitative analysis software to identify and organize key themes in the data. Coding is a process where meaningful labels are assigned to certain phrases, sentences, or paragraphs in each interview (DeCuir-Gunby et al 2011). This coding process can be used to "make connections between ideas and concepts", and can help support or contradict theories guiding the research being conducted (DeCuir-Gunby et al 2011, pg. 138). Structural coding, a question-based coding method, was used to begin the coding process by using the research questions, and interview protocol as an initial guide (Saldaña 2016). This was followed by the use of magnitude, or hierarchical coding, which utilizes sub-codes to organize themes into more distinct categories (Saldaña 2016). For example, 'economic considerations' were identified as a broad code based on the interview protocol, and positive economic and negative economic considerations were then sub-coded further into separate codes. Further thematic coding utilized themes identified during the SWOT process, the discourse during the interviews, and in the related literature.

# CHAPTER 4

# RESULTS

## 4.1 Characteristics of the aquaculture farmers, farms and IMTA projects

Eight individuals were interviewed from September to November 2016. All but one were owners or co-owners of an aquaculture facility. The other respondent was a researcher who was about to begin an IMTA facility growing abalone and sea cucumbers concurrently (in Washington). In the case of the abalone/sea cucumber project, the end goal was not commercialization (as for the other respondents), but restoration of declining abalone species due to overharvesting.

Over half of the respondents were located in Maine. One respondent was from Connecticut and two were from Washington state. All of the respondents were shellfish aquaculturists before attempting an IMTA project (five were mussel farmers, two were oyster farmers, and one was an abalone aquaculturist). The farms where respondents work range in age from 5-30 years old (with the exception of the abalone/sea cucumber project which is expected to begin within the year), and range in size from about 3 to 20 acres. All of the farms are seasonal (spring to early winter) and fluctuate in number of employees based on the time of year. The majority of the respondents used suspended mussel rafts to culture their product, however others used rack and bag systems, bottom trays, longlines, and tank systems.

The following species were grown (with varied success) on the farms while the various IMTA projects were underway: blue mussels (*Mytilus edulis*), oysters (unspecified), clams (unspecified), manila clams (*Venerupis philippinarum*), scallops (unspecified), kelp (unspecified), sugar kelp (*Saccharina latisima*), giant red sea cucumbers (*Parastichopus californicus*), abalone (unspecified), winged kelp (*Alaria escalanto*), horsetail kelp (*Laminaria digitata*), and *Gracilaria spp*. The majority of the IMTA projects were conducted with mussels and kelp.

Species were selected for all of the IMTA projects based on their geographic range. One respondent explained the rationale, "One of the reasons we chose sugar kelp was because it was growing there naturally. So, we thought that since it grew there naturally there might be a possibility that it would grow-out successfully." Species were also selected because they require similar conditions, as one farmer growing abalone and sea cucumbers stated:

> Both [are] cultured in a very similar way. So, as we were developing our programs we sort of realized that the same system in which we rear abalone would work really well for sea cucumbers with very little to no modification. Both of these species are native to this area, and cohabitate the same type of environment…They both like the same water temperatures, they both have fairly similar growth rates (both very slow growing). The similarities are pretty remarkable actually, which is really helpful when you are working with IMTA systems.

In one case, the sea cucumbers on a mussel farm were growing there naturally. Respondents growing seaweed explained that they tried using a variety of species by starting off with small quantities at the same time. In every case, only two trophic levels were grown concurrently, so none of the farms participated in what is considered by some to be a full IMTA system with finfish, shellfish and seaweed.

Of the eight respondents, only two stated that they plan to continue using IMTA methods on their farms in the future. Within the remaining six, one has not yet started the IMTA project, which is expected to run for only 6 months to 1 year due to financial reasons; three have stated they plan to continue growing only shellfish as they had before; and two have converted their facilities from the original shellfish species to seaweed species only.

Respondents were asked to define the term IMTA in their own words (Table 1). Only one respondent had not heard of the term before. Most of the individuals stated that IMTA was a method of aquaculture that utilized two or more species, and that growing the species together had a beneficial outcome. The identified outcome or end goal varied among respondents. One individual stated that the end goal is a harvestable product, while another focused on the benefits of using one species to reduce the waste created by the other. Most respondents acknowledged the importance of both economic and environmental benefits of IMTA. They tended to have an indifferent and in some cases negative attitude toward the term 'IMTA', but a positive attitude toward the method itself.

**Table 1. Aquaculturists' definitions of IMTA.**

| Aquaculturists' Definitions of IMTA |
|---|
| That's where you get beneficial effects of co-location of species. |
| A type of aquaculture system that uses at least two different species. And I think of each species as being a harvestable species. So you are co-culturing them in a way that either they are both interacting with each other, or one is interacting with another one, and both are harvested. |
| Growing multiple species together in one environment, that benefit each other with the goal of eliminating waste stream. |
| Two or more of the three categories of aquaculture: finfish, shellfish, and seaweeds grown together. |
| It is enhanced growth or profitability as a result of two species living together or being grown together. Everything in my world is profit. |
| Growing a number of species at different trophic levels in close proximity with some defined benefit. And I kind of throw in the defined benefit and leave the definition open in terms of what the benefit is. It could be as simple as a benefit of efficiency, in terms of use of equipment and time, and also of a dollar return in terms of making money. Or it could be a benefit where one species derives some benefit from being in the proximity of another species. Excess nutrients in the case of salmon farms that would be taken up by kelp as an example. |

A couple respondents stated that the term ‘IMTA’ is not good for marketing, and that they know other people who do not like the term. They believed that an expression used to describe this type of farming should not include the word ‘aquaculture’, which they felt has a negative connotation for many people. Respondents also felt the term should be more clear and easier to understand. Many respondents stated that they do not use any one term to describe IMTA, instead they just explain to others that they grow more than one organism at once. Of those that do not use the term ‘IMTA’, some were unsure of the proximity limits associated with the definition, meaning that they did not know how close the species had to be together to be considered IMTA. Respondents identified eight separate expressions they use or had heard of to describe IMTA (Table 2).

**Table 2. List of terms respondents identified to describe IMTA. More than one term was identified by some respondents.**

| Term to describe IMTA | Number of respondents that identified the term |
|---|---|
| IMTA | 5 |
| co-culture | 1 |
| polyculture | 2 |
| ocean farming | 1 |
| climate farming | 1 |
| 3D ocean farming | 2 |
| vertical farming | 1 |
| restorative farming | 1 |
| growing [species 1] and [species 2] | 2 |

4.2 Motivations to initiate IMTA

Respondents identified four distinct motivations for their decision to take part in an IMTA project (Table 3). The potential economic benefits that IMTA could bring to the aquaculturist was identified most often as a motivation for initial adoption.

**Table 3. Aquaculturists' motivations for attempting IMTA.**

| Motivations | Number of respondents |
|---|---|
| Inspiration from other aquaculturists | 4 |
| Reduction in maintenance effort | 1 |
| Potential economic benefits | 6 |
| Environmental sustainability | 2 |

Half of the individuals in this study stated that they had become interested in growing more than one species on their farm after hearing about someone else's experience with it. One stated that, "The people down there [at the farmers market] who are making cookies with it [kelp] and stuff out of it, is what inspired us to get into it [kelp farming]." Another respondent noticed that IMTA could help reduce the effort needed to maintain the farm, "A lot of other hatcheries in this area will put sea cucumbers in their broodstock tanks for instance…because they [sea cucumbers] tend to just keep things a lot cleaner, so you are reducing your maintenance level." One respondent with a background in marine biology stated that he "could see the potential for seaweed farming" after hearing about a current project, but also explained that it had been his plan when he started farming to expand to different trophic levels. The other half of the respondents decided to initiate IMTA projects because of their own personal interests.

Six of the respondents said that they wanted to develop seaweed as an aquaculture product because of its success in other countries and limited production in the US. One seaweed farmer explained the opportunity to grow seaweed in the US:

> The incentive to get into seaweed farming is that it is a global industry. It represents the largest volume by weight of aquaculture sector. So seaweeds represent about 40% of the weight, and it represents about $7 billion to the farmer, and it wasn't happening in the US, and we have great waters to do it. Here was an opportunity to come in with innovative products, get into farming, and start an industry here that didn't exist.

Other farmers echoed this idea, highlighting that seaweed farming had not been done much in the US, and that there was potential for increased profit from a new market. However, the perceived economic benefit of using IMTA was not the only incentive.

Two aquaculture farmers identified environmental sustainability as a motivation for initiating IMTA at their farms, and found its potential to improve water quality and reduce impacts from ocean acidification as additional incentives. One individual from the east coast even indicated that adopting these new IMTA methods was not a choice, but a requirement due to climate change:

> A main incentive was actually climate change, climate change requiring diversification and other crops that are more resilient and faster growing. I think fishermen and farmers on land are being pushed to grow and fish and catch different species because of climate change. And I will say that is the major primary pressure here that is coming on. And it's not environmental, it's actually an economic press on all of us that is forcing us to diversify. So that's the major message in a way. That's why this is different from "oh, let's just find some new things to sell"--we are actually being forced in this direction.

A few respondents did have some initial concerns about using IMTA on their farms. These concerns were mainly about the logistical feasibility of growing two species at the same time in one location (i.e. having enough space, potential for gear entanglement). Other concerns included the potential for disease transfer, the inability to sell new products (like kelp), and failure in general. Ultimately, none of these concerns prevented any of the individuals from attempting IMTA.

### 4.3 Perceptions of IMTA

When initially asked about the general challenges associated with IMTA as an open ended question, some respondents stated that there were none. Others identified challenges that are typical of aquaculture in general (biofouling, predation, equipment failure etc.), and two respondents stated challenges related to developing kelp aquaculture (unknown farming and packaging methods, and lack of a seaweed market). One stated that increased complexity was a major challenge in terms of trying to balance growing mussels and kelp at the same time.

During the interviews, respondents described specific challenges and benefits in terms of three categories: economic, environmental, and social. Note that interviews from only seven of the eight respondents were included in this part of the analysis, as the eighth farmer had not yet fully implemented IMTA. Only a few considerations were described as only benefits or only challenges, and there were no cases where all seven respondents identified the same consideration (Table 4). For instance, level of public interest was not identified as a challenge by anyone, but not all respondents thought it was a benefit either. In addition, expansion of aquaculture was described as a challenge by three respondents, and no one described it as benefit.

**Table 4. Benefits and challenges identified by respondents broken up by economic, environmental, and social considerations.**

| Considerations | # of respondents identified as a challenge | # of respondents identified as a benefit | Total # of respondents that discussed each consideration (n=7) |
|---|---|---|---|
| **Economic** | | | |
| Marketing | 2 | 2 | 4 |
| Product diversification | 2 | 3 | 5 |
| Risk | 2 | 1 | 3 |
| Lack of market | 2 | - | 2 |
| Potential for high return on investment | - | 2 | 2 |
| **Environmental** | | | |
| Organism growth rate | 2 | 2 | 4 |
| Water quality | - | 3 | 3 |
| **Social** | | | |
| Expansion of aquaculture | 3 | - | 3 |
| Level of public interest | - | 4 | 4 |
| Aquaculture's negative history | 2 | - | 2 |

### 4.3.1 Economic Considerations

Five major economic themes associated with the challenges and benefits of IMTA emerged from the interviews: marketing, product diversification, risk, lack of market, and the potential for a high return on investment (ROI).

Some respondents described how they viewed the use of IMTA as a marketing tool to draw attention to a product, and whether they believed that marketing their goods as 'IMTA products' would negatively or positively affect their revenue. The majority of respondents stated that IMTA was neither a benefit nor a hindrance to marketing. One respondent felt strongly that IMTA would be a good marketing tool because it was something new, different, and potentially exciting for customers. However, two respondents suggested that identifying products as 'IMTA products' may actually be bad for marketing because some consumers may have negative preconceived notions about aquaculture in general.

Product diversification is a component of IMTA because of the necessary adoption of an additional species. During most of the interviews, respondents discussed how product diversification was often difficult to manage, but a beneficial part of IMTA. In every case, the adopted species was not only new to the farmer, but also relatively new to the US aquaculture industry. Respondents found it difficult to grow more than one species especially when they had limited information on how to rear at least one of the species. One of the farmers felt that diversification was a burden, especially when both products did not earn the same revenue. For instance, he found that diversification was a bad business plan: "If you've got something that is making most of your money, and you're taking energy away from that for something that is making you less money, in a business sense, that can't ever work." On the other hand, other farmers identified product diversification as an advantage: "It opened up a whole new distribution channel for us, and a whole new avenue to go out and acquire customers that we would not traditionally have had access to just with shellfish. Vegetarians, for example."

Although one individual stated that IMTA reduced economic risk because of product diversification, another respondent felt that risk was increased with the use of IMTA. In this case, the risk was related to the challenge associated with learning how to culture a new organism. This concern was typical of the respondents that had decided to begin IMTA on their own. The following observation from one of the farmers illustrates the concern that was expressed by several respondents during the interviews:

> So the science would show it should work out fine, but we didn't know whether it would work out fine or not because we had never done it, and the mussel farm was our bread and butter. You lose the mussel farm, you lose the ranch. So that was risky from a physical standpoint, and then from a monetary standpoint we invested a significant amount of time and money into learning how to grow out the seaweed. The risk was, 'well maybe we couldn't grow it'. 'Maybe seaweed farming wasn't a thing that could happen'...for whatever reason we could not foresee. So that added a significant amount of risk to it.

The respondents who developed interest in IMTA after seeing others use it tended to feel that the risks related more to the lack of an existing market for the new organisms than to the actual ability of the farmers to grow them. This same group also felt that growing these additional species gave a high potential return on their investment because they did not require a lot of different or extra gear to grow them. In other words, they already had everything that they needed on their farm to grow the new species.

Two individuals did identify diversification of revenue as a benefit, and stated that this diversification led to a reduced risk of revenue loss if a high mortality event occurred in one species. For example, one individual explained that "if one crop fails or two crops fail you still have other things to sell which is good. It creates some stability." The same two also identified the benefit of growing species that peak during different seasons. This is specific to mussels and kelp IMTA in Maine because the peak growing time for kelp is during the winter when mussel aquaculture has slowed down. One of these two also stated how this is a benefit to employees as well because it allows them to continue to work during traditionally slow months.

### 4.3.2 Environmental Considerations

When individuals were asked how they believed the ecology/environment at their farm was affected by the adoption of IMTA, the change in organism growth rate was discussed by the highest number of respondents (Table 4). However, the majority of respondents stated that they did not notice any environmental or ecological effects (positive or negative) from using the IMTA method. Some speculated that each species provided symbiotic benefits that may have increased the growth rate, however, actual measurements of this were not made at any of the farms. In a few cases, an improvement in water quality was recorded and actively measured. In one case in particular, the presence of kelp reduced the amount of inorganic nitrogen, phosphorus, and carbon dioxide levels within the water column ultimately improving the overall water quality on the farm.

One respondent mentioned how growing two shellfish species together (although not technically IMTA) ended up with a surprising negative consequence. Although the two shellfish species (oysters and clams) seemed to grow well together, the overall taste of the oyster product was significantly reduced.

### 4.3.3 Social Considerations

Respondents also discussed social impacts, which were defined as the farmers' perceptions of the local community members' and commercial industry members' (fishermen, lobstermen, other aquaculturists, local restaurateurs, and farmers market vendors) attitudes toward their adoption of IMTA. Respondents discussed positive social interactions with local communities and industry more often than negative interactions. When respondents described their opinions on the overall attitudes of these groups, three major themes emerged: expansion of aquaculture, level of public interest, and aquaculture's negative history.

Expansion of the respondents' aquaculture leases was necessary in many cases in order to use IMTA. This created a variety of social conflicts associated with user rights issues, fear of reduced aesthetic value, and fear of the unknown. These disagreements are ultimately the same challenges felt by the aquaculture industry in general, and are typically seen during the leasing process for monoculture farms. Respondents noted that specific individuals in the surrounding community and commercial harvesting industry were concerned about the expansion of the leases, the development of a new (potentially competitive) industry, and the impacts on their own use of that area. Three of the respondents (who were adding seaweed to their sites) stated that they experienced some initial push-back from either land owners or commercial lobstermen and fishermen who voiced their opinions through public comment, or directly to farmers. However, all three of these individuals also stated that in their opinion, once the facility was up and running, the actual impact was practically non-existent, and that opposition decreased after that. This is most likely because the equipment necessary to grow the additional species was minimal, consisting of a few extra buoys and lines added to the site. One of the farmers attributed the opposition to the initial 'fear of the unknown' when something foreign is introduced to a community:

> You know, we share common waters with all the existing uses and there is a lot of perceived pressure on those waters. So, folks were a bit nervous about a new industry coming onto the water. It is understandable, but I think that their fears were proven to be

> unfounded. In the areas that we operate we just recently had a lease hearing and there wasn't any opposition at all to the seaweed farm. But when we started, you know, anytime you start something new it's like... 'Whoa, what is this?'.

Respondents differed in their perceptions of how much public interest there was in the adoption of IMTA methods. A few individuals believed that the general public did not really care about the adoption of IMTA, stating that there is a lack of awareness of it and that people just do not think or care enough about where their food is coming from. The following observation of one of the respondents summarizes this view:

> I don't know that there is even a high degree of awareness of IMTA. I don't know that it is in many peoples' vocabulary. There are always people that are interested in what's going on, and if they are open-minded enough then they see the potential, but that's not the case with everyone.

A lack of public awareness of how IMTA could improve on aquaculture impacts was considered important by one respondent in particular, who voiced the following concerns over how the negative image of the environmental impacts of the aquaculture industry are affecting the development of IMTA (and aquaculture in general):

> I think that there is a long way to go in educating the populous. Aquaculture in the US really shot itself in the foot in the '70s with the way we managed our salmon industry, and for the general consumer, got a black eye. The consumer thought, aquaculture is not sustainable environmentally, it's actually very bad for the environment. The modern practices and the way that farms are run today, particularly if you look at a shellfish farm and seaweed farm, they are restorative to the environment. The best practices in salmon farms, particularly if they are practicing IMTA, they are not what they were in the '70s. I think that there needs to be a fairly large education effort, and I'm not sure who has the pockets to do that because it will be trying to change perception, which is a difficult thing to do.

This respondent also believed using the term 'IMTA' was bad for marketing because it has the word 'aquaculture' in it. On the other hand, most respondents believed that

IMTA generated positive public interest. One respondent explained that the local community was highly supportive of the introduction of seaweed:

> We also had and continue to have tremendous support from the local community. Both material support (folks lent us equipment and a hand when we need it), and moral support in what we do. I think there are a number of people who are excited to see a whole new industry come on to the coast.

Two respondents stated that they were contacted by farmers from other states that were interested in learning about the new aquaculture methods they were using. Some farmers were interested in expanding into the seaweed industry, while others were interested in farming multiple species as well.

## 4.4 The Future of IMTA

All of the respondents that had actively used IMTA had a positive attitude toward it. When asked about the future of IMTA in general, most respondents believed that it has great potential. Some were specific about where they think the potential resides, as one farmer stated:

> In theory, though, I think it is awesome. There is a lot of really cool potential for cleaning up aquaculture…Anything that we can do to reduce the negative effects of large scale commercial aquaculture systems. So I think that is where IMTA has really great potential.

Others stated that IMTA is a promising method for growing and harvesting products from the sea, and they believe IMTA will grow in popularity and use. Two respondents also mentioned that they see great potential for seaweed to be used in beauty products and animal feed. On the other hand, one respondent, although still generally positive about IMTA, was more skeptical stating that:

> …it [IMTA] has its place in the aquaculture industry and it hasn't really been established in that space yet, but – I don't think it is going to work in all scenarios for everything. I think that there is definitely a niche for it…yeah, I think it has got potential, but it is not going to be a universal thing.

All of the respondents also emphasized the importance of economic sustainability and the requirement of a monetary benefit for the continued growth and success of IMTA. For example, one respondent noted the importance of economic benefits of IMTA:

> …in the end it [IMTA] has to be economically feasible or it's unsustainable. So when you think about sustainability, there's the sustainability from the environment and from the economic standpoint. If it's not sustainable from an economic standpoint, then it won't happen.

Finally, one respondent added that it will take a specific type of aquaculturist to successfully implement IMTA:

> I think that it is going to take folks that are willing to have a more complex operation than what they currently have. So it may take a different type of farm manager, a different type of risk profile for an aquaculturist…though I think in general, aquaculturists are a pretty risk-taking group of folks. It is just the nature of what we do. But it does add a level of complexity, and so that is going to take a change in how we manage and perhaps who manages our farms.

This respondent also identified the lack of support from regulatory and government agencies as a challenge to the continued development of IMTA:

> We tend to be a little slower in adopting some of the innovative aquaculture endeavors because of our regulatory environment and lack of support from government agencies. So I think that's been an impediment in the past…I don't think we need to change the laws, maybe a tweak here or there, but it is really around the process of obtaining leases. It takes an awful long time and costs an awful lot of money. Other states are doing it in a different way that seems to be allowing their aquaculture sectors to grow faster. I think if our aquaculture sector could grow faster, and there is a demand for it, we'd see a lot more polyculture because there would just be more activity.

Although all of the respondents had some positive views about IMTA, when asked whether they had plans to continue using this method, only two individuals were continuing to use IMTA after the initial adoption. When asked how long they expected to continue using IMTA, both of those farmers were adamant that the IMTA method was there to stay (i.e. “We don’t have any plans to stop”; “Until I die on my boat”). One of these respondents was the same individual who stated that it had been his plan when he started his aquaculture farm to expand to different trophic levels. The other respondent was the same individual who identified climate change as one of his incentives for initially adopting the IMTA method. While both of these individuals stated that the success and growth of IMTA was dependent on whether it was economically sustainable, they were more outspoken about the positive ecological impacts of IMTA than other respondents.

Of the remaining individuals, one had not yet begun the IMTA project (which only had funding for one year) and another had since retired from the business. The remaining four respondents had chosen not to continue using IMTA. When asked what was preventing them from continuing to use IMTA, these respondents identified three main reasons: the lack of a market (for seaweed products), the difficulty of managing two different species (especially because one was a completely new product for the grower), and the perception that using IMTA was not financially worth it. The following comment highlights how financial concerns have influenced the decision to continue IMTA methods:

> …we [the farm] are not convinced that IMTA is beyond just having a productive mussel farm and growing seaweed. We are not convinced that IMTA is something that we would really expand on…because of what’s involved anytime you deal with different species. It’s a whole

additional level of time and expenses…I think it's a great concept, but I think that for us it really comes down to whether it's a money maker or not. We are not using it from a marketing point of view. We would only have IMTA if we saw that there was some profit…money to be made…at this point, we are not making any efforts to further develop IMTA.

# CHAPTER 5

# DISCUSSION

This study investigated aquaculturists' views and experiences with IMTA. The majority of respondents were involved in mussel and kelp IMTA, while the others grew different shellfish and seaweed species, or shellfish and sea cucumber species. Overall, only two aquaculturists out of eight continued (or will continue) using IMTA after the initial adoption. Respondents described a variety of factors that affected both their initial adoption and continuation of IMTA use. Initial adoption of IMTA was mainly driven by aquaculturists' perceptions of potential economic benefits of IMTA. Other motivations included inspiration from other aquaculturists, environmental sustainability, and potential reduction in maintenance effort due to the uptake of waste material from the added species.

Respondents also described a variety of economic, environmental, and social benefits and limitations of IMTA. More economic considerations were discussed than environmental and social considerations, and included both challenges and benefits associated with marketing, product diversification, and risk, as well as challenges associated with the lack of a market for the new products being grown, and the benefits of a high potential return on investment. Environmental considerations focused on the potential water quality benefits of IMTA and the positive and negative effects that IMTA could have on organism growth. Finally, social considerations included challenges associated with aquaculture expansion and historically negative perceptions of the aquaculture industry, and benefits associated with high levels of public interest in IMTA.

Although the majority of respondents chose not to continue to use IMTA on their farms, they maintained a positive attitude toward the aquaculture method and were optimistic about its future in the US. Most of the respondents, however, did not feel that the term ‘IMTA’ was adequate or realistic as a way to describe to others what they were doing on their farms, or as a term that could be used as a marketing tool for their product. Respondents in this study also tended to agree that the shellfish aquaculture industry would not benefit from marketing their product as an IMTA item as much as that might benefit finfish aquaculture.

## 5.1 Factors affecting adoption of IMTA

Respondents identified perceived economic benefits as the major driving force for their adoption of IMTA. Economic benefits were identified as a reason for initially trying IMTA and for choosing to continue using it. Most respondents that did not experience any economic success with IMTA said that was why they chose not to continue using the method. As previously stated, there were only two respondents in this study who continued using IMTA after the initial trial stages. Interestingly, these two individuals stated that economic success was *not* why they had *continued* with the method. Although they had (and continue to have) financial success using IMTA, they believe that they would have continued (and do continue) to work on improving and utilizing the method regardless of whether they initially made money. In their perspective, it was the ecological benefits, like improvements in water quality, and the sustainable use of space that drove them to *continue* with IMTA.

Respondents also described many of the same challenges associated with IMTA complexity that were identified in Thomas (2010), including product diversification, market development, and difficulty of explaining the method to others (Figure 3). IMTA is not a simple idea, and respondents felt that it was hard to explain to others, and that using the term ‘Integrated Multi-Trophic Aquaculture’ to describe the method to the general public was not effective. IMTA can include all types of organisms in different trophic levels and quantities, for different purposes, and in many different locations and environmental conditions (Soto 2009), therefore, respondents felt that it was not exclusive enough to successfully describe the methods being used on their farms. In fact, many of the respondents chose to use alternative terms such as ‘co-culture’ or ‘3D ocean farming’ to describe their IMTA operations (Table 2).

Furthermore, the integrated aspect of IMTA is ambiguous. According to researchers and practitioners, the species that are grown in IMTA systems do not need to be in close proximity to each other for the method to be considered IMTA (Chopin 2006; Barrington, Chopin, and Robinson 2009). Species only have to be connected by nutrient and energy transfer through the water. Respondents found this broad conceptualization of IMTA to be a major hurdle if IMTA is to be used as a marketing strategy for aquaculturists. This is surprising because other studies have suggested the use of the term ‘IMTA’ as a marketing tool such as an ecolabel (e.g., Klinger and Naylor 2012; Barrington et al 2010). Although research has shown that consumers are willing to pay a higher price for sustainable products grown in IMTA systems

(Barrington et al 2010; Martínez-Espiñeira et al 2015), respondents from this study felt that the term 'IMTA' would not be an effective marketing tool because of the negative connotation of the word 'aquaculture' and because of the difficulty in describing the IMTA method clearly.

All of the respondents growing both seaweed and shellfish species highlighted how they were able to slowly introduce the new species (seaweed) to their lease(s), with relative ease, and increase the volume and area used by the new species over time. The scalability of shellfish-seaweed IMTA was therefore described as a benefit by respondents because adding seaweed to an existing shellfish farm did not require an excessive initial investment, and did not require a lot of gear that the aquaculturists did not already have at their facility. Furthermore, some respondents said they had success selling small quantities of the new product, in this case seaweed, at farmers markets and local restaurants, so they did not feel the effort spent experimenting with the new method was wasted.

Respondents also found that IMTA could affect risks associated with aquaculture, depending on what species the culturists were growing and how they grew them. Some respondents believed that IMTA reduced the risk that exists at a monoculture facility because it provides a secondary source of income from selling another product, creating a security net in the event that one of the organisms has a low yield in a particular season. However, other respondents felt that the use of IMTA could amplify risk in cases where multiple species were highly dependent on one another because unforeseen changes in one of the species, like rapid growth or large mortality event, would affect the entire system.

Although few, if any, studies have examined the adoption of IMTA, studies have investigated the adoption of more sustainable land-based techniques, like organic farming. Many factors that respondents identified as affecting the adoption of IMTA were similar to those in the studies of organic farming. For instance, in a review assessing organic farming, Padel (2001) noted certain critical factors important to successful adoption of organic farming to include obvious and economic advantages, simplicity, understandability, the capacity to try the idea on a small scale, a low risk association, and compatibility with current values and norms. Respondents in this study of IMTA highlighted how many of these factors were lacking in IMTA. For instance, they said IMTA provides few economic benefits, it is complex, it is difficult to understand, and there can be risks. Only the scalability of IMTA (or ability to start growing a new species at a small scale before investing lots of time, money, and resources) was seen as a positive factor of IMTA. These findings suggest that IMTA will not be easily adopted.

Adoption of any new idea is difficult (Rogers 2010). Rogers' (2010) diffusion of innovation theory supports the finding that complexity associated with IMTA is another major factor influencing its adoption. Diffusion of innovation is "a social process in which subjectively perceived information about a new idea is communicated" (Rogers 2010, pg. xvii). According to Rogers (2010), the adoption of a new idea or technology is related to how well the idea or the technology is communicated to others, and what society collectively decides is important (or not important) based on what is communicated. Therefore, it is not surprising that most participants in this study did not continue to use IMTA as they considered it to be a complicated method associated with significant uncertainty.

## 5.2 Important considerations for IMTA

During this study, no single social, economic or environmental consideration was mentioned by all of the respondents, indicating that perceptions vary by aquaculturist. During the interviews, more economic considerations were identified than environmental or social considerations (Table 4). The identified economic considerations included both benefits and limitations, but a few were described as only benefits or challenges. For instance, the lack of an existing market for the added species was considered only a challenge. The potential for a high return on investment was considered only a benefit. The remaining considerations, marketing to the public, product diversification, and risk, were considered as both challenges and benefits. Product diversification was mentioned by the greatest number of respondents with a few stating that it was a benefit and a few stating that it was a challenge (Table 4).

In terms of product diversification, opening the market to create opportunities for aquaculturists to sell at different times of the year, or to sell to different people and reach more people was seen as a very promising aspect of IMTA. This was especially true for many shellfish farmers as shellfish tends to be a relatively niche market. Some respondents stated that product diversification was a challenge because there was limited knowledge on how to grow the newly cultured organisms. The benefit of product diversification was especially apparent to those who were growing seaweed because, as they said in the interviews, seaweed can be used for a wide variety of products including those used for direct consumption and as an additive to other products. In fact, seaweed's diverse and numerous uses led two respondents to adopt seaweed aquaculture as their new cultured species, and stop shellfish aquaculture altogether.

It is possible for aquaculturists to diversify their products by combining species from the same trophic level (growing multiple shellfish or fish species together), however, one respondent found that this is less likely to be effective because the similarity between the organisms often creates competition for resources leading to a lower quality product. Respondents also expressed that in order for them to consider IMTA, the work put into the added species had to be worth their time and money, and in many cases, adding an additional species was not worth it.

All of the economic considerations expressed by the respondents in this study were identified as economic impacts in Thomas (2010) with the exception of high return on investment. Respondents from the SWOT analysis identified "greater capital costs for start-up" as a weakness of IMTA. This difference could be due to the different species compositions of the IMTA systems that were used by the respondents of this study, and those used by the respondents in the SWOT analysis. For instance, many IMTA systems include a fed-species (e.g., finfish or crustaceans), which require a higher initial investment than non-fed species (e.g., shellfish or seaweed) and have a higher production cost because of the need to purchase food, pesticides, and antibiotics.

In terms of environmental considerations, respondents only identified two factors in this study: organism growth, which was reflected as both a benefit and limitation, and water quality, which was only considered a benefit by three respondents.

However, many of the respondents did not acknowledge the environmental benefits that are often discussed in research on IMTA, including overall water quality enhancement, coastal health improvement, and the reduction in nutrient concentration in the surrounding water column (biomitigation ability) (Chopin 2007; Sarà 2009; Abreu 2011; MacDonald et al 2011; Gallagher 2012; Tedesco 2013). Again, this could be due to the particular species being used by the respondents before they adopted IMTA methods. Shellfish aquaculture operations, on their own, have been identified as potentially effective in improving water quality through their ability to convert fixed nitrogen to nitrogen gas (Humphries et al. 2016). For example, in a recent study, Humphries and colleagues (2016) found that oyster aquaculture may increase sediment denitrification rates and sediment oxygen demand at ecologically important levels. Therefore, the beneficial environmental effect of seaweed or sea cucumbers may not be as apparent to shellfish aquaculturists as it would be for finfish aquaculturists. The majority of the ecological benefits are directed more toward full IMTA systems that include fed-species.

The specific benefits some seaweed species can have on the shellfish industry were recognized by the two individuals who continued to use IMTA. One major benefit was the effect that seaweed species can have on reducing the impacts caused by ocean acidification. The amount of carbon that different species of seaweed can sequester is currently being researched (Mongin et al 2016; Pettit et al 2015). Ocean acidification is becoming a concern for shellfish culturists because of its negative effect on the shellfish larvae's ability to form their calcium carbonate shell (Gazeau et al 2007). As one of the respondents pointed out, there may come a time when growing organisms with an ecosystem approach in mind may not even be a choice because of the affect that climate change will have on the ocean environment.

Similar to environmental considerations, social considerations were acknowledged less often in the interviews than economic considerations. Only three social factors were identified by respondents. Aquaculture expansion and historically negative perceptions of the aquaculture industry were considered limitations, and high levels of public interest in IMTA was considered a benefit. The expansion of aquaculture is an issue facing the entire aquaculture industry regardless of the number of trophic levels included on a farm. This is especially true of aquaculture in the coastal environment as these areas are already highly utilized for many other commercial and recreational purposes (D'Anna and Murray 2015). Of all the social considerations discussed by respondents, the level of public interest in IMTA was discussed by the most respondents.

## 5.3 Implications for Stakeholders

Although studies have highlighted the many ecological benefits of IMTA (e.g.,Chopin et al 2001; Neori et al 2004; Blouin et al 2007; Abreu et al 2011; Martínez-Espiñeira et al 2015), the majority of respondents in this study described how economic advantages have greater influence in driving the adoption of this method. Based on these findings and similar results from a 2010 IMTA workshop (e.g., Thomas 2010), managers (government employees charged with the promotion of aquaculture) and scientists (professionals researching IMTA and providing data on the benefits and limitations of it ) should consider using product diversification, rather than improvements in water quality or environmental health, when encouraging aquaculturists to adopt IMTA practices. In addition, managers and scientists may consider focusing their efforts on promoting IMTA systems that only include two trophic levels because respondents felt that growing species within two trophic levels was already challenging enough. It seems as though the highly integrated type of IMTA depicted by Joyce Hui (Figure 2) that includes many trophic levels is more of an idealized concept for commercial operations, and that in reality aquaculturists may not feel comfortable implementing that type of system.

Managers and scientists should also consider clarifying what IMTA means in terms of its level of integration, and the benefits that it offers aquaculturists. This could be accomplished by adopting a new unambiguous term (or set of terms) from the respondents' preferred choices (Table 2) or coming up with a new term entirely. While the general definition of IMTA does not give specific parameters for distance between species, studies from other countries have shown that increasing distance reduces the effect that the extractive species have on improving water quality and energy transfer from the fed-species (Kerrigan and Suckling 2016; Sara et al 2012; Peharda et al 2007). Stakeholders involved in developing these parameters should consider these models when distinguishing between what is to be considered an IMTA lease, and what is just a multi-species lease.

Currently, IMTA's integrated nature prevents easy recognition of whether an aquaculture site is truly using the full IMTA system, or is simply growing biodiverse systems where multiple species are grown on the same lease but do not affect one another. This factor also impacts the marketability of these systems. In a European study, Altintloglou et al (2010) found that clear and balanced messaging to consumers about farmed fish had a positive effect on the consumers' overall image of fish from aquaculture. Therefore, because the term IMTA can be confusing, managers and scientists might consider avoiding the promotion of IMTA as an effective tool for marketing at this time.

Based on the interviews in this study, IMTA did not offer adequate financial returns for aquaculturists to continue using the method. It may be useful for managers and others interested in promoting IMTA to identify ways to provide initial incentives as well as *continued* financial support throughout the project to aquaculturists who are interested or willing to attempt IMTA methods. The continued financial support could come from nutrient/carbon trading credits once the initial project is underway. This suggestion has been identified by the CIMTAN as a way to maximize the economic incentives of growing shellfish and seaweeds in these systems (CIMTAN 2011). Without external financial support, it is unlikely that aquaculturists will completely adopt IMTA on their own.

Aquaculturists might want to consider using IMTA because it could help reach more consumers and utilize different markets through product diversification, such as the market for seaweed. Those who are interested in IMTA should consider the adoption of low maintenance species to ensure a better chance of success. For example, seaweed aquaculture was considered by respondents to be a low maintenance aquaculture method especially when compared to fed-aquaculture species. Seaweed is a common cultured organism around the world with approximately 37 different seaweed species cultured worldwide (20 genera reported for temperate regions), with a world production of about 1,181,953 tons (freshwater and marine) (2014 FAO Statistical Query (sea cucumbers- 36,115 tons). The fact that seaweed aquaculture is a global industry was a major reason why it was selected by respondents (2014 mariculture production valued at $6 billion (96% from aquaculture), and steadily increasing at a rate of 8% per year (2003-2012 (Moffitt 2014)). In addition, in 2014, the US imported over $60 million worth of seaweed and algae from other countries for human consumption alone (National Marine Fisheries Service 2015). Furthermore, aquaculturists should consider attempting an IMTA method on a small scale in order to see if it is something they would want to invest more time and money into without increasing the risk to their business.

5.4 Limitations of study

While this study provides insights into aquaculturists' perceptions of IMTA, there are some limitations worth mentioning. Due to the difficultly in identifying individuals who had previously participated, or who were currently participating in IMTA, only individuals who had experience with shellfish/seaweed, and shellfish/sea cucumber IMTA methods were represented. Other aquaculturists' perceptions are not represented in the results. This is especially true for those who are conducting IMTA using fed-species as the highest trophic level. It is also important to keep in mind that the IMTA methods used by respondents in this study typically differed from those used in other countries (Barrington, Chopin, and Robinson 2009; Moffitt and Cajas-Cano 2014). The majority of IMTA systems utilize a fed-species, like salmon or shrimp, as the highest trophic level because of the bio-remediation benefits from the lower trophic organisms. There are likely different concerns and benefits among different types of IMTA aquaculturists that are present between these different aquaculture sectors.

CHAPTER 6

# CONCLUSION

The results of this study suggest that that aquaculturists that *have* tried IMTA, regardless of whether they continued using it or not, remain positive about IMTA and its future in the industry. Overall, the respondents that chose not to continue using IMTA were not convinced that it was worth the time they were spending on learning the new culture and harvesting methods, while those who did chose to continue using IMTA did so because of the ecological benefits that the method brought to the leased area, as well as the economic benefits gained through their product diversification.

Promotion of IMTA by scientists has been focused mainly on the ecological benefits that it may bring to disruptive aquaculture systems. This study suggests that promoting IMTA's ecological benefits is not as relevant to lower trophic IMTA approaches like shellfish IMTA. If faster adoption of IMTA is truly warranted, then there needs to be a change in the way IMTA is advertised to the aquaculture industry. Focusing on IMTA's ability to increase product diversification (and therefore increase revenue) may be a more effective promotional strategy for IMTA adoption. This strategy is also more relevant to *both* non-fed and fed aquaculture sectors because it does not exclusively focus on the benefits of IMTA for fed-species aquaculture.

This study found that the largest challenges for aquaculturists who have attempted IMTA were finding a market for the new product and learning how to culture a new organism successfully. Furthermore, the study implies that the use of IMTA as a marketing strategy to establish not only more, but higher paying, customers might not be effective. Although other studies have shown that the public may be willing to spend more on IMTA products, the lack of a specific definition explaining the level of integration required for IMTA prevents effective marketing from taking place. Individuals in this study were also skeptical about the level of concern that typical consumers have about the sustainability of their seafood products and whether or not IMTA would truly benefit them as a marketing tool.

Development of the aquaculture industry in the US will continue in the coming years. The increasing human population and impending climate change will only intensify the nation's need for more plentiful, safe, and secure seafood resources. Developing and investing in sustainable aquaculture methods, like IMTA, might help increase the public support for the aquaculture industry and play a significant role in reducing the enormous seafood trade deficit facing the US. Further evaluation of aquaculturists' perceptions of IMTA is needed to better understand how the method can be utilized most effectively in the US, whether it can be an effective tool to help reduce the US seafood trade deficit in a sustainable way, and in determining the best way to promote the method to aquaculturists. The following is a list of possible topics for future research:

1. This study included only two types of IMTA. To improve the understanding of a more general population of aquaculturists, perceptions of aquaculturists participating in different types of IMTA could be studied, for example, instances where finfish and mussels are grown together.

2. Another way to widen the range of understanding of aquaculturist's attitudes towards IMTA could be to evaluate *all* aquaculturists' perceptions of IMTA whether they have tried it or not to determine why they have not used IMTA. Are culturists simply not aware of it, or do they have a specific reason why they have not tried it? What about it do they like or not like? What are their concerns? And what would have to change for them to switch to IMTA?
3. Offshore IMTA is another method that is considered by some to be a more sustainable option than other coastal methods. Future studies could evaluate aquaculturists' perceptions of offshore IMTA, and could look into whether coastal or offshore IMTA is more likely to be adopted by aquaculturists and why?

# APPENDICES

## APPENDIX A: Recruitment script

Telephone:

My name is Heather Kinney, and I am a graduate student working with Dr. Tracey Dalton at the University of Rhode Island. I am currently doing a URI research study on aquaculture facilities that have grown [species of interest] at the same time in one location. Through my research I discovered that [farm of interest] was involved in a pilot study in 2011 growing [species of interest]. I am contacting you to see if you would be willing to participate in an interview about this farming method. I specifically interested in what farmers think about the method and what benefits or concerns you think it brings to the aquaculture industry in Maine.

To be eligible for participating you must be 18 years or older and have worked at [farm of interest] during the years 2011-2014. The interview would take about 1 hour of your time, and can be arranged at a location of your choosing. There is no reimbursement being offered however, by participating, you will be able to contribute to the development and understanding of this aquaculture method. Any information will be kept confidential, and you would be able to stop the interview at any point. This research has been approved by the University of Rhode Island Institutional Review Board.

Do you have any questions? Would you like to participate?

Email:

My name is Heather Kinney, and I am a graduate student working with Dr. Tracey Dalton at the University of Rhode Island. I am currently doing a URI research study on aquaculture facilities that have grown [species of interest] at the same time in one location. Through my research I discovered that [farm of interest] was involved in a pilot study in 2011 growing [species of interest]. I am contacting you to see if you would be willing to participate in an interview about this farming method. I specifically interested in what farmers think about the method and what benefits or concerns you think it brings to the aquaculture industry in Maine.

To be eligible for participating you must be 18 years or older and have worked at [farm of interest] during the years 2011-2014. The interview would take about 1 hour of your time, and can be arranged at a location of your choosing. There is no reimbursement being offered however, by participating, you will be able to contribute to the development and understanding of this aquaculture method. Any information will be kept confidential, and you would be able to stop the interview at any point. This research has been approved by the University of Rhode Island Institutional Review Board.

Please let me know if you are interested in participating and/or if you would like any more information about my research.

# APPENDIX B: Interview Protocol

Interview protocol

I. Opening

The purpose of my research is to learn about aquaculture farms that have grown more than one species at a time in one location (mussels and kelp) (salmon/mussel). I am trying to find out what their experiences were to get an idea of different strengths and weaknesses this method of farming brings to the aquaculture industry. I have selected you as a participant because the farm you work at/own was involved in growing [species of interest] together with [species of interest] on the farm. Your insight and expertise in working with this method is valuable to my research and understanding the future direction that the US aquaculture industry may be headed.

Discuss risks because of small sample size and inclusion of their names in the pilot projects. Discuss benefits? Explain how I will be using this info from them.

II. Main Interview

I would like to talk about the project you were involved with in [year or project where you grew [species of interest] together on this farm, but before that I would like to learn a little more about you and this farm in particular.

*Participant*

a. What is your position on the farm?

b. How long have you worked here?

*Farm*

Tell me about this farm's history…

a. How long has this farm been running?

b. Have you always grown [species of interest] here? If not what else have you grown?

c. What is the size of this farm?

d. How many people work here?

*Pilot project*

First I would like to ask you some questions that focus on the time before the pilot project got started. This is the time when the farm was asked to participate/thinking about participating. I want to know what you were thinking at that point. A little later in the interview, I'll ask you for your thoughts on the project after it got started.  For now, let's focus on the time before the farm started the project…."

1. How did this farm get involved/learn about this pilot project?

2. What were the major incentives for participating in the project?

3. What were your initial thoughts or concerns about growing [species of interest] on this farm?

Now we are going to switch gears and discuss what happened once the project was underway.

4. What was required of you to participate in the pilot project?

5. What were some of the challenges the farm ran into while growing the [species of interest] together, if any?

Economic (Can you give an example?)

Environmental (Can you give an example?)

Social (Can you give an example?)

Other (Can you give an example?)

6. What were some of the benefits while growing the [species of interest] together, if any?

Economic Descriptions? (What do you mean by that?) Examples?

Environmental? Descriptions? (What do you mean by that?) Examples?

Social? Descriptions? (What do you mean by that?) Examples? (example of social would be if community members took interest in the project or were against it.)

Other

7. In your perspective what are the reasons [species of interest] are/are not still grown on this farm? Or why did you continue or stop practicing this method?

8. How much longer do you expect to keep on doing this?

    a. (If not still growing)
    What would be necessary in order to attempt this method again?

9. After having used this method, what are your thoughts about growing more than one type of organism in the same aquaculture lease?

*General aquaculture*

For the last part of this interview I would like to ask some more general questions about aquaculture.

10. Have you heard the term IMTA before? From where? If you can, how would you personally define it?

11. Is there a different name that you use to describe this method of aquaculture?

12. What do you think about the future of this method of aquaculture in [state]?

APPENDIX C: Consent Form

THE UNIVERSITY OF RHODE ISLAND
COLLEGE OF THE ENVIRONMENT AND LIFE SCIENCES
THINK BIG WE DO
DEPARTMENT OF MARINE AFFAIRS
1 Greenhouse Road, Suite 205, Coastal Institute Building, Kingston, RI 02881 USA p: 401.874.2596 f: 401.874.2156 cels.uri.edu/maf

Perceptions of Integrated Multi-Trophic Aquaculture (IMTA) Pilot Study Participants

## RESEARCH PROJECT CONSENT FORM

Dear Participant:

You are invited to take part in a research project examining perceptions participants have about growing more than one organism from different trophic levels in one area on an aquaculture lease in Maine. The research is being led by Principal Investigator, Dr. Tracey Dalton from the Marine Affairs department at the University of Rhode Island (c: 401-874-2434; Dalton@uri.edu), and Masters student Heather Kinney (860759-4799; heather_kinney@uri.edu).

By completing the interview, you are helping to identify the benefits and constraints this method of farming creates, and ensuring that your views are included in the final results of this study. Your participation can help increase understanding of aquaculturists' perspectives on alternative aquaculture methods and give valuable insight into the future of aquaculture in Maine.

There are minimal risks to participation in this study. Please keep in mind that all final results will be based on grouped data and will not identify you or any individual as a participant in this study. Your name and any other identifiable information such as occupation will not be associated with the information you provide and will remain confidential. Access to interview data will be limited only to the researchers involved.

This interview will ask you general information about your experiences and involvement in a Maine Sea Grant Pilot Project where more than one organism was grown together on an aquaculture lease. The interview will take approximately one hour to complete.

The decision to participate in this interview is your decision. You do not have to participate and you may refuse to answer any question. If you chose not to participate or answer any questions, it will not affect any future contact with the University of Rhode Island.

## Consent to Record

You understand that this study involves recording of your interview with the researcher. Your name or any other identifying information will be associated with the recording.

You understand that the recorded interview will be transcribed and may be reproduced in part or in whole for use in the final results of this study. Your name and any other identifying information will not be used in the final results of this study. Following transcription and accuracy check, the recording will be erased.

You understand that your participation is voluntary and may refuse to have the interview recorded. You further and understand that should you wish to withdraw your consent to participate in this study, you may request all recorded information erased.

**By signing this form I am consenting to (please initial):**

__________ Having my interview be recorded.

__________ Having the recording being transcribed.

__________ Use of the written transcription in final results of this study. **By initialing**

**the line in front of each item above, I am consenting to participate in that**

**procedure.**

If you have any questions, feel free to contact Heather Kinney (860-759-4799 or heather_kinney@my.uri.edu) or Dr. Tracey Dalton, her thesis advisor at the University of Rhode Island (401-874-2434 or Dalton@uri.edu), the people mainly responsible for this study.

In addition, if you have questions about your rights as a research participant, you may contact the office of the Vice President for Research and Economic Development, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

**You have read the Consent Form. Your questions have been answered. Your signature on this form means that you understand the information and you agree to participate in this study. You also certify that you are at least 18 years old.**

________________________ ________________________

Signature of Participant Signature of Researcher (consent to participate)

________________________ ________________________

Typed/printed name Typed/printed name

________________________ ________________________

Date Date

**I am requesting to have this interview recorded. By signing below I am consenting to have the interview recorded.**

___________________________ ___________________________
Signature of Participant Signature of Researcher

___________________________ ___________________________
Typed/printed name Typed/printed name

____________________ ______________________
Date Date

***Please sign both consent forms, keeping one for yourself***

# BIBLIOGRAPHY

Abreu, M. H., Pereira, R., Yarish, C., Buschmann, A. H., & Sousa-Pinto, I. (2011). IMTA with *Gracilaria vermiculophylla*: Productivity and nutrient removal performance of the seaweed in a land-based pilot scale system. *Aquaculture, 312*(1–4), 77-87.

Alexander, K. A., T.P. Potts, S. Freeman, D. Israel, J. Johansen, D. Kletou, M. Meland, et al. (2015). The Implications of Aquaculture Policy and Regulation for the Development of Integrated Multi-Trophic Aquaculture in Europe. *Aquaculture* 443(1) 16-23.

Alexander, K. A., D. Angel, S. Freeman, D. Israel, J. Johansen, D. Kletou, M. Meland, et al. (2016). Improving Sustainability of Aquaculture in Europe: Stakeholder Dialogues on Integrated Multi-Trophic Aquaculture (IMTA). *Environmental Science & Policy* 55(1) 96-106.

Altintzoglou, T., Verbeke, W., Vanhonacker, F., & Luten, J. (2010). The image of fish from aquaculture among Europeans: Impact of exposure to balanced information. *Journal of Aquatic Food Product Technology, 19*(2), 103.

Angel, D. and Freeman, S. 2009. Integrated aquaculture (INTAQ) as a tool for an ecosystem approach to the marine farming sector in the Mediterranean Sea. In D. Soto (ed.). Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper. No. 529. Rome, FAO. pp. 133–183.

Atkinson, R., & Flint, J. (2001). Accessing hidden and hard-to- reach populations: Snowball research strategies. *Social Research Update,* (33) doi:http://dx.doi.org.uri.idm.oclc.org/10.1016/j.aquaculture.2010.12.036

Aquaculture Science Branch. 2013. Ecosystems and Oceans Science Sector, Fisheries and Oceans, Canada. ISBN: 978-1-100-54529-5

Barrington, K., Chopin, T. and Robinson, S. **(**2009). Integrated multi-trophic aquaculture (IMTA) in marine temperate waters. In D. Soto (ed.). *Integrated mariculture: a global review. FAO Fisheries and Aquaculture Technical Paper.* No. 529. Rome, FAO. pp. 7‑46.

Barrington, K., Ridler, N., Chopin, T., Robinson, S., & Robinson, B. (2010). Social aspects of the sustainability of integrated multi-trophic aquaculture. *Aquaculture International; Journal of the European Aquaculture Society, 18*(2), 201-211. doi:10.1007/s10499-008-9236-0

Bansemir, A., Blume, M., Schröder, S., & Lindequist, U. (2006). Screening of cultivated seaweeds for antibacterial activity against fish pathogenic bacteria. *Aquaculture, 252*(1), 79-84. doi:http://dx.doi.org/10.1016/j.aquaculture.2005. 11.051

Bert TM, ed. 2007. *Ecological and Genetic Implications of Aquaculture Activities*. Dordrecht, Neth.: Springer-Verlag

Biernacki. (1981). *Snowball sampling: Problems and techniques of chain referral sampling*. Thousand Oaks, Calif.

Blouin, N., Xiugeng, F., Peng, J., Yarish, C., & Brawley, S. H. (2007). Seeding nets with neutral spores of the red alga *Porphyra umbilicalis* ( L.) kützing for use in integrated multi- trophic aquaculture (IMTA). *Aquaculture, 270*(1), 77-91. doi:10.1016/j.aquaculture.2007.03.002

Braun, V. and V. Clarke. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology* 3(2), 77-101

Center for Food Safety. (2016). Fishing and Public Interest Groups File Challenge to Feds' Unprecedented Decision to Establish Aquaculture in Offshore U.S. Waters. Press Release. http://www.centerforfoodsafety.org/press-releases/4229/fishing-and-public-interest-groups-file-challenge-to-feds-unprecedented-decision-to-establish-aquaculture-in-offshore-us-waters#. Accessed: Nov. 2016.

Chopin, T., Buschmann, A. H., Halling, C., Troell, M., Kautsky, N., Neori, A., . . . Neefus, C. (2001). Integrating seaweeds into marine aquaculture systems: A key toward sustainability. *Journal of Phycology, 37*(6), 975-986. doi:10.1046/j.1529-8817.2001.01137.x

Chopin, T. (2006). Integrated multi-trophic aquaculture. What it is and why you should care … and don't confuse it with polyculture. *North Aquaculture* 12(4).

Chopin T, Yarish C, Sharp G (2007). Beyond the monospecific approach to animal aquaculture-The light of integrated multi-trophic aquaculture. In: Bert, M.T. (Ed.), *Ecological and Genetic Implications of Aquaculture Activities*. Springer Netherlands, pp. 447-458.

Chopin, T., Macdonald, B., Robinson, S., Cross, S., Pearce, C., Knowler, D.,... Hutchinson, M. (2013). The Canadian integrated multi-trophic aquaculture network (CIMTAN)—A network for a new era of ecosystem responsible aquaculture. *Fisheries*, *38*(7), 297-308. doi:10.1080/03632415.2013.791285

CIMTAN. (2011). Background. http://www.cimtan.ca/about_us. Accessed: April 2017.

D'Anna, L. M., & Murray, G. D. (2015). Perceptions of shellfish aquaculture in British Columbia and implications for well- being in marine social-ecological systems. *Ecology and Society, 20*(1), 57. doi:10.5751/ES-07319-200157

DeCuir-Gunby, J. T., P. L. Marshall, A. W. McCulloch. (2011). Developing and using a codebook for the analysis of interview data: an example from a professional development research project. *Field Methods*. 23 (2) 136-155.

Diana, J. S., Egna, H. S., Chopin, T., Peterson, M. S., Cao, L., Pomeroy, R., . . . Cabello, F. (2013). Responsible aquaculture in 2050: Valuing local conditions and human innovations will be key to success. *Bioscience*, *63*(4), 255-262. doi:10.1525/bio.2013.63.4.5

FAO Statistical Query. (2014). http://www.fao.org/figis/servlet/TabLandArea?tb_ds=Capture&tb_mode=TABLE&tb_act=SELECT&tb_grp=COUNTRY. Accessed: Feb.2017.

Gallagher, D. 2012. Oysters and Seaweed: Better Together? *Marine Biological Laboratory*. Woodshole, Massachusetts. Retreived from: http://www.mbl.edu /blog/oysters-and-seaweed-better-together-3/. Accessed: March 2016.

Gazeau, F., C. Quiblier, J. M. Jansen, J.-P. Gattuso, J. J. Middelburg, *and* C. H. R. Heip (2007), Impact of elevated $CO_2$ on shellfish calcification, *Geophysical. Research Letters,* 34, *L07603, doi:10.1029/2006GL028554.*

Goldburg, R. (2001). Marine Aquaculture in the United States: Environmental Impacts and Policy Options, edited by Matthew Sterling Elliott, Rosamond Naylor and Pew Oceans Commission. Arlington, Va.: Pew Oceans Commission.

Guest, G. (2013). In Namey E. E., Mitchell M. L. (Eds.), *Collecting qualitative data : A field manual for applied research*. Los Angeles, Calif.: SAGE.

Handå, A., Ranheim, A., Olsen, A. J., Altin, D., Reitan, K. I., Olsen, Y., & Reinertsen, H. (2012). Incorporation of salmon fish feed and feces components in mussels (*Mytilus edulis*): Implications for integrated multi-trophic aquaculture in cool-temperate north Atlantic waters. *Aquaculture*, *370–371*, 40-53. doi:http://dx.doi.org.uri.idm.oclc.org/10.1016/j.aquaculture.2012.09.030

Humphries, A. T., Ayvazian, S. G., Carey, J. C., Hancock, B. T., Grabbert, S., Cobb, D., . . . Fulweiler, R. W. (2016). Directly measured denitrification reveals oyster aquaculture and restored oyster reefs remove nitrogen at comparable high rates. *Frontiers in Marine Science, 3* doi:10.3389/fmars.2016.00074

Kerrigan, D., & Suckling, C. C. (2016). A meta-analysis of integrated multitrophic aquaculture: Extractive species growth is most successful within close proximity to open-water fish farms. *Reviews in Aquaculture*. doi:10.1111/raq.12186

Kite-Powell, H., Rubino, M.C. and Morehead, B. (2013). The Future of U.S. Seafood Supply. *Aquaculture Economics & Management* 17 (3): 228-250. doi:10.1080/13657305.2013.812691.

Klinger, D., & Naylor, R. (2012). *Searching for solutions in aquaculture: Charting a sustainable course* doi:10.1146/annurev-environ-021111-161531

Knapp, Gunnar and Michael C. Rubino. (2016). The Political Economics of Marine Aquaculture in the United States." *Reviews in Fisheries Science & Aquaculture* 24 (3): 213-229. doi:10.1080/23308249.2015.1121202.

Lander, T. R. (2010). *A two-year comparison of spawning and spat settlement cycles in blue mussels (Mytilus edulis) from a salmon farm and its implications for integrated multi-trophic aquaculture (IMTA) in the Bay of Fundy*. Ottawa, Ont.: Her Majesty the Queen in Right of Canada.

Läpple, D., & Rensburg, T. V. (2011). Adoption of organic farming: Are there differences between early and late adoption? *Ecological Economics*, 70(7), 1406-1414. doi:http://dx.doi.org/10.1016/j.ecolecon.2011.03.002

MacDonald, B. A., Robinson, S. M. C., & Barrington, K. A. (2011). Feeding activity of mussels (*Mytilus edulis*) held in the field at an integrated multi-trophic aquaculture (IMTA) site (*Salmo salar*) and exposed to fish food in the laboratory. *Aquaculture, 314*(1), 244-251. doi:10.1016/j.aquaculture.2011.01.045

Marine Aquaculture Task Force. (2007). "Sustainable Marine Aquaculture: Fulfilling the Promise; Managing the Risks". Takoma Park, Maryland. Retrieved from http://www.pewtrusts.org/~/media/legacy/uploadedfiles/peg/publications/report/sustainable20marine20aquaculturepdf.pdf. Accessed: Nov.2016.

Martínez-Espiñeira, R., Chopin, T., Robinson, S., Noce, A., Knowler, D., & Yip, W. (2015). Estimating the biomitigation benefits of integrated multi- trophic aquaculture: A contingent behavior analysis. *Aquaculture, 437*, 182-194. doi:10.1016/j.aquaculture.2014.11.034

Mongin, M. and Baird, M. E., Hadley S., & Lenton A. (2016). Optimising reef-scale $CO_2$ removal by seaweed to buffer ocean acidification. *Environmental Research Letters*, *11*(3), 034023. Retrieved from http://stacks.iop.org/1748-9326/11/i=3/a=034023

Moffitt, C. M., & Cajas-Cano, L. (2014). Blue growth: The 2014 FAO state of world fisheries and aquaculture. *Fisheries*, *39*(11), 552-553. doi:10.1080/03632415.2014.966265

Mongin M., Baird M. E., Hadley S. & Lenton A., (2016). Optimising reef-scale CO2 removal by seaweed to buffer ocean acidification. *Environmental Research Letters* 11(3):34023-34032(10).

Morse, D. (PC), S. Redmond (PI). (2014). A pilot project to stimulate seaweed production on mussel farms in Maine. Maine Aquaculture Association. Available at: http://www.seagrant.umaine.edu/files/Dana%20Morse/ 2011%20MAIC%20 Seaweed%20Project%20Final%20Report.pdf. Accessed: Feb.2016.

Murray, G., & D'Anna, L. (2015). Seeing shellfish from the seashore: The importance of values and place in perceptions of aquaculture and marine social–ecological system interactions. *Marine Policy*, *62*, 125-133. doi:http://dx.doi.org/10.1016/j.marpol.2015.09.005

National Marine Fisheries Service. (1999). U.S. Department of Commerce Aquaculture Policy. Available at: http://www.nmfs.noaa.gov/aquaculture/ docs/policy/ doc_aq_policy_1999.pdf. Accessed: Feb.2016.

National Marine Fisheries Service. (2015). “Fisheries of the United States, 2014”. U.S. Department of Commerce, NOAA Current Fishery Statistics No.2014. Available at: https://www.st.nmfs.noaa.gov/commercial-fisheries/ fus/fus14/index. Accessed: Feb.2016.

National Ocean Council. (2013). National Ocean Policy Implementation. Washington, DC. Available at: http://www.whitehouse.gov/sites/default/files/national _ocean_policy_implementation _plan.pdf. Accessed: Feb. 2016

Naylor, Rosamond, Josh Eagle, and Whitney Smith. 2003. "Salmon Aquaculture in the Pacific Nortwest: A Global Industry with Local Impacts." *Environment* 45 (8): 18-32, 34-39.

Neori, A., Chopin, T., Troell, M., Buschmann, A. H., Kraemer, G. P., Halling, C., . . . Yarish, C. (2004). Integrated aquaculture: Rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. *Aquaculture, 231*(1-4), 361-391. doi:10.1016/j.aquaculture.2003.11.015

NOAA. (2011). National Oceanic and Atmospheric Administration: Marine Aquaculture Policy. Available at: http://www.nmfs.noaa.gov/aquaculture/docs/ policy/noaa_aquaculture_policy_ 2011.pdf. Accessed: Feb.2016.

NOAA. (2016). NOAA Fisheries: Stock Status as of December 31, 2016. Available at: http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/archive/2016/f ourth/q4-2016-stock-status-update.png. Accessed: April, 15, 2016.

Nobre, A. M., Robertson-Andersson, D., Neori, A., & Sankar, K. (2010). Ecological–economic assessment of aquaculture options: Comparison between abalone monoculture and integrated multi-trophic aquaculture of abalone and seaweeds. *Aquaculture, 306*(1–4), 116-126. doi:http://dx.doi.org.uri.idm.oclc.org/10.1016/j.aquaculture.2010.06.002

Noy, C. (2008). Sampling knowledge: The hermeneutics of snowball sampling in qualitative research. *International Journal of Social Research Methodology, 11*(4), 327-344. doi:10.1080/13645570701401305

Olin, P. G. 2011. "National Aquaculture Sector Overview. United States of America: National Aquaculture Sector Overview Fact Sheets." FAO Fisheries and Aquaculture Department. Rome. http://www.fao.org/fishery/countrysector/naso_usa/en

Onwuegbuzie, A., & Leech, N. (2007). Sampling designs in qualitative research: Making the sampling process more public. *Qualitative Report, 12*(2), 238-254.

Padel, S. (2001). *Conversion to organic farming: A typical example of the diffusion of an innovation?* Wiley Online Library. doi:10.1111/1467-9523.00169

Pang, S. J., Xiao, T., & Bao, Y. (2006). Dynamic changes of total bacteria and vibrio in an integrated seaweed–abalone culture system. *Aquaculture, 252*(2–4), 289-297. doi:http://dx.doi.org/10.1016/j.aquaculture.2005.06.050

Parker, Nick. (1989). History, status, and future of aquaculture in the United States. *Critical Reviews in Aquatic Sciences*. 1989, 1 (1): 97-109.

Patton, M. Q. (2002). In Patton M. Q. (Ed.), *Qualitative research and evaluation methods* (Third edition .ed.). Thousand Oaks, Calif: Sage Publications.

Peharda, M., Župan, I., Bavčević, L., Frankić, A., & Klanjšček, T. (2007). Growth and condition index of mussel *Mytilus galloprovincialis* in experimental integrated aquaculture. *Aquaculture Research, 38*(16), 1714-1720. doi:10.1111/j.1365-2109.2007.01840.x

Perdikaris, C., A. Chrysafi, K. Ganias. (2016). Environmentally friendly practices and perceptions in aquaculture: a sectoral case study from a Mediterranean-based industry. *Reviews in Fisheries Science and Aquaculture*. 24(2), 113-125

Pettit L. R., Smart C. W., Hart M. B., Milazzo M. & Hall-Spencer J. M.,. (2015). Seaweed fails to prevent ocean acidification impact on foraminifera along a shallow-water CO2 gradient. In Press. *Ecology and Evolution.*

Pew Oceans Commission. (2003). America's Living Oceans: Charting a Course for Sea Change. A report to the nation. Pew Oceans Commission, Arlington, Virginia. Art by: John Michael Yanson adapted from the David Suzuki Foundation 1996.

Price, C., Black, K., Hargrave, B., & Morris, J. (2015). Marine cage culture and the environment: Effects on water quality and primary production. *Aquaculture Environment Interactions, 6*(2), 151-174. doi:10.3354/aei00122

Reid, G. K., Robinson, S. M. C., Chopin, T., & MacDonald, B. A. (2013). Dietary proportion of fish culture solids required by shellfish to reduce the net organic load in open- water integrated multi- trophic aquaculture: A scoping exercise with co-cultured Atlantic salmon (*Salmo salar*) and blue mussel (*Mytilus edulis*). *Journal of Shellfish Research, 32*(2), 509-517. doi:10.2983/035.032.0230

Ridler, N., Wowchuk, M., Robinson, B., Barrington, K., Chopin, T., Robinson, S., . . . Boyne-Travis, S. (2007). Integrated multi − trophic aquaculture (IMTA): A potential strategic choice for farmers. *Aquaculture Economics & Management, 11*(1), 99-110. doi:10.1080/13657300701202767

Robson, C. (2011). Real World Research: A resource for users of social research methods in applied settings. (3) Cornwall, UK: John Wiley and Sons LLC.

Rogers, E. M. (2010). *Diffusion of innovations* Simon and Schuster.

Ruddle, K., Furtado, J. I., Zhong, G. F., & Deng, H. Z. (1983). The mulberry dike-carp pond resource system of the Zhujiang (Pearl River) delta, People's Republic of china: I. environmental context and system overview. *Applied Geography*, (3), 45-62. doi:http://dx.doi.org.uri.idm.oclc.org/10.1016/0143-6228(83)90005-X

Saldaña J. (2016). The coding manual for qualitative researchers (3rd ed.). London, England: SAGE.

Sara, G., Reid, G., Rinaldi, A., Palmeri, V., Troell, M., & Kooijman, S. (2012). Growth and reproductive simulation of candidate shellfish species at fish cages in the southern Mediterranean: Dynamic energy budget (DEB) modelling for integrated multi- trophic aquaculture. *Aquaculture, 324-325*, 259-266. doi:10.1016/j.aquaculture.2011.10.042

Sarà, G., Zenone, A., & Tomasello, A. (2009). Growth of *Mytilus galloprovincialis* (Mollusca, Bivalvia) close to fish farms: A case of integrated multi- trophic aquaculture within the Tyrrhenian sea. *Hydrobiologia; the International Journal of Aquatic Sciences, 636*(1), 129-136. doi:10.1007/s10750-009-9942-2

Shi, H., Zheng, W., Zhang, X., Zhu, M., & Ding, D. (2013). Ecological–economic assessment of monoculture and integrated multi-trophic aquaculture in

Sanggou Bay of China. *Aquaculture, 410–411*, 172-178. doi:http://dx.doi.org.uri.idm.oclc.org/10.1016/j.aquaculture.2013.06.033

Skår, C., K., & Mortensen, S. (2007). Fate of infectious salmon anemia virus (ISAV) in experimentally challenged blue mussels *Mytilus edulis*. *Diseases of Aquatic Organisms, 74*(1), 1.

Soto, D., & Food and Agriculture Organization of the United Nations. (2009). *Integrated mariculture: A global review*. Rome: Food and Agriculture Organization of the United Nations.

Tacon, A. G. J., & Metian, M. (2015). Feed matters: Satisfying the feed demand of aquaculture. *Reviews in Fisheries Science & Aquaculture, 23*(1), 1-10. doi:10.1080/23308249.2014.987209

Tedesco, M. 2013. Sea farming shellfish and seaweed in Long Island Sound, Available at: https://blog.epa.gov/blog/2013/01/sea-farming-shellfish-and-seaweed-in-long-island-sound/. Accessed: March 2016.

Thomas, S.A. (ed). (2010). White Paper. Integrated multi-trophic aquaculture: a workshop. Peninsula College, Port Angeles, Washington.

Troell, M. 2009. Integrated marine and brackish water aquaculture in tropical regions: research, implementation and prospects. In D. Soto (ed.). Integrated mariculture: a global review. *FAO Fisheries and Aquaculture Technical Paper*. No. 529. Rome, FAO. pp. 47–131.

Troell, M., Halling, C., Neori, A., Chopin, T., Buschmann, A. H., Kautsky, N., & Yarish, C. (2003). Integrated mariculture: Asking the right questions.

*Aquaculture*, *226*(1–4), 69-90. doi:http://dx.doi.org/10.1016/S0044-8486(03)00469-1

Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A. H., & Fang, J. (2009). Ecological engineering in aquaculture — potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. *Aquaculture*, *297*(1–4), 1-9. doi:http://dx.doi.org.uri.idm.oclc.org/10.1016/j.aquaculture.2009.09.010

United States National Agricultural Statistics Service. (2013). 2012 Census of Agriculture. Volume 3, Special Studies. Part 3, Census of Aquaculture 2012. Washington, D.C: U.S. Department of Agriculture, National Agricultural Statistics Service.

Waters, J. (2015). Snowball sampling: A cautionary tale involving a study of older drug users. *International Journal of Social Research Methodology, 18*(4), 367-380. doi:10.1080/13645579.2014.953316

Whitmarsh, D., & Palmieri, M. G. (2009). Social acceptability of marine aquaculture: The use of survey-based methods for eliciting public and stakeholder preferences. *Marine Policy*, *33*(3), 452-457. doi:http://dx.doi.org.uri.idm.oclc.org/10.1016/j.marpol.2008.10.003