FINANCIAL RISK ASSESSMENT OF OFF-BOTTOM TRIPLOID OYSTER AQUACULTURE ALONG THE WEST COAST OF FLORIDA

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA
2018

To my Grandma.
We miss you.

ACKNOWLEDGMENTS

I would like to thank my committee, Dr. Kelly Grogan, Dr. Charles Adams, and Dr. Richard Weldon for their assistance and guidance throughout the research and writing process. Also, I would like to thank the UF IFAS Shellfish Extension team, Leslie Sturmer, Reggie Markham, Carter Cyr, and Natalie Simon for their assistance in researching off-bottom oyster production along the west coast of Florida and allowing me to gain hands-on experience in oyster production and water quality monitoring. Without the help of this team and my committee, I would not have been able to complete this project and had the gratification and enjoyable memories from the past two-years.

I would like to thank the entire faculty and staff in the Food and Resource Economics (FRE) Department at the University of Florida for their continued insights, instruction, and support throughout my undergraduate and graduate career. Coming into the department, I was unsure about my future career goals. However, thanks to the FRE departments help, I am focused and excited about the future of my career and research.

I would like to thank all my friends in Gainesville and Cedar Key that kept me motivated outside of the classroom and making some of the best memories of my college experience. You all made Gainesville feel like home. Also, I would like to thank my brothers in West Palm Beach, FL for supporting me throughout my undergraduate and graduate career.

Finally, I would like to thank my parents and Becky and Jason for their continued support and push throughout my undergraduate and graduate career. I would not be in this position without the encouragement of my family.

TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

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August 2018

Chair: Kelly Grogan
Major: Food and Resource Economics

The Florida oyster industry once thrived, producing 6.47 million pounds of wild-harvested Eastern oysters in 1984 and 15% of the national harvest. Atypical environmental conditions and policy changes caused decreases in wild oyster stocks and reduced harvests to approximately 815,000 pounds by 2015. Wild stock reductions and legislative approval of the use of the water column for aquaculture production to utilize off-bottom gear incentivized the Florida oyster industry to adjust from primarily wild-harvest to aquaculture production. Additionally, triploid oyster seed has the potential to improve the profitability of aquacultured oysters in Florida. Unlike naturally occurring diploid oysters, triploid oysters contain three sets of chromosomes that remove their ability to reproduce, allowing more energy for growth.

Along the west coast of Florida, four primary counties utilize off-bottom triploid oyster aquaculture due to ideal water quality: 1) Levy County, 2) Franklin County, 3) Escambia County, and 4) Wakulla County. Each county has unique probabilities of a variety of environmental risk events. Growers also experience market risk through variability in output prices. This thesis sought to determine how risk affects the profitability of triploid oyster aquaculture in these four counties. The results will allow potential growers to make informed decisions about whether to

enter the shellfish aquaculture industry or, in the case of Levy and Franklin counties, to diversify current clam aquaculture production to include oyster aquaculture production.

Simulation results indicate that the modeled aquaculture operation is not profitable in any county in Year 1. In the absence of environmental and market risk, operations in all counties have a positive expected net income after Year 2. In the presence of all environmental and market risk variables, operations in all counties but Levy County have the potential of a negative net income for Year 5. Operations in all counties have a positive expected NPV in the presence of all environmental and market risk events over the five-year time horizon considered. Additionally, operations in Levy County have the smallest spread of potential net income values while ones in Escambia County have the greatest spread in the presence of all environmental and market risk.

CHAPTER 1
INTRODUCTION

The Florida oyster industry once thrived in Apalachicola Bay, contributing to 90% of the wild-harvested Eastern oysters (*Crassostrea virginica*) in Florida until atypical environmental conditions and policy adjustments took a toll on regional oyster stocks (Wildber, 1992). Harvests from wild stocks fell from 6.6 million pounds in 1981 to 815 thousand pounds in 2014 (FDACS, 2016; Andee, 1983). In 2016, the bay's regional production was only approximately 42% of wild harvest in Florida (FWC, 2017a). This decrease in the supply of Apalachicola-region oysters has caused a decrease in overall domestic oyster supply and an increase in market price. In response to higher prices, other states in the U.S. increased production, but price has remained high due to strong consumer demand for oyster products. These high prices also provide an incentive for Florida oyster farming to innovate production methods and increase yields.

In 2013, the Florida Legislature amended the state constitution to allow the use of the entire marine water column for aquaculture purposes; previously marine aquaculture was allowed no higher than six inches from the bottom surface. This recent policy adjustment allows for new floating production gear, known as off-bottom gear. Floating gear elevates the oysters away from natural predators on the bottom and tumbles them via wave movement, thereby forcing the oysters to develop a more marketable shape. This emerging and innovative gear, coupled with an optimal environment, could significantly increase oyster production and help to revitalize Florida's commercial oyster industry.

Research from other states suggests that off-bottom gear increases labor costs and reduces profit margins compared to traditional on-bottom farming gear and wild-harvest methods (eg. tonging), causing skepticism of the profitability of this emerging practice. All marine aquaculture gear suffers from biofouling organisms, such as sea squirts, barnacles, and various types of algae which attach to the gear. In the upper water column, water temperatures are higher than on the bottom, which increases biofouling. Much of the increased labor-hours associated with off-bottom gear result from greater biofouling maintenance. This increase in labor cost of off-bottom gear may be offset by the increased growth rate of the oyster and the natural tumbling that creates a highly marketable shell shape (i.e., deep cup in the shell allowing for a larger, thicker oyster). The former allows the grower to reach market size faster and the latter may allow the wholesaler to sell to the half-shell market and receive a higher price.

Given that biofouling and growth rates vary by production region within the Gulf, Florida growers require a region-specific financial assessment to determine the profitability of off-bottom gear. A thorough assessment must consider all the inherent risks of oyster production: significant variation in salinity and water temperature, declines in market price, and the occurrence of natural events like hurricanes, droughts, and floods. The occurrence of these events may increase operational costs and/or constrain yields, further reducing the profitability of off-bottom production oyster aquaculture.

This thesis helps fill the knowledge gap pertaining to the profitability of off-bottom oyster production along the west coast of Florida. The financial assessment considered in this thesis is especially valuable for existing clam growers along the west coast of Florida who may seek to diversify their current molluscan shellfish crop and increase profitability.

Objectives

The primary objectives of this thesis are to:

- Analyze operational costs and revenues of emerging off-bottom oyster production using triploid (sterile) seed with a regional focus on the west coast of Florida.

- Create a financial model that describes oyster production and predicts profitability under a wide range of environmental and economic conditions.
- Provide existing and prospective oyster growers with a financial spreadsheet that can be utilized to predict each grower's unique costs and revenues.

The overarching goal of this project is to provide information for prospective growers to determine the financial feasibility associated with investing in off-bottom, triploid oyster culture in Florida.

Oyster Markets

Oysters in the U.S. are sold into two distinct markets: the half-shell market and the processed shucked (e.g. removed from the shell) market. The half-shell market consists of meticulously selected live oysters of the highest grade, known as "counter stock oysters" (Wirth & Minton, 2004). Such oysters have a premium shell appearance (i.e. minimum biofouling) and are deeply cupped. These oysters, sold as shellstock (in the shell), are commonly consumed on the half-shell raw, steamed, grilled, or baked with popular recipes. Accordingly, consumers consider these half-shell oysters a premium product in the market and, thus, shellstock oysters receive a higher price compared to oysters sold into the shucked market. A relatively small percentage of nationally harvested oysters are sold into the half-shell market due to the demand for high-grade standards. However, approximately 86% of Florida oysters are sold into the half-shell market while the remaining go into the shucked market (Morgan et al., 2010).

Most wild-harvested oysters, on a total U.S. basis, are sold into the shucked market. Oysters sold into this market do not have a desirable shell appearance and frequently have a smaller shell length and cup size as compared to oysters sold in the half-shell market. Thus, oysters destined for the shucked market receive a lower market price than half-shell oysters.

Unlike the half-shell market, oysters sold into the shucked market are sold by weight or volume (Walton et al., 2013). Shucked oysters are primarily processed into five distinct products; “fresh raw shucked oysters, breaded oysters, canned or stewed oysters, and smoked oysters” (Wirth & Minton, 2004; Lipton & Kirkley 1994). Nonetheless, the Gulf of Mexico is the primary producer of total wild-harvested oysters nationally, producing over 50% of the U.S. wild-harvested oyster weight since 1980 (VanderKooy, 2012).

U.S. Economics of Oysters

Between 1994 and 2015, the nominal sales value of all oysters produced nationally increased by 128.1%, while the total quantity of oysters produced decreased by 27.7% (NMFS, 2016). These values include all species of wild-harvested and aquacultured oysters from all regions in the U.S. During the 1983 to 2015 period, wild-harvested and aquacultured Eastern oyster production specifically, increased in sales value by 179.5%, while decreasing in the quantity produced by 35.9% throughout the U.S. (Figure 1-1). The increase in oyster value is in part due to the increase in cultured oyster production and a decrease in wild stocks; as cultured oysters became more common, the average nominal price per pound in the U.S. increased from $1.51 to $6.58 from 1983 to 2015 (Figure 1-2).

The Gulf of Mexico, the Chesapeake Bay, New England, and the Mid-Atlantic regions produce the greatest quantity and value of Eastern oysters including wild-harvested and aquacultured oysters (Figures 1-3 and 1-4). Northern regions, such as the Mid-Atlantic and New England, produce oysters in colder waters that experience lower amounts of bio-fouling. Such an environment produces oysters that can have a better shell appearance (i.e., deep cup) and demand a higher market price reflecting the higher value per pound (Figure 1-5). Additionally, the Chesapeake Bay primarily produces cultured oysters, which allows production to increase despite reductions in wild stocks. On the other hand, the Gulf of Mexico primarily produces wild-harvested oysters resulting in a decrease in production due to reductions in wild stocks, such as has been seen recently with production in the Apalachicola Bay region.

The Gulf of Mexico region includes five states; Texas, Louisiana, Mississippi, Alabama, and the west coast of Florida. These states account for the Eastern oyster production previously discussed. The top three producing states measured in pounds and value in 2015 were Louisiana, Texas, and the west coast of Florida (Figures 1-6 and 1-7). The decrease in wild-harvested oyster production within the Gulf of Mexico is providing an incentive for researchers to study the viability of cultured oysters within their region as a potential strategy to restore production to historic levels, while also increasing total market value.

Florida Oyster Economics

While the national trend of Eastern oyster production has increased from 2005 to 2015, Florida oyster production has decreased over the same period (NMFS, 2016). Wild-harvested diploid oysters (oysters with two sets of chromosomes) make up the majority of oyster production in Florida. Although wild harvesting is relatively low cost, requiring only fuel, harvesting tools, and paid labor, the Florida industry is shifting from wild harvests to aquaculture production due to changing environmental conditions that have greatly reduced oyster stocks on natural reefs. In 2015, Florida produced approximately 900,000 pounds of wild oysters, relative to an annual average of 2.2 million pounds between 2000 to 2010 and an annual average of 4.4 million pounds during the 1980s (Florida, 2016; VanderKooy 2012, FWC, 2017a).

Lack of Florida-specific cost data for the new culture process impedes increased participation by potential growers in Florida’s emerging oyster aquaculture industry. Based on research from other states, as mentioned above, oyster culture is currently a labor-intensive process with low-profit margins, making potential growers hesitant to enter the industry. However, Florida's unique environmental conditions could increase the profitability of the endeavor. For example, Florida's water temperature is higher than the northern states, which potentially allows Florida oysters to grow more quickly. This reduces the growout period, allows access to markets earlier in the year, and possibly increases revenues.

On the other hand, higher temperatures allow biofouling organisms to grow more quickly and regularly throughout the year. This requires more gear replacement and labor to clean equipment, thereby increasing costs. This project addresses the operational and startup costs associated with emerging production methods in the Gulf of Mexico.

Apalachicola Bay Oyster Industry History

Apalachicola, a small town deep-rooted in history dating back to the 1500s, is located in the panhandle of Florida and sits on the edge of the nutrient-rich waters of the Apalachicola Bay, into which the Apalachicola River flows. Further north, the natural convergence of the Chattahoochee River and the Flint River at the Jim Woodruff Dam forms the Apalachicola River and the 106-mile Apalachicola-Chattahoochee-Flint (ACF) Basin (Edmiston, 2008; Wilber, 1992). The ACF Basin discharges into Apalachicola Bay, creating the required mix of fresh and saltwater, thereby fueling oyster growth and abundance along with countless other fishery species to form a unique ecosystem only found in the Gulf of Mexico (Wilber, 1992). These conditions have provided for the development of many natural oyster "reefs," upon which the commercial, wild-harvest oyster industry has been dependent.

Apalachicola Bay was once the largest producer of wild-harvested Eastern oysters in the U.S., producing approximately 90% of recorded harvests in Florida and 10% of the national harvest (Wilber, 1992). From 1971 to 1976, commercial harvests averaged 2.5 million pounds annually. Production increased substantially in the following years averaging 6 million pounds from 1980 to 1984 and a record high of 7.2 million pounds in 1981 (Andree, 1983).

However, in the mid-1980s, environmental and demographic changes began that contributed to a stressed industry. In 1985, two hurricanes struck Apalachicola Bay within the span of three months causing massive damage to natural reefs and oyster stocks that were already overfished (Livingston et al., 1999). The first storm to strike, Hurricane Elena, hit the bay on September 1 and 2, bringing wind speeds of 126 miles per hour and 18 centimeters of rainfall (NOAA, 2016a). Less than three months later, on November 21, Hurricane Kate made landfall with maximum wind speeds of 98 miles per hour and an average of 11.7 centimeters of rainfall (NOAA, 2016b). The primary damage occurred in stocks located on the east side of the bay, where reefs were buried with sediment, causing suffocation (Berrigan, 1988). Oysters that had recovered from Hurricane Elena were small when Hurricane Kate arrived due to the short time between storms. This lead to a greater rate of oyster mortality and further reductions in stock densities than normal. Concurrently, in September 1985, the Florida Department of Natural Resources shut down the entire oyster industry in the region through September 1986 due to significant declines in oyster stocks (Livingston et al., 1999). Once the industry reopened, restrictions on harvesting limited oystering to only Monday through Thursday from sunrise to 4:00 PM with daily bag limits of twenty-five 60-pound bags per day (Dugas et al., 1997). The purpose of this new regulation was to allow oyster stocks to recover by limiting the effort.

In addition to the hurricanes, Apalachicola Bay experienced three consecutive drought years from 1986 to 1988 causing high levels of salinity, further threatening oyster stocks (Dugas et al., 1997). As will be explained further oysters require a specific range of salinity. Water that is too fresh or too salty introduces hurdles for a resident oyster population.

Following the environmental damage caused by the hurricanes and drought, population increases and urban development caused increased upstream demand for freshwater from the ACF Basin. As a result, greater volumes of water were diverted from the river for drinking water, industrial use, and other uses. Furthermore, in 1989, Atlanta requested to double water withdrawals from the Chattahoochee River to 529 million gallons per day for “drinking, sanitation and industrial uses” (Beaverstock, 1997). Soon after Atlanta issued the request, Alabama filed a lawsuit, claiming that the request would reduce development and diminish water quality downstream. Florida similarly filed a lawsuit claiming that the lower freshwater levels would disrupt their oyster industry and ecology within Apalachicola Bay (Beaverstock, 1997). Georgia, Alabama, and Florida agreed to end legal action and fund a five-year study conducted by the United States Army Corps of Engineering (USACOE) (Keene, 2004). The three states agreed to form a water planning authority called the Apalachicola-Chattahoochee-Flint Commission while the USACOE conducted the study. The commission included one representative from each state and a Federal representative. Each representative had one equal vote on the distribution of freshwater flow once the study was finished. At the conclusion of the study, the commission failed to reach a consensus, causing the three states to enter a very complicated legal battle that continues today, reaching as high as the U.S. Supreme Court and referred to as the “Tri-State Water War” (Beaverstock, 1997).

The reductions in freshwater flow to Apalachicola Bay due to drought and diversions resulted in higher salinity levels. Research suggests that increases in salinity correlate with an increase in oyster predators, such as the *Stramonita haemastoma*, *Melogena corona*, and various parasites, that increase mortality and devastate oyster stocks (Havens et al., 2013; Menzel et al., 1966). A sample of oysters taken in 2012, revealed that 97% of oysters contained *Perkinsus*

marinus, a single-celled parasite that causes mortality in oysters 2 to 3 years of age, commonly referred to as Dermo or the "Summer Mortality Syndrome" (Havens et al., 2013; FWC, 2013; Petes et al., 2012). Local oystermen also commented on the increase in mortality from this parasite that wiped-out oyster populations in Apalachicola Bay (Camp et al., 2015).
Reduced water flows to the bay also reduce nutrient inputs, which are a critical oyster food source. As a result, oyster growth has slowed and predation has increased leading to a rise in oyster mortality (Havens et al., 2013). The water quality conditions that have led to the "collapse" of the Apalachicola Bay oyster stocks may continue to persist for the foreseeable future providing a sustained incentive to enhance oyster production from other regions of Florida and create a further incentive for innovative culture methods (Pine et al., 2015)

Cedar Key Aquaculture

The molluscan shellfish aquaculture industry in Cedar Key owes its start to various regulations. In 1990, the U.S. Food and Drug Administration (FDA) banned Suwannee Sound oystering due to bacteria escaping septic tanks and polluting local stocks of oysters (Stephenson, 2013). As a result, Project OCEAN opened applications for shellfish aquaculture leases in areas with approved water conditions and graduated 130 students trained in clam and oyster aquaculture production.

Following the FDA-mandated oyster stock closures, an amendment of Article X, Section 16 of the State Constitution came into effect, which restricted the use of entanglement nets in state waters to be no larger than 500 square feet (Smith et al., 2003). Entangling nets were the primary gear used by near-shore commercial fishers who targeted mullet, sea trout, and other finfish species. Advocates of the regulation, such as the *Save Our Sealife* campaign, stated that entanglement nets, also known as "gill" nets, killed endangered marine animals and caught anything that swims, not just targeted finfish species. However, opponents of the gill net restriction claimed that the controversy was primarily a social issue pitting commercial and recreational fishers in a battle over "who gets the fish." The regulation, enacted on July 1, 1995, caused approximately 1500 near-shore net fishers across Florida to lose revenues or their livelihood entirely (Smith et al., 2003).

To help impacted fishers prepare for life following the enactment of the new restrictions, the Florida Department of Labor and Employment Security introduced job-retraining programs. Due to the success of Project OCEAN, Project WAVE was initiated in 1995 with the mission of training displaced net fishers in clam aquaculture. Throughout the life of this project, 69 former net fishers were provided clam and oyster aquaculture leases to begin production (Colson & Sturmer, 2000). While the amendment forced many out of their net-fishing occupation, the retraining projects helped create a successful hard clam culture industry that is worth $18.7 million in annual farmgate sales and generates $52 million in economic impact to the Florida economy (USDA, 2014). The current shellfish aquaculture infrastructure coupled with the decline in Apalachicola oyster stocks and increased oyster prices provide Suwanee Sound clam growers the opportunity to expand into the oyster culture industry, help fill Florida's production gap, and meet a growing demand for oysters.

Eastern Oyster Life Cycle

The Eastern oyster is naturally occurring along the Atlantic coast, from the Gulf of the Saint Lawrence in Canada to the Gulf of Mexico in the U.S. Throughout these regions, the Eastern oyster commonly grows in salt marsh environments and other subtidal and intertidal zones, growing in clumps and forming oyster reefs that provide habitat for other marine species (Grabowski et al., 2012; Buroker, 1983). Eastern oysters have various life cycle phases, including a planktonic larvae phase, a pre-reproduction or spat phase, and a final adult phase allowing for reproduction. Each of these phases are critically dependent on specific water quality parameters and food sources.

The life cycle begins with the reproductive process, which is controlled by water temperature, with critical threshold temperatures differing among regions. For example, Eastern oysters found further north in the Chesapeake Bay tend to reproduce when water temperatures reach 60°F to 68°F, while oysters found further south in the Gulf of Mexico tend to spawn at water temperatures above 68°F (Wallace, 2001). The female oyster releases eggs and the male releases sperm into the water column. The sperm fertilizes the egg, forming an embryo. Approximately 4 to 6 hours post-fertilization, the embryo develops into a microscopic free-swimming planktonic larva, which soon reaches the trochophore stage (Wang et al., 2005; Wallace, 2001). Due to the warmer water temperatures, Gulf oysters experience a longer spawning season and produce more larvae (Dekshenieks et al., 1993). Once the oyster larva develops a thin shell and begins feeding on microscopic algae, in approximately 24 to 48 hours, the oyster reaches the D-larvae stage. In roughly 12 to 20 days, the larva will develop a foot and eye allowing the oyster to attach to a permanent location. This stage is referred to as the pediveliger stage and the developing oyster is known as an eyed larva (Wallace, 2001). Once the planktonic pediveliger settles onto a substrate, it will cement itself to that location with strong abyssal threads and begin growing. The newly set oyster is known as a spat (Wallace, 2001). After setting, the oyster can reach sexual maturity within 4 months but may take an additional 12 to 36 months before reaching marketable size. In the Gulf region with warmer water, this time period can be shorter. Oysters will settle upon and attach to substrate or other oysters, a compounding process that will eventually create an oyster reef.

Oyster growth is dependent on food availability and precise water parameters such as temperature, salinity, dissolved oxygen (DO), pH, and the presence of various other micronutrients during early lifecycle stages (Hayes & Menzel, 1981). Of these parameters, temperature and salinity have the greatest impact on growth. For example, planktonic oyster larvae growth is fastest at temperatures between 27.5°C and 32.5°C and salinities from 15.0 to 27.0 ppt (parts per thousand) (Stanly 1986; Cake, 1983; Davis & Calabrese, 1964). Also, compared to larvae and spat, adults can survive and grow in more extreme water temperatures and salinities. For instance, adult oysters found in the Gulf of Mexico can survive water temperatures up to 35 °C. However, southern oysters are less tolerant to freezing compared to oysters found in the north (Stanly 1986; Cake, 1983; Galtsoff 1964). While adult Eastern oysters can survive salinities as low as 2 ppt or as high as 40 ppt in colder waters for up to 30 days, growth only occurs in salinities between 10 and 30 ppt (Stanly 1986). There is no single optimum temperature nor salinity for growth and survival that applies to all oysters.

Similar to water temperature and salinity, the optimum food level can vary. Adult oysters primarily feed on plankton, such as naked flagellates and small bacteria, through a water filtration process that utilizes their gills (Wikfors et al., 1996). Research has shown that oysters can survive in extreme conditions, but growth to marketable size in the shortest time period is dependent on narrow ranges of temperature and salinity coupled with food availability. Knowing the water quality parameter's "sweet spot" is crucial to commercial oyster growers as they strive to cultivate a market oyster in the shortest time frame, with the least mortality, and at the lowest cost.

Diploid vs. Triploid Oysters

Historically, oyster growers throughout the U.S. produced diploid oysters naturally found in the wild. However, as is prevalent throughout all agriculture, growers constantly search for innovative production methods that increase yields or output prices. In 1960, scientists began researching traits within oysters that provide resistance to common parasites, bacteria, or viruses. For example, Delaware Bay successfully bred a diploid oyster resistant to Multinucleated Sphere Unknown, MSX, a fatal disease that reduced oyster reef restoration in the Chesapeake Bay (Harding, 2007). Soon after, scientists began researching the possibility of introducing genetic variants of Eastern oysters that would be more resistant to disease and stress. These genetically altered oysters can potentially demonstrate increased growth and survival.

Unlike diploid oysters, triploids contain three sets of chromosomes. This genetic structure removes their ability to reproduce. As a result of sterility, triploid oysters do not expend energy toward reproduction and can focus more of their energy on growth. Also, triploid oysters can potentially grow more quickly than diploids (Dégremont et al., 2012). Thus, accelerated growth and less spawning-related mortality allow growers to harvest marketable-sized triploid oysters sooner and produce, on average, more oyster crops per year, thereby increasing revenues. Currently, there are two common methods to propagate triploid oysters: 1) chemical induction and 2) a tetraploid and diploid cross. In 1978, scientists treated fertilized oyster eggs with cytochalasin B to assess the effectiveness of polyploidy in Eastern oysters (Stanely 1981). Results revealed over 50% of the diploids treated with cytochalasin B became triploids and approximately 33% survived (Stanely, 1981). However, in 1995, additional efforts cross-bred a *Crassostrea gigas,* Pacific oyster tetraploid (containing sets of four chromosomes) with a Pacific diploid oyster. The results revealed that approximately 28% of fertilized eggs survived while producing 100% triploids. As a result, this latter method is currently the most preferred method for producing triploid oysters (Guo et al., 1996). Therefore, most triploid oyster seed produced today comes from a tetraploid and diploid cross due to an acceptable mortality rate and a 100% rate of triploidy within the surviving oysters.

In terms of growth, diploid and triploid oysters have similar growth rates until spawning. After spawning, diploids only increased wet tissue weight by 49% while triploids increased by 137% (Allen & Downing, 1986). A comparison of the triploid Eastern oyster versus the diploid Eastern oyster showed that triploids had a significantly larger average shell height, larger cup ratio, and a higher percentage of market size oysters within a cohort compared to diploids (Stone et al., 2013). As a result, producing triploid oysters is becoming more common within the oyster culture industry despite the higher cost of producing triploid seed. Triploid seed is the primary seed type utilized by growers in the northeast and pacific northwest regions. Other states in the Gulf region have also begun research on triploid oyster viability and are assessing potential benefits.

Farming Oysters in the Gulf of Mexico

Throughout the Gulf of Mexico, oyster farming is gaining interest as wild stocks have declined and market prices continue to increase. Due to recent policy changes allowing growers to produce aquacultured products in the water column, alternative growout methods are emerging. Apalachicola and Suwanee Sound oystermen looking to remain in the industry by switching from wild harvest to aquaculture, along with existing conventional clam growers seeking to expand production, are beginning to purchase diploid and triploid seed from hatcheries and are trying to assess the feasibility of producing farm-raised oysters.

From spawning in hatcheries to growout on a lease site, oyster culture follows an intricate path. Oysters spawned in hatcheries have two common methods of setting. The first and most common method allows the oyster larvae to set on old oyster shell or clamshell, known as cultch, placed on wire mesh at the bottom of a tank (Wallace, 2001). The next method, known as remote setting, involves spawning the oysters and placing the larvae into large tanks called wellers. In the wellers, microscopic pieces of cultch material lie on top of a wire mesh. The individual larvae will set on a piece of culture material, producing single set, or individual, oysters (Wallace et al., 2008; Wallace, 2001). Wellers circulate clean water and food through a wire-mesh bottom tank, with the water exiting through a PVC pipe located near the top of the tank. (Wallace, 2001). To feed the oyster larvae, the hatchery cultivates single-celled algae and, depending on oyster density and size, delivers precise volumes of algae into the culture tank. As a result, the process of remote setting oysters is more expensive than the traditional method due to increased capital and labor that provide accurate spat and food density into the wellers (Sturmer et al., 2003; Wallace et al., 2008). While remote setting has the potential for future automation, this process is currently done by hand which leads to increased labor costs.

Hatcheries typically sell single set oyster seed to growers to plant on their leases at different sizes and prices. The growers typically place seed in gear along the substrate for final growout, known as on-bottom culture (Wallace, 2001). On-bottom culture is common throughout the Gulf of Mexico and along the east coast of the U.S. (Walton et al., 2013). To allow the oysters to grow without being suffocated by sediment, the gear is typically placed on hard bottom as opposed to softer muddy bottom. Along with possible sediment suffocation, other disadvantages associated with on-bottom culture include increased bio-fouling, less inventory control, such as cleaning and drying time through growout, and an increase in oyster predation.

However, the on-bottom method requires less labor than other growout methods. While on-bottom methods can produce large amounts of oysters, the inconsistent shapes and often poor visual appearance of the shell cause wholesalers to sell a large percentage of these oysters into the lower-priced processed shucked market (Walton et al., 2013). As a result, growers recently urged the Florida legislature to approve new regulations that grant the use of various water column production methods that produce higher quality oysters.

On June 25, 2013, Governor Rick Scott and the Florida Cabinet approved the use of the water column for shellfish aquaculture on two leases in Alligator Harbor stating that "it is in the state's economic, resource management, and food production interests to promote aquaculture" through the leasing of "submerged lands and water columns" (FDACS, 2014a; Governor Rick Scott, 2013). In 2016, Chapter 253.68 to the Florida Statues officially authorized the lease or use of "submerged lands and water column for aquaculture activities" in all counties in Florida (FLA. STAT. §253.68). To obtain a water column lease, the grower must go through a lengthy application process. First, the grower files an application with the Florida Department of Agriculture and Consumer Services (FDACS) who then sends the application to the Department of Environmental Protection (DEP) and the Florida Fish and Wildlife Conservation Commission (FWC) for final approval. Then the grower files with the United States Army Corps of Engineers (USACOE) and the U.S. Coast Guard (USCG) and marks each lease with a 36" by 36" diamond sign and navigation lights. In total, this process costs approximately $1,000, including application fees, marking costs, and installation of lights (FDACS, 2014a; FDACS, 2014b). If approved, the grower pays additional annual rental fees to the state of $53.46 per 2-acre parcel for bottom leases, and $86.92 per 2-acre parcel for water column leases (FDACS, 2014b). Once the grower completes the application, pays the necessary fees, and the lease is prepared, the grower may begin locating culture apparatuses and planting oysters on the lease. Currently, culture methods are shifting from on-bottom to off-bottom gear such as floating bags, floating cages, and adjustable long-lines (Figure 1-8).

Each off-bottom gear type carries unique benefits and drawbacks making them favorable or unfavorable to various growers and environmental conditions. For example, off-bottom bags are lighter and smaller than cages, allowing for varied setups desired by the grower, but they are also more vulnerable to environmental damage due to their light weight. Next, floating cages are heavier, allowing them to withstand environmental damage and allowing growers to sink them if necessary. However, the increase in weight requires an increase in labor to set up and maintain. Finally, longlines are easier to handle than floating gear but they require precise measurements to ensure that bags are submerged and exposed with the changing tides. Further research is needed to determine the most cost-effective gear type for a given set of environmental conditions.

All off-bottom gear places the oysters in mesh containers that elevate them into the water column. Growers clean off-bottom gear regularly via flipping or scrubbing, allowing oysters to grow more quickly and have a more consistent shell shape and appearance (Walton et al., 2013; Adams et al., 2011). However, maintaining this gear type increases labor cost throughout the growout cycle. Therefore, off-bottom production will only be financially viable if the oysters receive higher prices than conventionally grown and wild-harvested oysters in the half-shell market (Walton et al., 2013). For example, from 2006 to 2010, wild-harvested oysters from the Gulf Coast received $3.17 per pound, compared to cultured oysters from New England that received $33.67 per pound during the same period (Walton et al., 2012); most wild oysters from the Gulf region, excluding Florida, go to the shucked market while many New England cultured oysters go to the half-shell market. However, if Gulf oysters grown in the water column can compete with the New England market and other half-shell markets, then this innovative production method may be profitable enough to provide Florida shellfish growers with a financially viable production option.

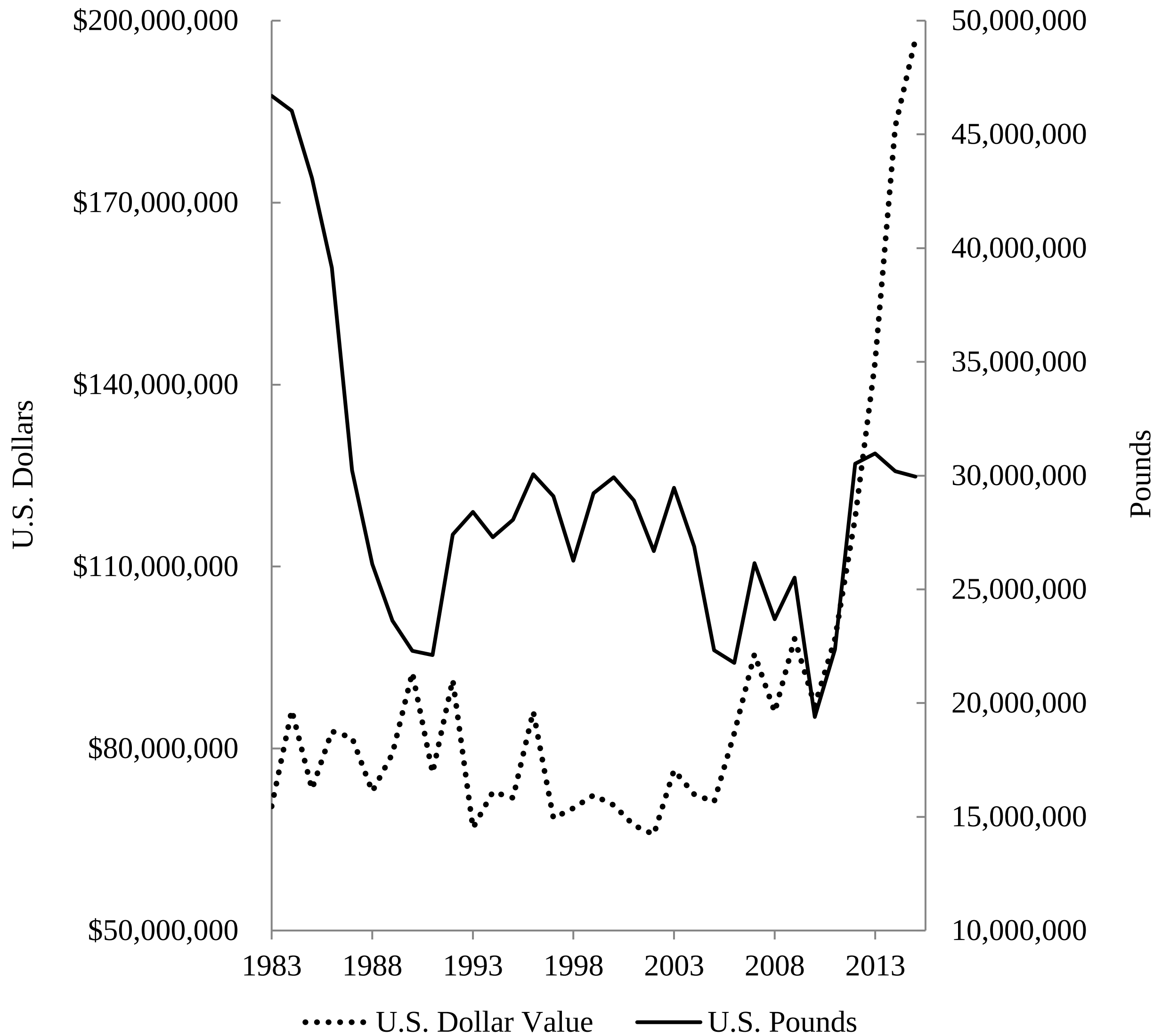


Figure 1-1. U.S. Oyster Production, Measured in Pounds of Meat Weight, and Nominal Value[1]

[1] NMFS, 2016

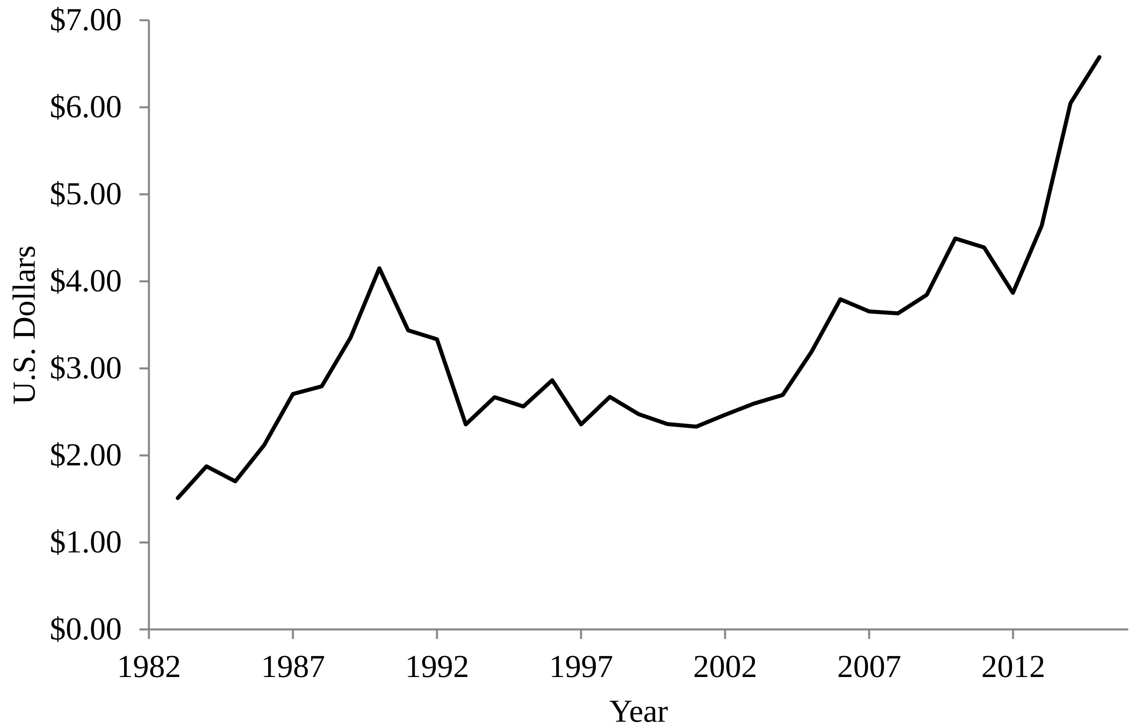


Figure 1-2. Average U.S. Market Price per Pound of Meat Weight of Eastern Oysters[2]
Note: Measured in nominal U.S. dollars

[2] NMFS, 2016

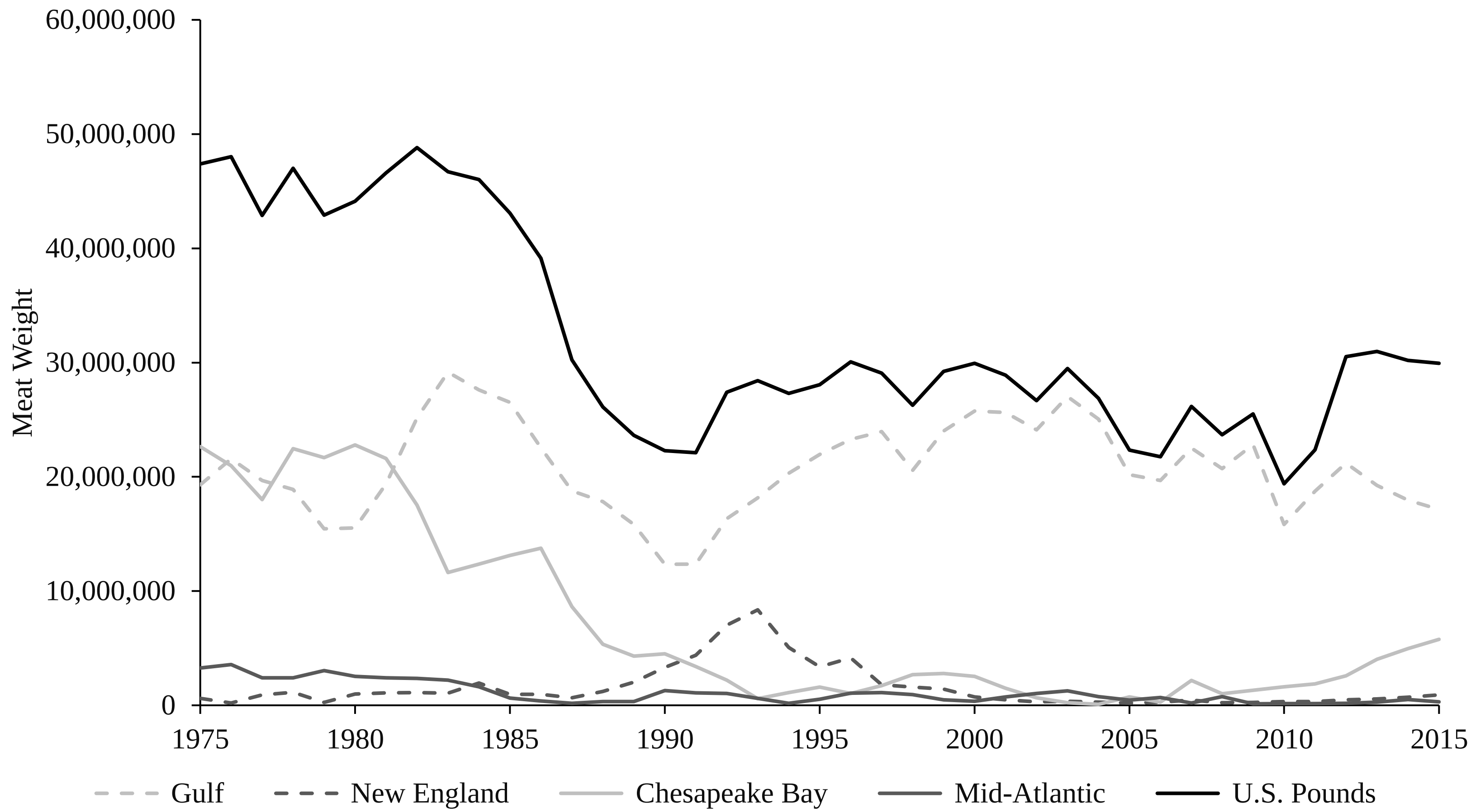


Figure 1-3. Wild-caught and Aquacultured Eastern Oyster Production in the U.S. Note: Units are pounds of meats.

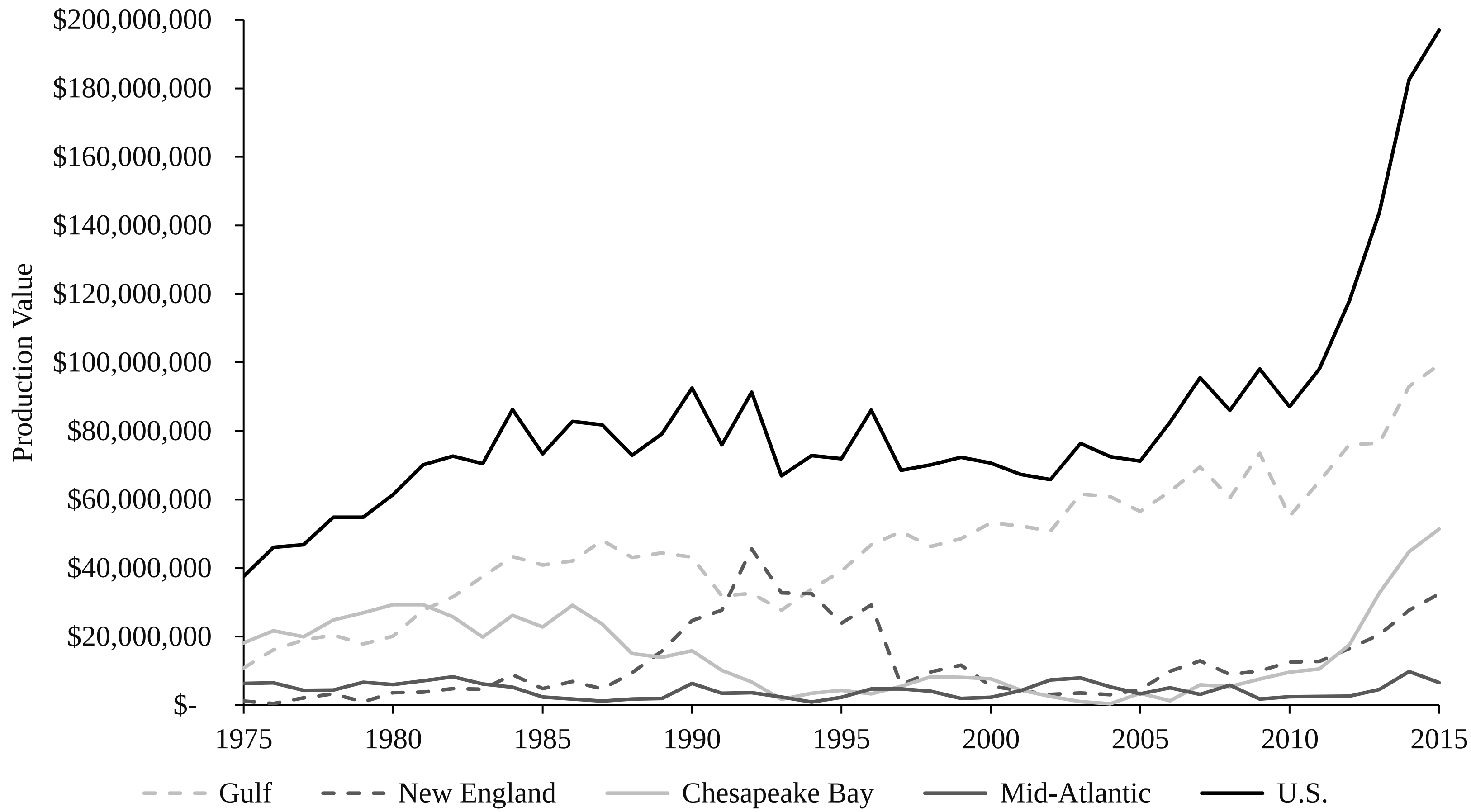


Figure 1-4. Total Production Value of Wild-caught and Aquacultured Eastern Oysters in the U.S. Note: Units are nominal U.S. dollars

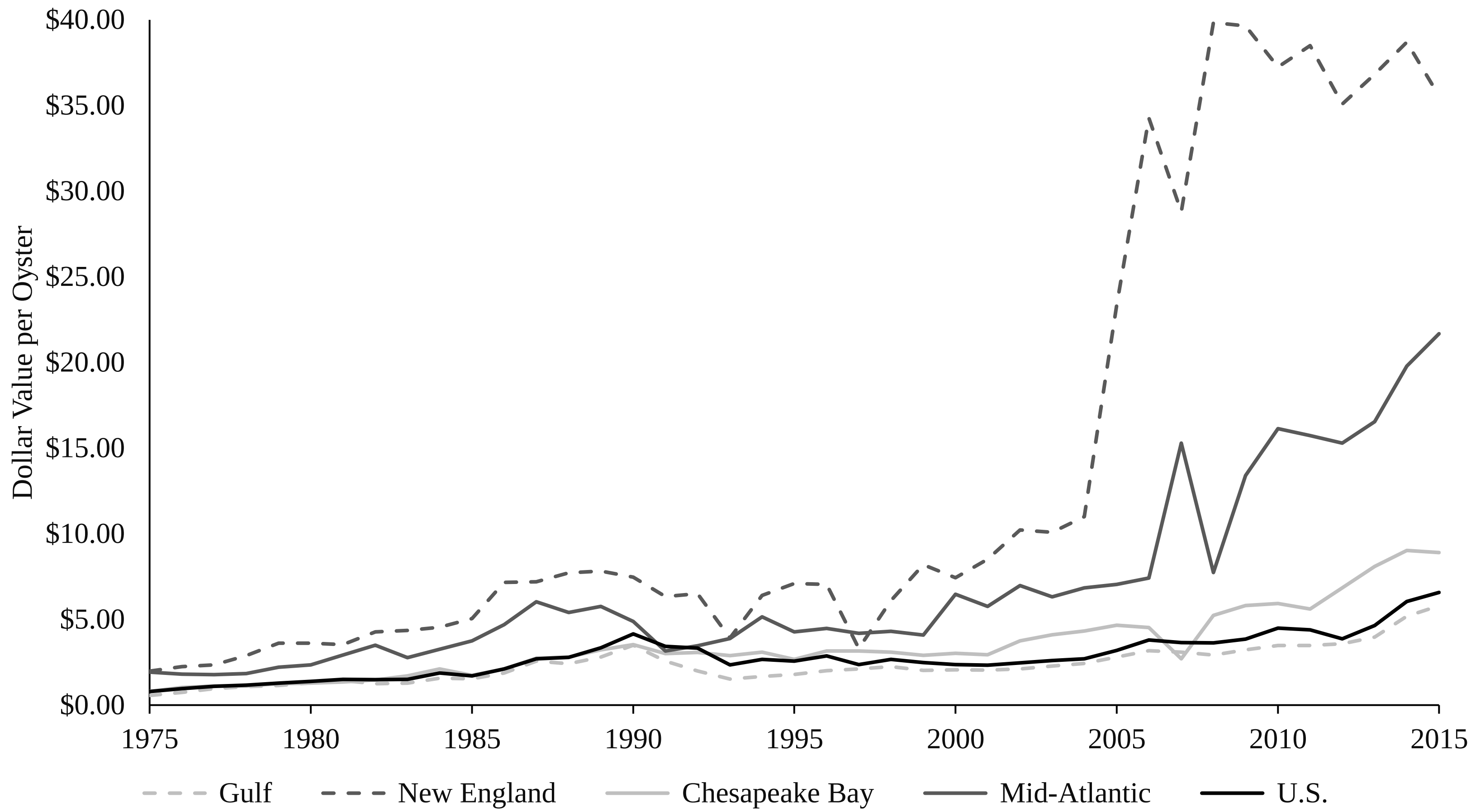


Figure 1-5. Average Market Price per Pound of Meat Weight of Wild-caught and Aquacultured Eastern Oysters among Regions. Note: Units are nominal U.S. dollars

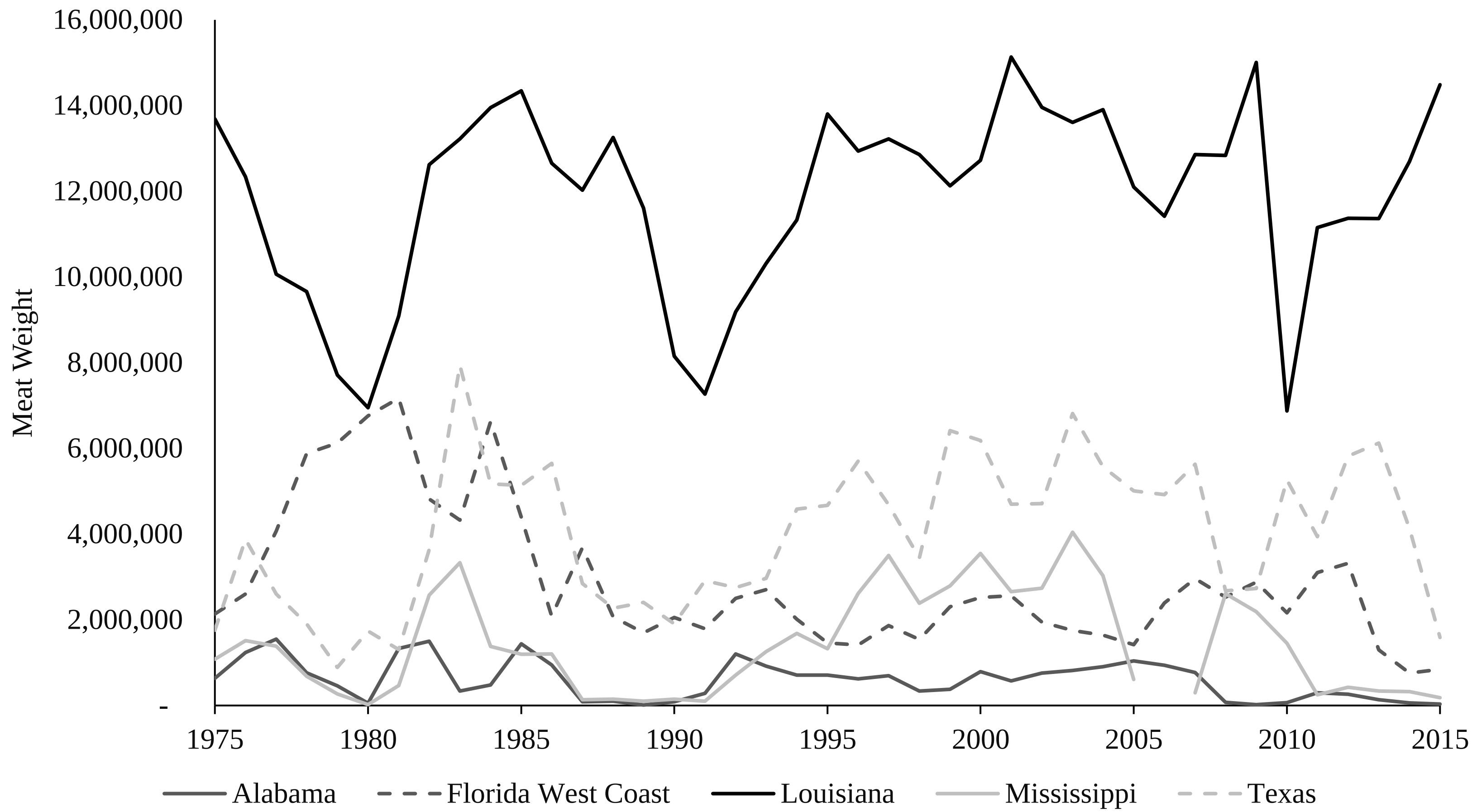


Figure 1-6. Total production of Wild-caught and Aquacultured Eastern Oysters in the Gulf of Mexico Region Separated by State. Note: Units are pounds of meat.

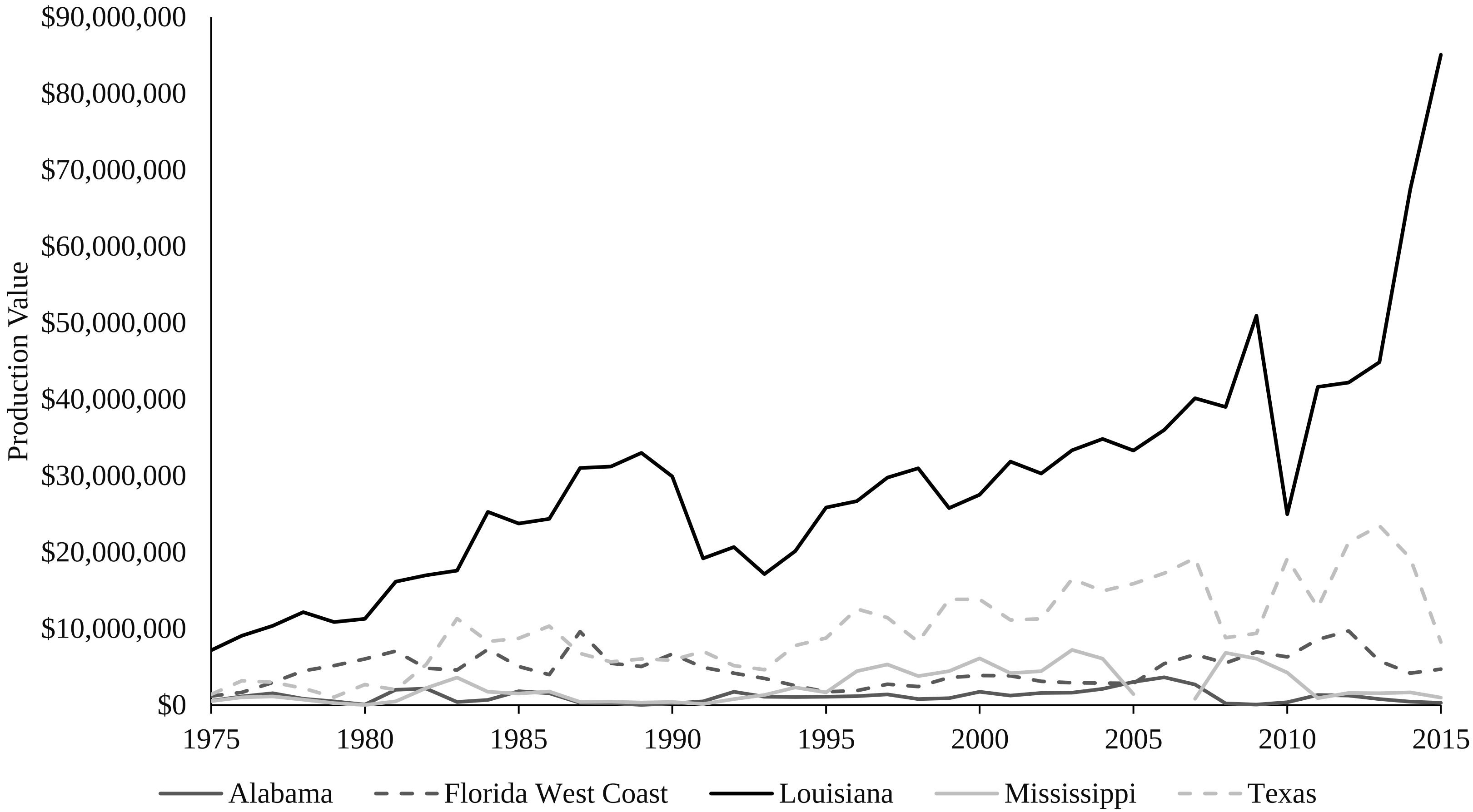


Figure 1-7. Total production Value of Wild-caught and Aquacultured Eastern Oysters within the Gulf of Mexico Separated by State. Note: Units are nominal U.S. dollars

	Exposed	Submerged
Floating Cages	A) 	B) 
Floating Bags	C) 	D) 
Adjustable Longlines	E) 	F) 

Figure 1-8. Examples of Three Types of Floating Gear Exposed for Aerial Drying and Submerged for Growout
A) *Exposed Off-Bottom Cages*. April 18, 2018. Cedar Key, FL. Photo courtesy of author. B) Source: Comeau, (2014). C) *Exposed Off-Bottom Bag*. September 21, 2016. Cedar Key, FL. Photo courtesy of author. D) *Submerged Off-Bottom Bag*. September 21, 2016. Cedar Key, FL Photo courtesy of author. E) Auburn, (2014). F) Source: Saoysters, (2008).

CHAPTER 2
LITERATURE REVIEW

Formally, economists define agricultural risk as the “uncertainties inherent in weather, yields, prices, government policies, global markets, and other factors that impact farming” (USDA, 2016). Growers confront countless decisions incorporating various levels of risk throughout a production season. All individuals contain unique preferences towards and perceptions of risk, leading to various decision-making techniques and conclusions.

While there is an infinite number of risk preferences, researchers classify individual risk attitudes into three common categories: 1) risk-averse 2) risk-neutral and 3) risk-preferring (Hillson & Murray-Webster, 2007). A risk-averse individual is uncomfortable with risk and considers high levels of uncertainty to be unfavorable. Therefore, decision-making by such an individual tends to ignore profitable opportunities and instead focuses on threats or possible losses. Risk-neutral individuals embody preferences in between risk-averse and risk-seeking preferences. Risk-neutral individuals accept risk as a necessity for future benefits leading to rational decision-making regarding threats or benefits. Risk-preferring individuals appreciate the challenge within risky decisions, sometimes underestimating risk levels and their potential impacts, leading to decisions with large risk but potentially higher payoffs (Hillson & Murray-Webster, 2007).

Economists depict individual risk attitudes using Snyder’s preference curve, as seen in Figure 2-1. To derive this curve, interviewers ask an individual a series of questions regarding the amount of money they are willing to accept immediately instead of future risky payoffs. The interviewer creates a minimum of three scenarios. Each scenario contains a gamble with two possible payouts with an associated probability of obtaining each payout. For example, the interviewee may face a gamble with a 50% chance of winning \$0 and a 50% of winning \$400. The interviewer asks the participant the sum of money they are willing-to-accept immediately for certain instead of taking the gamble. Researchers develop Snyder's curve using the data points from the questionnaire. The horizontal axis of Snyder's curve represents the achievable payoffs with \$0 representing the minimum possible payoff and $\$400$ representing the maximum possible payoff. The vertical axis represents the utility received from the individual taking the gamble. The solid curve represents the utility gained from taking the immediate payoff without participating in the gamble ($u(E(v))$). The dotted line represents the expected utility from participating in the gamble ($E(u)$). Risk-adverse individuals have utility such that $E(u) < u(E(v))$, risk-neutral individuals have utility such that $E(u) = u(E(v))$, and risk-loving individuals have utility such that $E(u) > u\big(E(v)\big)$, illustrated in Figure 2-1. Preference curves are concave for risk-averse individuals, straight lines for risk-neutral individuals, and convex for risk-seeking individuals (Hammond, 1967).

Risk Distributions

The variance or distribution around the expected value of the decision illustrates the variation in possible outcomes of a decision involving risk. Therefore, as risk varies, so does the variance around the expected value, creating various distributions. The analysis describes two categories of distributions below: 1) continuous and 2) discrete (Richardson et al., 2006). Continuous distributions do not have any breaks or gaps in possible values, resulting in an uninterrupted function. On the other hand, discrete distributions, often called non-parametric distributions, contain breaks or gaps in possible values and researchers must integrate them using summation (Richardson et al., 2006). This thesis utilizes 6 distributions classified as continuous or discrete distributions discussed below.

Uniform Distribution

A uniform distribution is a continuous distribution where the probability of choosing any given value is equal to the probability of choosing any other value. Its probability distribution function (PDF) is a horizontal line and the cumulative distribution function (CDF) is a straight, positively-sloped line (Figure 2-2). This distribution is commonly used to generate random numbers during simulation. In the event that simulation requires random numbers that are constant across runs of the same simulation, simulation software uses a pseudo-random number generator (Richardson et al., 2006). A pseudo-random number generator randomly obtains a deterministic sequence of numbers between 0 and 1 using a uniform distribution to create a uniform standard deviate (USD) (Ripley, 2009). The software stores the USD and uses it for each iteration (Richardson & Gray, 2002).

Normal Distribution

Normal distributions are symmetric, continuous functions characterized with a bell-shaped PDF. Figure 2-3 illustrates a PDF and CDF of a standard normal distribution with a mean of 0 and a standard deviation of 1. For a normal distribution, 66% of values fall within one standard deviation of the mean and 95% of values fall within two standard deviations of the mean. The symmetry of the distribution implies that 50% of values are above and 50% are below the mean of the dataset (Dixon & Massey, 1969; Richardson et al., 2006). Normal distributions are often used due to their familiarity and mathematical adaptability (Richardson et al., 2006). Many biological processes, such as mortality, weather occurrences, and crop yields approximate normal distributions.

GRKS Distribution

A GRKS distribution, named after Gray, Richardson, Klose, and Schumann, is a continuous function that utilizes empirical data, as seen in Figure 2-4. A GRKS distribution only requires minimum, median, and maximum values but contains the same mathematical properties as a normal distribution. A GRKS distribution extends the tails of the distribution by 2.28% of the minimum and maximum values to account for the possibility of worse or better cases than the three collected data points (Richardson et al., 2006; Richardson et al., 2012).

Empirical Distribution

An empirical distribution uses empirical observations to determine the shape of the PDF and CDF, as illustrated in Figure 2-5. Due to the use of empirical data, an empirical distribution is a discrete function containing finite minimum and maximum values determined by the dataset. The parameters of an empirical distribution are the empirical values, S_i, sorted from least to greatest and the cumulative probabilities, $P(S_i)$, of each sorted value occurring. During simulation, the simulation software makes the CDF continuous (Richardson et al., 2006).

Bernoulli Distribution

A Bernoulli distribution is a discrete distribution function used for binary outcomes, illustrated in Figure 2-6. The parameters of a Bernoulli distribution are the probability of an event occurring, (P), which is also the expected value of the binary variable. For example, when analyzing the probability of a hurricane striking a location, the variable equals 1 if the storm occurs and 0 if it does not. Therefore, the mean is the probability of a hurricane striking a specified location.

Agricultural Risk Management

Agriculture is an extremely risky industry that relies on external inputs, such as weather and biological processes, along with internal operations, such as management decisions regarding labor and capital (Fleisher, 1990). Hence, examples of risk within agriculture, such as the probability of a storm destroying yields or market forces resulting in low output prices, are numerous. To increase information regarding decisions involving risk, individual growers utilize risk management tools and unique methods to minimize negative payoffs.

In the late 1980s, economists began to develop computer-based financial tools in the form of optimization problems that farmers utilized to manage risky situations. Economists express optimization problems using an objective function that is maximized subject to constraints and commonly solve them using mathematical programming (Hardaker, 2004). The first mathematical programming developed for applied risk was linear programming (Hardaker, 2004; Kwak, 1987). This kind of programming can accommodate two types of risk: 1) embedded risk and 2) non-embedded risk. Non-embedded risk occurs when a decision is made and then an outcome is realized with no more decisions made after the uncertain event occurs. Embedded risk occurs when additional decisions are made after an initial uncertain outcome is realized. The programming associated with these two kinds of risk are known as risk programming and stochastic programming, respectively (Hardaker, 2004). Outputs from stochastic programming and risk programming do not always provide a single, optimal decision. Therefore, economists began utilizing unique methods that ranked decisions based on positive outcome probabilities.

Risk Ranking Using Mean-Variance Efficiency

In 1984, King and Robinson outlined five commonly used efficiency criteria, or risk ranking preferences, as follows: (1) first-degree stochastic dominance, (2) second-degree stochastic dominance, (3) mean-variance efficiency, (4) mean-absolute deviation efficiency and, (5) stochastic dominance with respect to a function (King & Robinson, 1984). Decision makers utilize each method to select and rank various risky alternatives based on unique mathematical processes. In this thesis, the mean-variance efficiency, discussed below, is used to rank and compare various scenario outputs.

The mean-variance (EV) efficiency criteria uses only two distribution parameters, the expected value and the variance. Consider two alternatives with payoff distributions represented by $F(x)$ and $G(x)$ with $\bar{X}_F$ and $\bar{X}_G$ representing the mean values of each distribution, respectively, and σ_F^2 and σ_G^2 representing the variances of each distribution, respectively. The EV criteria states that if $\bar{X}_F \geq \bar{X}_G$ and $\sigma_F^2 \leq \sigma_G^2$, then the alternative represented by $F(x)$ is the dominant strategy. This criterion requires that the alternatives' payoffs are normally distributed and that the individual's wealth preferences can be represented by a quadratic utility function (King & Robinson, 1984). Managers commonly use the mean-variance efficiency in risk decision-making due to ease of use.

Stochastic Simulation and Modeling

The use of simulations to analyze decisions became popular in the 1970s as firms experimented with the effects of various scenarios and their resulting outcomes (Anderson, 1974). Unlike linear programming utilized earlier, simulations can be used to determine the most likely outcome instead of solving for optimality (Richardson et al., 2006). Simulation models are defined into two categories: 1) discrete and 2) continuous simulation models. Discrete simulation models have defined increments of time within which conditions are considered to be fixed. These kinds of simulations are common among agricultural economists with a single growing season often being the time unit and crop yield being the variable of interest. On the other hand, continuous models have a continuous time component incorporated where conditions change continuously over time and are commonly associated with optimization problems utilizing continuous data (Richardson et al., 2006). Modeling crop growth within a single season could be simulated with continuous time.

Stochastic models include variables that are not known with certainty but have known or estimated PDFs. These types of models consist of one or more random variables that simulation software can generate to describe a specific output distribution. (Richardson et al., 2006). Stochastic variables include terms that management cannot control, such as rainfall, yields, and prices that contribute to risk due to the uncertainty associated with the realization of each in the future (Richardson et al., 2006). Once the stochastic variables have been determined and the model finalized, the user can simulate the model using Monte Carlo sampling or Latin Hypercube sampling (LHS) to generate numerous iterations of the Key Output Variables (KOVs) (Hardaker, 2004).

For each iteration, Monte Carlo sampling randomly selects a value for each input variable, such as rainfall, in the model using a pseudo-random number generator (Mooney, 1997; Hardaker, 2004; Richardson et al., 2006). The simulation software uses the values chosen each iteration to solve the model and calculate the key output variable or KOV, such as crop yield or profits. After approximately 1,000 iterations, the simulations create a distribution for the KOV that researchers can analyze based on the risk involved within each stochastic variable (Hardaker, 2004). Similarly, LHS selects a value from each distribution for each input variable and calculates the associated KOV, storing the output value, and calculating the final distribution of the output (Helton & Davis, 2003; Hardaker, 2004). However, as opposed to Monte Carlo sampling, LHS divides the distribution of each input variable into N intervals, where N is the number of desired iterations. From there, the software selects a random number from each interval without replacement, allowing for increased coverage from the entire distribution (Helton & Davis, 2003). Hence, LHS requires fewer iterations than the Monte Carlo sampling method (Helton & Davis, 2003; Richardson et al., 2006). Simulating a uniform distribution should create a straight line for its CDF. Figure 2-7 illustrates such a simulation with 100 iterations using both Monte Carlo sampling and LHS. Although neither method is perfect, the LHS method contains a straighter line; Monte Carlo simulation would require more iterations to recreate the correct underlying distribution. LHS requires a minimum of 500 iterations while Monte Carlo sampling requires at least 1,000 (Richardson et al., 2006).

Simetar

As the use of computer programs increased, risk simulation software packages were developed that integrate various distributions of stochastic variables with mathematical modeling capabilities. In 1997, Richardson developed the Simulation for Excel to Analyze Risk (Simetar) software and researchers commonly use Simetar throughout the literature to analyze complex scenarios, such as environmental, production, and consumption risk. Simetar is a Microsoft Excel Add-on with a unique simulation language that contains over 230 functions, allowing researchers the ability to model and simulate an industry with numerous deterministic and stochastic variables. Simetar randomizes numbers using the inverse transformation method of a USD and then simulates the model using the LHS method previously discussed. Risk is estimated based on the distribution of KOVs illustrated by a PDF or CDF from the simulation output (Richardson & Gray, 2002). Due to many simulation features and output graphs, Simetar is a popular software program used for risk analysis in public and private industries.

For example, Clark et al. (2010) analyzed the risk associated with grapefruit producers adjusting portions of their production land into shrimp aquaculture by examining the probability of a positive net present value (NPV) in the presence of risk. Within the analysis, Clark analyzed eight scenarios, two of which had no risk and six of which contained various forms of risk. Simetar simulated each scenario using the LHS method, reporting various CDFs of NPV for each scenario. Similarly, Bishop et al. (2010) used Simetar to analyze the risk associated with farms in Nevada changing production from water-intensive alfalfa production to alternative crops with less water use. Bishop collected data from secondary sources to generate stochastic yields associated with the various crops (Bishop et al., 2010).

Risk Assessments and Sensitivity Analysis in Aquaculture

The Food and Agriculture Organization of the United Nations (FAO) defines economic and financial risk within aquaculture as "the potential loss associated with an aquaculture investment" due to imperfect knowledge or the likelihood of an unfavorable event occurring (Bondad-Reantaso et al., 2008). Aquacultural production faces many risks such as production risk from environmental factors reducing yields or market threats caused by fluctuating prices (Bondad-Reantaso et al., 2008). Therefore, risk analyses and sensitivity analyses are critical to the financial success of the global aquaculture industry.

While aquaculture is beginning to expand throughout the U.S., international aquaculture industries are maturing and stabilizing (NMFS, 2016). Due to greater historical production data, researchers have conducted risk assessments and sensitivity analyses on various species internationally. For example, Jeffs and Hooker (2000) analyzed the effects of risk on the profitability of aquacultured *Jasus edwardsii*, commonly referred to as spiny lobster, produced in New Zealand. They derived the primary cost data for a hypothetical farm that best represents industry practices and interviewed local seafood wholesalers to collect local and international output price data. Using these data, they predicted cash flows for the first 10 years of operation (Jeffs & Hooker, 2000).

Similarly to Jeffs and Hooker's study, Ali (2012) conducted a financial sensitivity analysis on Tilapia production using a recirculating aquaculture system in Egypt. Ali collected operational cost data from one actual fish farm and one experimental farm located at Banha University. The study conducted a breakeven analysis, identifying the breakeven market price and breakeven unit quantity. The sensitivity analysis varied key production variables by 10% to determine the effects on net present value (Ali, 2012). The methodology used by Jeffs and Hooker's and Ali's studies is similar to the methods used throughout this project. There are many available studies analyzing financial risk characteristics associated with specific aquaculture species and production practices beyond what is discussed above. Table 2-1 reports additional research that has analyzed economic risk on a specific aquacultured species or production method using sensitivity analyses, stochastic modeling, or scenario analysis. All studies conducted a sensitivity analysis on one or more variable. Researchers commonly analyzed the effect of changes in market price, species survival, stocking density, feed costs, and growth rates on net income and net present value. Over 50% of the species analyzed were finfish species, such as grouper, tilapia, or catfish, followed by mollusks, and seaweed.

Shellfish Economic Risk Assessments

Researchers have conducted various economic risk assessments and sensitivity analyses on shellfish in the U.S. However, research has primarily focused on restoration and conservation projects while placing less emphasis on aquaculture. The four journal articles discussed below all collected data through surveys and/or experimental farms and then utilized the data to parameterize models for financial analysis.

Adams and Van Blokland (1998) conducted an economic analysis of a small-scale commercial hard clam, *Mercenaria mercenaria*, farm located in Florida. The study designed an experimental farm to collect operational costs coupled with data collected from existing commercial clam growers in the region. Adams and Van Blokland used the operational cost data to create a cash flow statement and an operational enterprise budget. They found that a hard clam bottom bag grow-out operation would be profitable after the second year and remain profitable through the end of the 5-year planning horizon considered. Additionally, Adams and Van Blokland conducted a sensitivity analysis that considered five variables: the stocking density per bag, 2) the number of bottom bags, 3) the price of seed clams, 4) the market price and, 5) the survival percentage. The study varied each of these variables individually while holding all other variables constant to determine the effect on net returns of an individual farm.

Similar to Adams and van Blokland, Bedecarratz et al. (2011) conducted an economic feasibility study on aquaculture production of *Austromegabalanus psittacus*, commonly known as the giant barnacle, located in Southern Chile. The study collected economic data for the production of giant barnacles cultured for canned products and frozen meat. Data included operational costs, yields, and average market prices. Bedecarratz et al. created a cash flow budget for these products and analyzed four profitability indicators: 1) net present value (NPV), 2) internal rate of return (IRR), 3) the discounted payback period, and 4) an economic profitability index. The study conducted a sensitivity analysis on six key production variables, including mortality and growth rates, to determine the effects on NPV and IRR. Under all scenarios, the NPV for canned production exceeds that for frozen production and the NPV of frozen production is more sensitive to biological and economic parameter values relative to the NPV of canned production (Bedecarratz et al., 2011).

Theodorou et al. (2014) conducted a similar economic feasibility study on the profitability of farming the Mediterranean Mussel, *Mytilus galloprovincialis*, in Greece (Theodorou et al., 2014). Theodorou collected data via a survey conducted with eight farms throughout the country, differing in size and location, and through personal interviews with 48 growers in the main production regions. Theodorou uses the data collected on various farm sizes to create a production cost budget and an income statement. The study reported that in the absence of EU subsidies, small farms (≤ 1 hectare) are not profitable for all but the highest price considered, while large farms (≥ 3 hectares) are profitable at all analyzed market prices. Additionally, the study conducted a sensitivity analysis to examine the effect of changes in yields, farm sizes, labor costs, and industry policies on profit and breakeven price.

Valderrama and Engle (2001) analyzed the effects of risk on the profitability of shrimp aquaculture. They distributed surveys from October 1997 to April 1998 to a stratified random sample of shrimp farms located in Honduras to collect data on operational costs and production methods. From there, the study developed three scenarios to consider three farm sizes common to shrimp aquaculture in the region. Valderrama and Engle created enterprise budgets for each scenario based on the survey data using the averages for each input cost, market price, and yield amount. To simulate risk, the project utilizes Crystal Ball, a risk simulation software package, using Monte Carlo sampling for each scenario. The output reported the probabilities of achieving a given level of net profit along with other selected KOVs such as total revenue, total costs, and breakeven yield and price (Valderrama & Engle, 2001).

Eastern Oyster Financial Feasibility Studies

Several researchers conducted regional financial feasibility studies for triploid off-bottom Eastern oyster production along the east coast of the U.S. and states bordering the Gulf of Mexico. Rhodes et al. (2016) conducted an economic feasibility assessment of a regional small-scale off-bottom oyster aquaculture farm in Maine. The authors discussed five risk factors that impact off-bottom oyster growers but did not include risk in their analysis. Similarly, North Carolina Sea-Grant conducted a financial analysis of regional off-bottom oyster aquaculture farms, comparing flip bags and bottom cages. While the analysis found similar profits in year two for both methods, losses in year one were about three times as large for flip bags due to higher initial investment costs (Turano, 2013).

While the previous studies did not consider risk, Kallen et al. (2001) did include risk in their analysis of the profitability of oyster aquaculture farms in the Chesapeake Bay. The studies consider the effects of all combinations of two different mortality rates and four different prices on profit. After the first year of production, all combinations of prices and mortality yielded positive profits; negative profits were incurred in the first year under high mortality and low to moderate prices (Kallen et al., 2001).

Summary

While risk has been incorporated into the economic analysis of other shellfish products, only minimal work has considered risk in oyster aquaculture. This thesis contributes to the existing literature by incorporating two kinds of risk into a stochastic model: economic risk from variations in market prices and environmental risk from the occurrences of major storms and sustained low or high salinity events. This assessment simulates various scenarios and includes a sensitivity analysis to determine which risk event has the greatest impact on net income.

Incorporation of these forms of risk creates a distribution of possible profitability levels for various counties along the west coast of Florida during independent and collective risk events. A distribution of profitability determines the probability of achieving a negative net income for each environmental event.

Table 2-1. List of Additional Publications Addressing Risk in Aquaculture

Author Names	Year	Study Location	Type of Risk Analyzed	Risk Analysis Method Used	Species
Adams, C., Stevely, J., & Sweat, D.	1995	Pohnpei	Wage Rate, Survival Rate, and Market Price	Sensitivity Analysis	Sponges
Adams, C., Sturmer, L., Sweat, D., Blake, N., & Degner, B.	2001	Florida, U.S.	Market price, stocking density, survival, marketability, and cost of seed/cages	Sensitivity Analysis	Southern bay scallop (*Argopecten irradians concentricus*)
Afero, F., Miao, S., & Perez, A. A	2009	Indonesia	Survival rates, production rates, market price, farm size	Sensitivity Analysis	Tiger grouper (*Epinephelus fuscoguttatus*) and Humpback grouper (*Cromileptes altivelis*)
Agbayani, R., Baliao, D., Samonte, G., Tumaliuan, R., & Caturao, R.	1990	Philippines	Wholesale market price	Sensitivity Analysis	Mudcrabs (*Scylla serrata*)
Bombeo-Tuburan, I., Coniza, E., Rodriguez, E., & Agbayani, R.	2001	Philippines	Price of juveniles, feed price, yields, survival, and feed conversion ratio	Sensitivity Analysis	Grouper (*Epinephelus coioides*)
Bouras, D., & Engle, C.	2007	U.S.	Interest rates, feed conversion ratios, survival rates, catfish prices, harvesting costs, and availability of operating capital	Sensitivity Analysis	Catfish
Dave, A., Huang, Y., Rezvani, S., McIlveen-Wright, D., Novaes, M., & Hewitt, N.	2013	Europe	Feed stock cost and market price	Sensitivity Analysis	Cold-water seaweed (*Laminaria digitata*)

Table 2-1. Continued

Author Names	Year	Study Location	Type of Risk Analyzed	Risk Analysis Method Used	Species
de Carvalho Gomes, L., Chagas, E., Martins-Junior, H., Roubach, R., Ono, E., & de Paula Lourenço, J.	2005	Brazil	Sales price, feed cost, culture period, and stocking density	Sensitivity Analysis	Tambaqui (*Colossoma macropomum*)
de Oliveira, E., Pinheiro, A., de Oliveira, V., da Silva Júnior, A., de Moraes, M., Rocha, Í., & Costa, F.	2012	Brazil	Market price and feed cost	Sensitivity Analysis	Pirarucu (*Arapaima gigas*)
Doupe, R., & Lymbery, A.	2002	Australia	Commercial operation vs. Existing operation; growth rate, and fish survival	Sensitivity Analysis	Black bream (*Acanthopagrus butcheri*)
Fong, Q., Ellis, S., & Haws, M.	2005	Central Pacific	Market price, survival, cost of seed, and other inputs	Sensitivity Analysis	Black-lipped pearl oyster (*Pinctada Margaretifera*)
Gonzalez, E., Hurtado, C., Gace, L., & Augsburger, A.	2013	Chile	Bag type	Sensitivity Analysis	Trout (*Oncorhynchus mykiss*)
Grimm-Greenblatt, J., Pomeroy, R., Bravo-Ureta, B., Sinh, L., Van Hien, H., & Getchis, T.	2015	Vietnam	Discount rate, cost of capital, market price, feed price, and feed type	Sensitivity Analysis and Scenario Analysis	Snakehead (*Channa striata*)
Guy, J., Johnston, B., & Cacho, O.	2009	Australia	Intra-specific cross between two fingerlings of fish species and growth rates	Sensitivity Analysis	Freshwater silver perch (*Bidyanus bidyanus*)

Table 2-1. Continued

Author Names	Year	Study Location	Type of Risk Analyzed	Risk Analysis Method Used	Species
Hatch, U., Hanson, T., Kim, M., & Lovell, R.	2008	U.S.	Feed conversion ratios, stocking rates, and market prices	Sensitivity Analysis	Channel catfish (*Ictalurus punctatus*)
Hernandez-Llamas, A., Gonzalez-Becerril, A., Hernandez-Vazquez, S., & Escutia-Zuñiga, S.	2004	Mexico	Mortality rate, sales price, stocking density, cost of feed, and other production parameters (21 parameters total)	Sensitivity Analysis and Stochastic Simulation	Blue shrimp (*Litopenaeus stylirostris*)
Kam, L., Martinez-Cordero, F., Leung, P., & Ostrowski, A.	2003	Hawaii, U.S.	Sale price, production yield, labor, feed, and stocking	Sensitivity Analysis	Milkfish (*Chanos chanos*)
Ligeon, C., Dunham, R., Jolly, C., Crews, J., Argue, B., Liu, Z., Yant, R., Benfrey, J., & Gagalac, F.	2004	U.S.	Farm price, feed conversion, feed price, fingerling price	Sensitivity Analysis	Channel catfish (*Ictalurus punctatus*)
Lipton, D., & Kim, D.	2007	Korea	Feed cost, fingerling cost, survival	Sensitivity Analysis and Stochastic Simulation	Rock Bream (*Oplegnathus fasciatus*)
Liu, Y., & Sumailia, U.	2007	British Columbia	Market price, discount rates, fish density, feed costs, environmental costs, length of growth cycle, survival rate, and feed conversion ratio	Sensitivity Analysis	Salmon (*Oncorhynchus tshawytscha*)

Table 2-1. Continued

Author Names	Year	Study Location	Type of Risk Analyzed	Risk Analysis Method Used	Species
Medley, P., Nelson, R., Hatch, L., Rouse, D., & Pinto, G.	1994	Southeastern U.S.	Cost of Juveniles, Percentage of Harvested Biomass, Market Price, Length of Growing Season	Sensitivity Analysis	Red claw crayfish (*Cherar guudricurinutus*)
Paquotte, P., Chim, L., Martin, J. L., Lemos, E., Stern, M., & Tosta, G.	1998	Brazil	Growth rate, food conversion rate, larvae availability, yields, legal salary, market price	Sensitivity Analysis	Whiteleg shrimp (*Penaeus vannamei*)
Penney, R., & Mills, T.	2000	Newfoundland, Canada	Stocking mortality, operational costs, market price, culling, and net mesh size	Sensitivity Analysis and Simulation	Sea scallop (*Placopecten magellanicus*)
Guerra, J. M. H., Marbán, D. V. P., & Leyva, E. G.	2006	Yucatan, Mexico	Sales price, feed cost, and seed cost	Sensitivity Analysis	Nile tilapia (*Oreochromis niloticus*)
Ponzoni, R., Nguyen, N., & Khaw, H.	2007	-	Survival rate, Market price, Feed cost, Quantity of fish marketed, and Annual costs	Sensitivity and Scenario Analysis	Nile tilapia (*Oreochromis niloticus*)
Cordero, F. J. M., Zazueta, E. S., Medina, V. A., & Enríquez, R. P.	2009	Sinaloa, Mexico	Farm management as a result disease risk, pond stocking densities, culture times	Scenario Analysis	Shrimp
Thacker, S., & Griffin, W.	1994	Southeastern U.S.	Annual Growth and Survival, Hurricanes, Feed Price, Red Drum Price, and Initial Cash Reserve	Sensitivity Analysis & Stochastic Simulation	Red drum (*Sciaenops ocellatus*)

Table 2-1. Continued

Author Names	**Year**	**Study Location**	**Type of Risk Analyzed**	**Risk Analysis Method Used**	**Species**
Tisdell, C., Tacconi, L., Barker, J., & Lucas, J.	1993	Australia	Price of Clam Meat, Drip Weight Loss in Meat, Discount or Interest Rates, and Mortality Rates	Sensitivity Analysis	Giant clams (*Tridacna gigas*)
Traesupap, S., Matsuda, Y., & Shima, H.	1999	Japan	Changing exchange rates, stock holdings	Sensitivity Analysis	Japanese shrimp (*Caridina multidentata*)
Valenti, W., de Arruda Hayd, L., Vetorelli, M., & Martins, M.	2011	Brazil	Sales price, supply costs, and productivity	Scenario analysis	Amazon River Prawn (*Macrobrachium amazonicum*)
van den Burg, S., van Duijn, A., Bartelings, H., van Krimpen, M., & Poelman, M.	2016	Netherlands	Market price	Sensitivity Analysis	Seaweed
Watanabe, W., Dumas, C., Carroll, P., & Resimius, C.	2015	North Carolina, U.S.	Stocking density and fingerling size	Sensitivity Analysis	Black seabass (*Centropristis striata*)

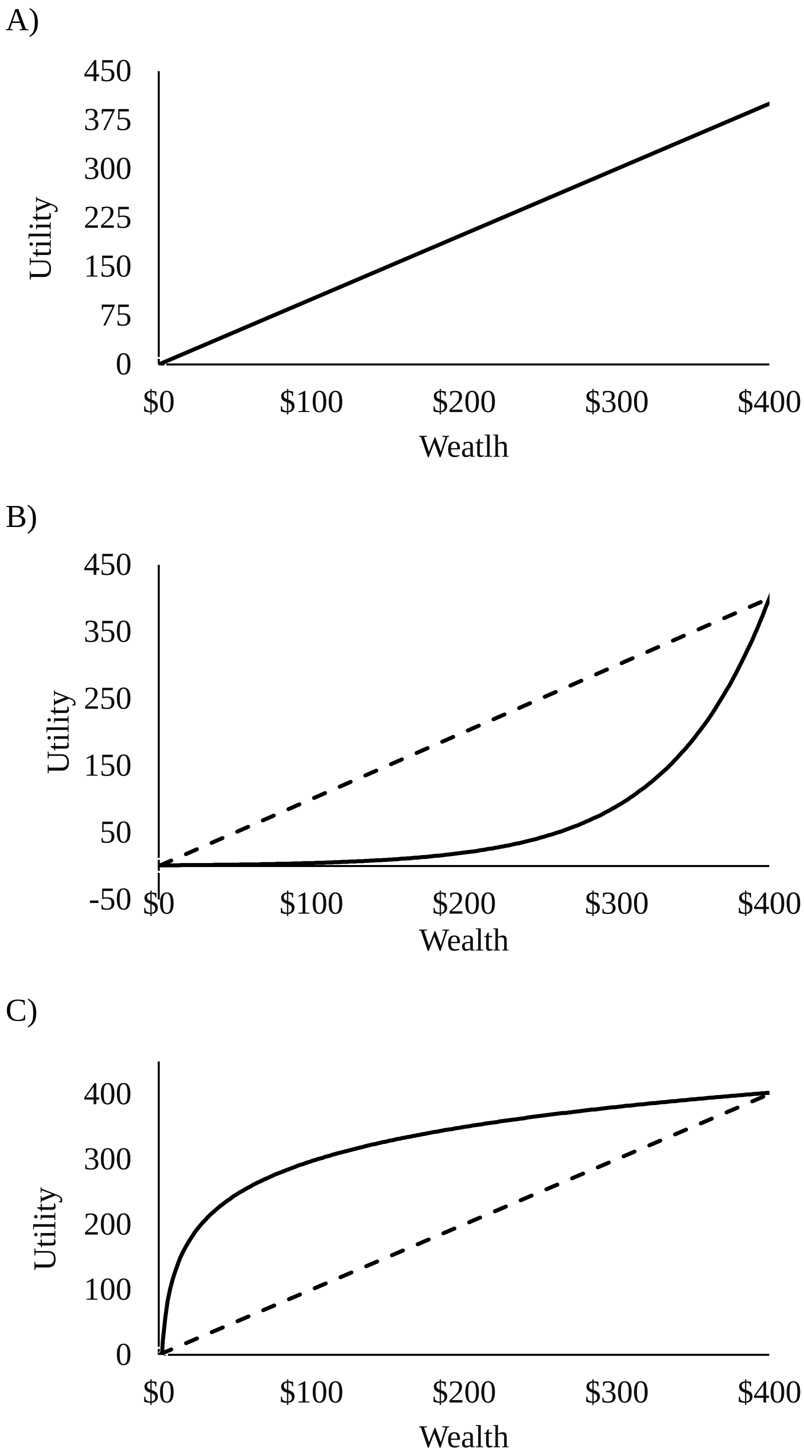
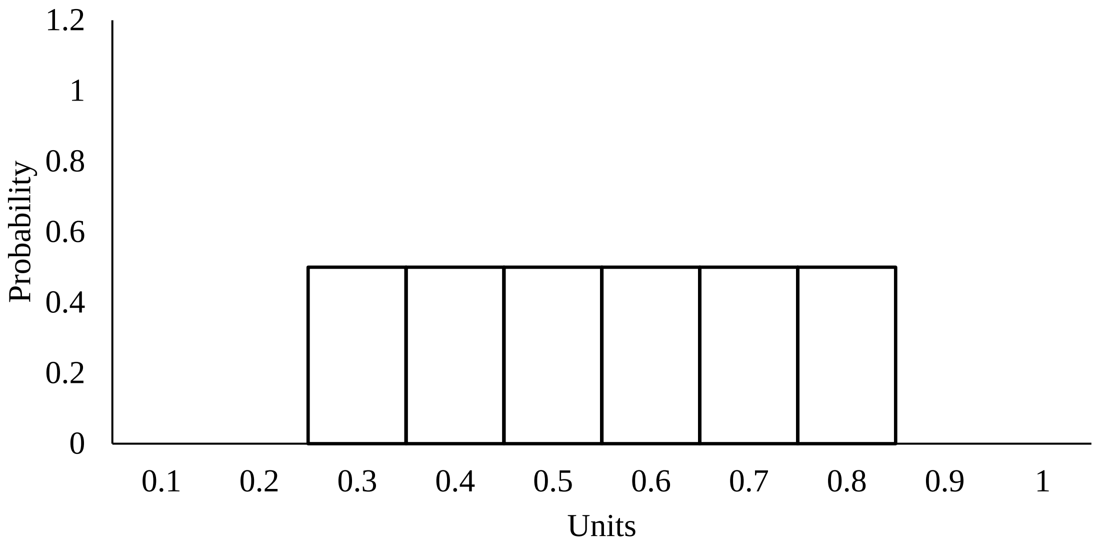


Figure 2-1. Snyder's Preference Curves A) Risk Neutral; B) Risk Loving; C) Risk Adverse

A)



B)

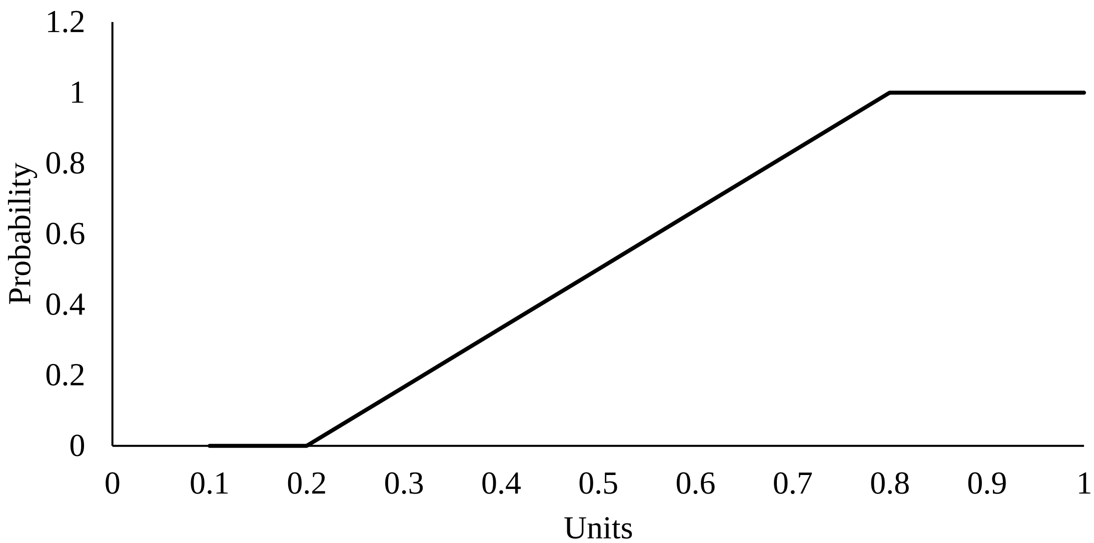


Figure 2-2. PDF and CDF of a Uniform Standard Deviate (USD) A) Probability distribution function; B) Cumulative distribution function

A)

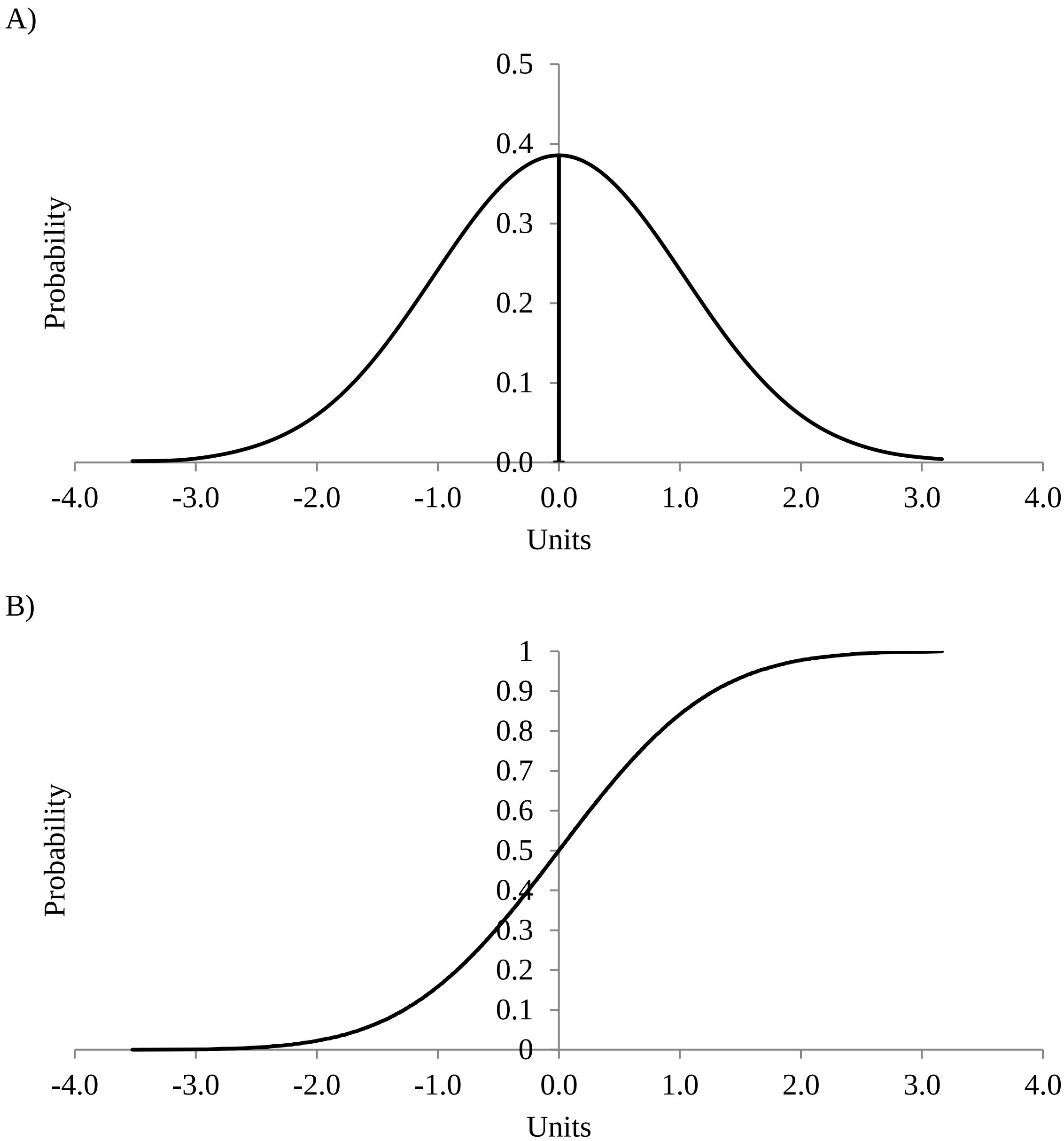
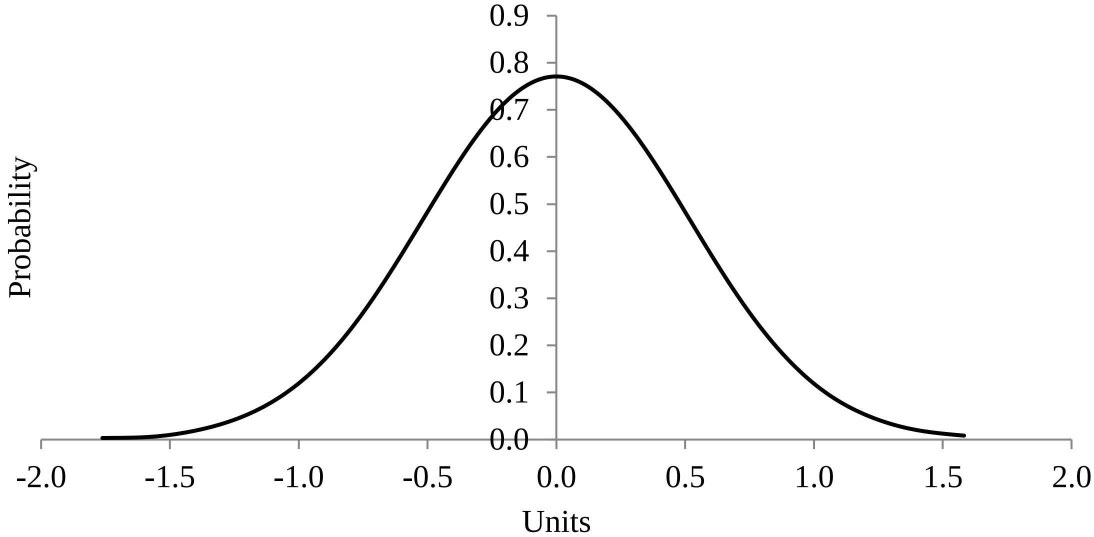


Figure 2-3. PDF and CDF of a Standard Normal Distribution A) Probability distribution function; B) Cumulative distribution function

A)



B)

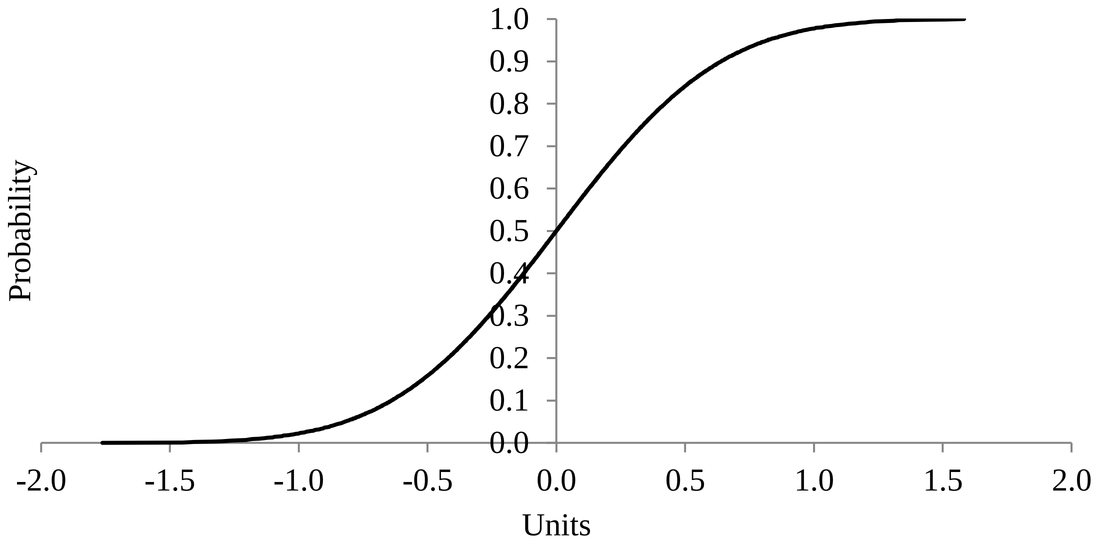
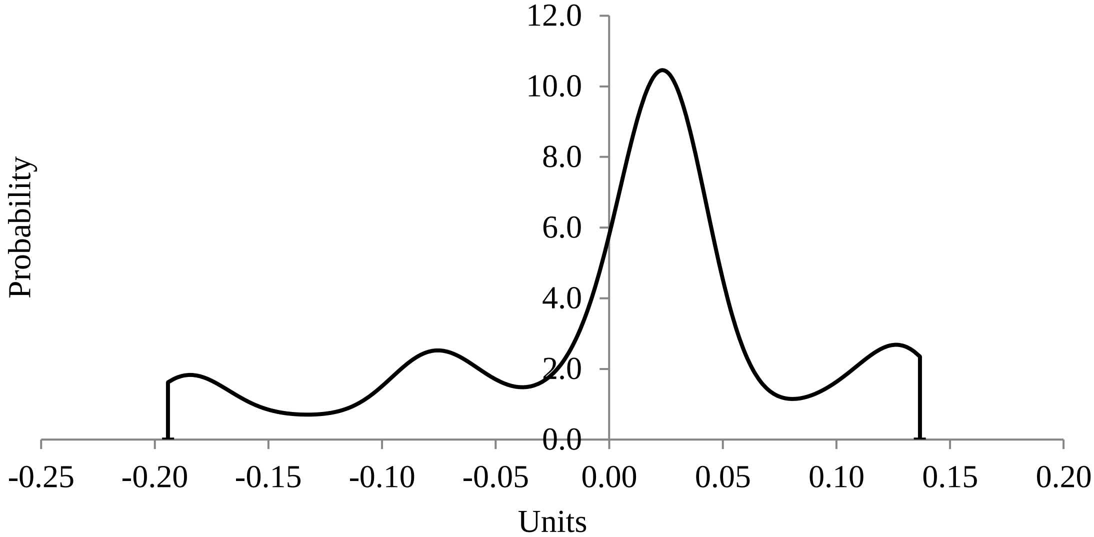


Figure 2-4. PDF and CDF of an GRKS Distribution A) Probability distribution function; B) Cumulative distribution function

A)



B)

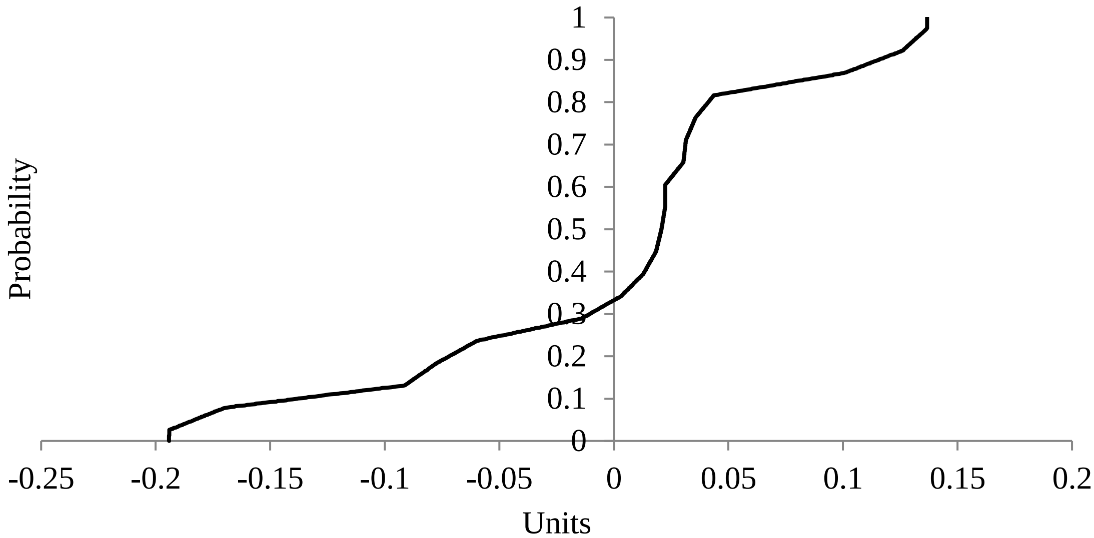
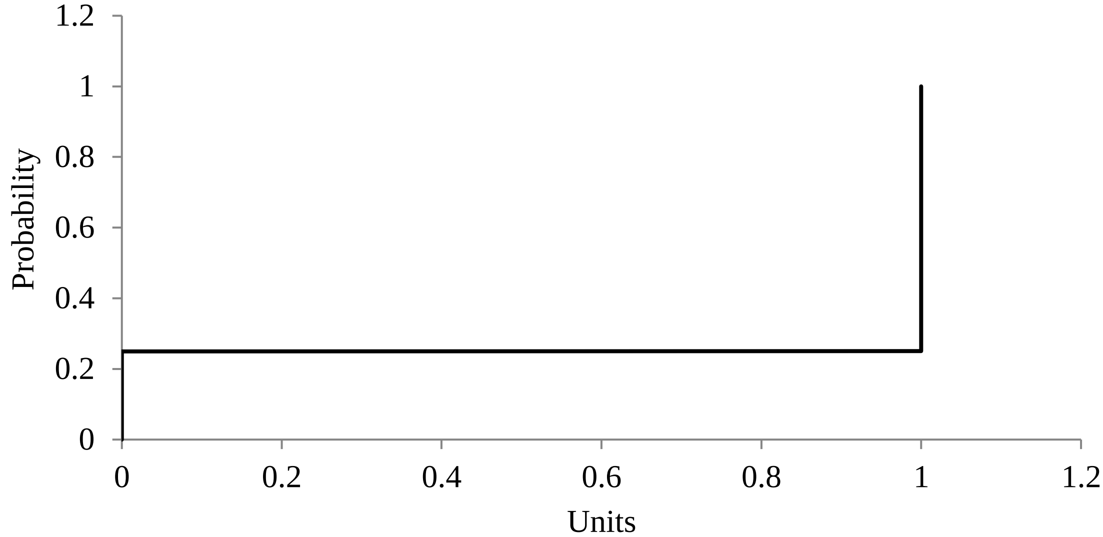


Figure 2-5. PDF and CDF for an Empirical Distribution A) Probability distribution function; B) Cumulative distribution function

A)



B)

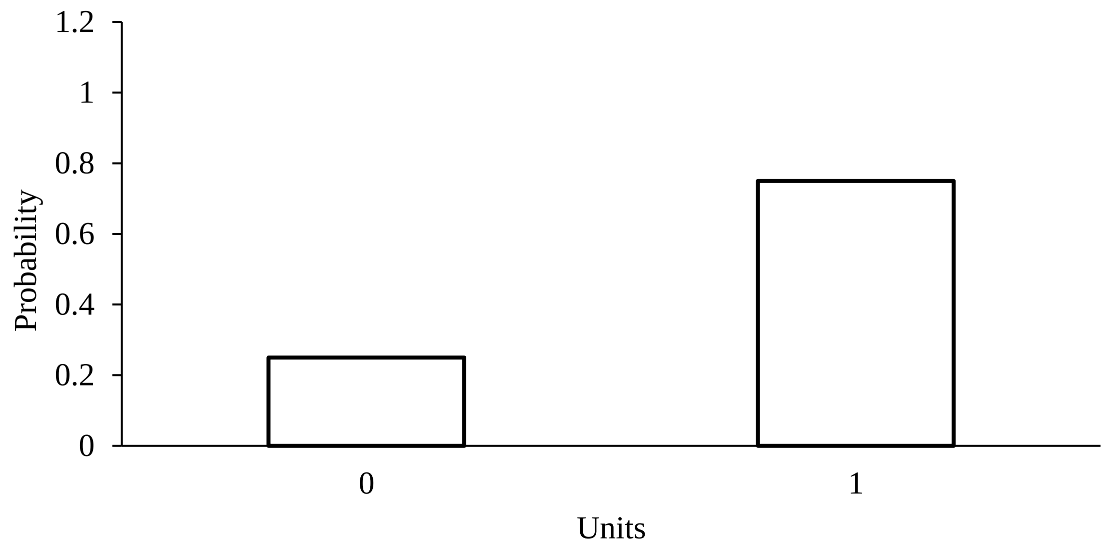


Figure 2-6. PDF and CDF of a Bernoulli Distribution A) Probability distribution function; B) Cumulative distribution function

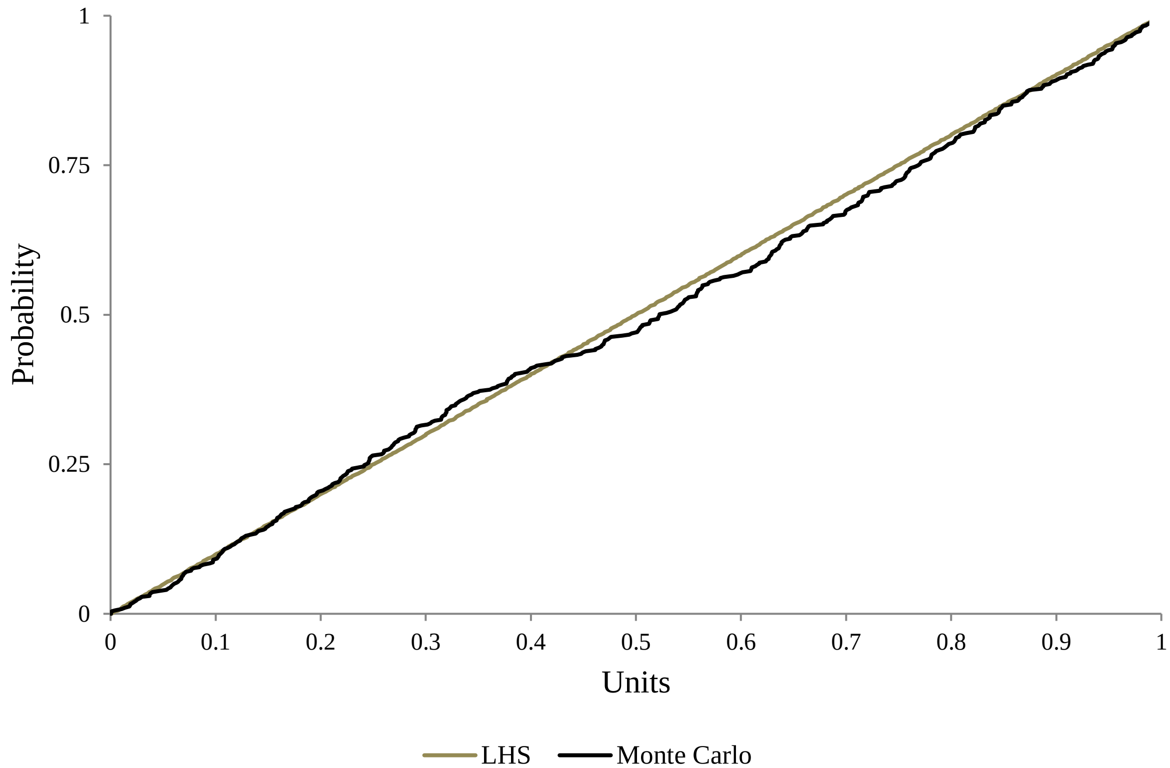


Figure 2-7. Comparison of Latin Hypercube Sampling method to Monte Carlo Sampling Method (Richardson et al., 2006)

CHAPTER 3
METHODS

This thesis constructs a model to predict an individual grower's profitability by county, considering the accompanying environmental and market risk. Growers sell oysters into the wholesale market and receive a price known as the dockside price (P_{DS}) based on wholesaler demand. The dockside price (P_{DS}) varies based on seasonality in consumer oyster demand and regional oyster quality. The expected quantity of oysters sold into the wholesale market (Q_{DS}) is used to determine the grower's expected revenue, modeled below:

$$(1)\ \boldsymbol{E}[\boldsymbol{Revenue_t}] = E[P_{DS}]E[Q_{DS,t}]$$

where the expected quantity, $\boldsymbol{E}[\boldsymbol{Q_{DS,t}}]$, is given by:

$$(2)\ \boldsymbol{E}[\boldsymbol{Q_{DS,t}}] = \delta_{DS}\left[Q_{Planted,t} - Q_{Planted,t}\left(X_{NM} + \sum_{i=1}^{s}\left(\Pr(Storm = i) * X_{Storm_i}\right) + \left(\Pr(High = 1) * X_{High}\right) + \left(\Pr(Low = 1) * X_{Low}\right)\right)\right]$$

$$\text{where } 0 \leq \delta_{DS} \leq 1$$

The expected quantity of oysters sold into the wholesale market, $Q_{DS,t}$, in the present season, *t*, depends on the quantity planted at the beginning of season t, $Q_{Planted,t}$, and various mortality rates, X_k. Expected normal mortality, X_{NM}, is estimated based on the stocking density of 250 oysters per bag. This mortality accounts for normal predation, food availability, and natural loss during a typical season not affected by abnormal environmental risk. However, three environmental risk events occur within the region, in the form of major storms, sustained high salinity events, and sustained low salinity events. $\Pr(Storm = i)$ is the probability of a storm with wind speed and direction combination *i* affecting the oyster farm and $X_{Storm,i}$ is the mortality associated with that combination of storm attributes. $\Pr(High = 1)$ is the probability of a sustained high salinity (≥ 35 ppt) event, and X_{High} is the mortality associated with such an event. $\Pr(Low = 1)$ is the probability of a sustained low salinity (≤ 10 ppt) event i and X_{Low} is the mortality associated with the low salinity event.

The sum of mortality rates cannot be greater than 1 since oyster mortality cannot be greater than the quantity of oysters planted, illustrated below:

$$(3)\ X_{NM} + \sum_{i=1}^{s}\left(\Pr(Storm = i) * X_{Storm_i}\right) + \left(\Pr(High = 1) * X_{High}\right) + (\Pr(Low = 1) * X_{Low}) \leq 1$$

Equation 4 multiplies the firm's labor and capital by a determined wage and rental rate to determine the expected total costs (TC) of producing oysters associated with each grower listed below:

$$(4)\ \boldsymbol{E}[\boldsymbol{TC}] = Q_{Planted}\left(wL + w\sum_{i=1}^{s}\left(\Pr(Storm = i) * L_{Storm_i}\right) + w\left(\Pr(High = 1) * L_{High}\right) + w(\Pr(Low = 1) * L_{Low}) + v_t K + v_G\sum_{i=1}^{s}\left(\Pr(Storm = i) * K_{Storm_i}\right) + v_G\left(\Pr(High = 1) * K_{High}\right) + v_G(\Pr(Low = 1) * K_{Low})\right)$$

where w is the wage rate and v_t is the rental rate of capital during period t. L is the average labor used, measured in minutes, required for one growout season accounting for all bag construction, labor and gear maintenance, and harvesting activities associated with the oyster farm and facility under normal conditions. K, measured in growout bags, is the average capital required for one growout season accounting for bag construction costs under normal conditions. L_{Storm_i}, L_{High}, and L_{Low} represent the expected additional units of labor time for all additional labor from maintenance and fouling control due to a major storm or a sustained high or low salinity event of severity *i* respectively. Similarly, K_{Storm_i}, K_{High}, K_{Low} represent the expected additional gear and supplies required for repair to growout bags and v_G is the rental rate of total growout bags on a grower's lease at a given time. Using the information above, subtracting the expected total cost from the expected revenue determines the expected profitability, $E(\pi)$, of the firm illustrated below:

$$(5)\ \boldsymbol{E}[\boldsymbol{\pi}] = E[Revenue] - E[TC]$$

Along the west coast of Florida, four unique regions exist where oyster aquaculture is prevalent: 1) Levy County, 2) Franklin County, 3) Wakulla County, and 4) Escambia County. Each of these regions contains different levels of environmental risk due to different probabilities of storm occurrences and varying average salinity levels. Additionally, two regions, Levy County and Franklin County, experience higher average salinities allowing growers to produce *Mercenaria mercenaria*, commonly referred to as hard calms, in addition to off-bottom oyster production. Hard clams prefer salinities above 25 parts per thousand (ppt) while oysters grow in salinities up to 30 ppt. Therefore, if average salinities fall within this range, growers can produce oysters and clams on the same lease. The analysis assumes that the Levy County and Franklin County oyster growers represented in the simulation that follows also produce hard clams. I utilize partial budgeting to allocate 50% of boat and fuel costs to the oyster operation and 50% to the clam operation. The equations listed above are simulated based on each region's unique environmental and financial conditions.

Data Collection

Logbook Distribution

The University of Florida, Institute of Food and Agricultural Sciences (UF IFAS) Shellfish Extension team distributed logbooks and 2,500 diploid and triploid oysters to 12 growers along the west coast of Florida, including 7 to growers in Levy County, 3 in Wakulla County, and 2 in Franklin County. In each logbook, participating growers recorded the estimated labor spent on individual activities associated with the determined quantity (5,000) of oysters distributed by UF IFAS Shellfish Extension. The logbook categorized each activity into separate pages in the logbook titled: 1) Planting, 2) Fouling Control and Maintenance, 3) Transfer to Additional and/or Larger Mesh Bag (Basket) Sizes, 4) Culling/Sorting, 5) Harvesting, and 6) Miscellaneous Activities. For each activity, the grower recorded the location, date, and estimated time, measured in minutes, spent on each activity for a given day. Appendix A contains sample logbook pages issued to growers.

Grower Interviews

This analysis utilized individual interviews from 3 farm owners in total located in Levy County, Wakulla County, and Franklin County to collect environmental risk data, growth statistics, and unique operational costs. This verbal interview consisted of 27 questions lasting approximately 25 minutes per interview. Appendix B contains a sample questionnaire containing the questions asked to growers. First, growers provided background farm information, such as individual experiences farming oysters, the methods used to stock bags, and planting bag mesh sizes. Next, growers provided unique operational costs including the average costs per bag, average gear costs per employee, average wage per hour received by labor, and financing data. Then, each grower estimated oyster mortality percentages during normal seasons followed by any noticeable seasons that experienced abnormally high or low mortality levels in the absence of environmental events. The analysis used the estimated percentages of planted oysters that reached, or would have reached, marketable size within one season in the absence of environmental events collected during the interview. Growers that experienced major storm events or sustained high or low salinity conditions reported the percentage mortality and estimated additional labor time and costs of replacement gear and supplies required from maintenance and repairs associated with each event.

Experimental Farm Design

The UF IFAS Shellfish Extension program built an experimental off-bottom farm for the purpose of replicating industry practices. This research farm grew 5,000 oysters of each ploidy in off-bottom bags varying in stocking densities during the summer and winter seasons. The Shellfish Extension team recorded detailed mortality rates among stocking densities as mortality percentages per bag and total quantity. Then the UF IFAS Shellfish Extension team randomly sampled each bag to record the percentage of oysters that reached marketable size within one year. In addition, the UF IFAS Shellfish Extension team logged times spent on each activity, including bag and lease construction, bag repairs, and other minor activities. The analysis that follows combines the operational costs and labor time data associated with the experimental farm with data collected from participating growers. The experimental data augment industry-reported data where the latter contains missing information.

Environmental Risk Data

Public online databases provided environmental data, such as water quality parameters and major storm wind speed and direction. The risk analysis uses storm data collected from NOAA's interactive map detailing tropical storms and hurricanes that struck within 60 nautical miles of Levy County, Franklin County, Wakulla County, and Escambia County (NOAA, 2016a). The risk analysis considers these discrete regions because of the increased likelihood of oyster production in each region due to the presence of essential water quality parameters and historic production. If wind speeds sustained 38 MPH for one minute or more, then the characteristics of the major storm were recorded when making immediate landfall including each storm's wind speed, direction, category, and location. These data coupled with mortality from interviews allow for the estimation of $X_{Storm,i}$ in equation 2. To obtain the probability of a major storm of category type *c* and wind direction type *w*, the summation of years that experienced one or more of this kind of storm since 1900 was divided by the total number of years (117).

Extreme salinity events devastate oyster farming due to the rise in oyster mortality from increased predation and major reductions in growth. Research suggests that increased salinity causes a rise in oyster predators such as *Stramonita haemastoma*, *Melogena corona*, and various other parasites as reported in Apalachicola Bay in 2012 (Havens et al., 2013; Menzel et al., 1966). In addition, oyster growth occurs between 10 and 30 ppt depending on the region but halts once salinity is out of this range (Stanley & Sellers, 1986). This assessment classifies low salinity events as salinities less than 10 ppt and high salinity events as salinities greater than 35 ppt. Three Florida Department of Agriculture and Consumer Services (FDACS) agents provided data for multiple weather stations located within each county. Each county contains 2 to 4 weather stations that report water quality data in or near off-bottom oyster leases. FDACS agents collect water parameter samples monthly or after extreme environmental events. After an extreme environmental event, FDACS agents record water quality daily until salinity and other water parameters return to “normal” levels. Each weather station in each county was sorted by month to determine which months contained multiple recordings. If multiple recordings took place, all recordings were discarded except the first reported value to provide the same quantity of samples from each weather station in each county. By discarding months with multiple recordings, each reading contained the same statistical weight. Levy County contained data from April 1992 to January 2018 and Escambia County, Franklin County, and Wakulla County contained data from April 1985 to March 2006. The analysis conducted an analysis of variance (ANOVA) test among weather stations in each county using Microsoft Excel’s Data-Solver package to determine that the means of all weather stations in a single county were not statistically different. From there, the probabilities of obtaining a month with high or low salinity recordings for each weather station in each county were determined. The analysis used the weather stations that contained the greatest probabilities of extreme salinity conditions as estimates of environmental risk in each county. If a given year contained two consecutive months of a low salinity or high salinity event, then the analysis considered that year to contain a sustained low or high salinity risk event.

Dockside Pricing Data

The Virginia Institute of Marine Science (VIMS) posts an annual situation and outlook report of shellfish aquaculture production in Virginia. In the most recent report, VIMS reported the minimum, mean, and maximum dockside price paid to growers for cultured oysters from 2005 to 2016 (Hudson & Murray, 2017). Based on grower interviews discussed above, the dockside market price recorded in 2016 was $0.43 per oyster while Virginia's dockside market prices were $0.42 in the same year. Although the maximum and minimum market price per oyster in Virginia in 2016 was $1.00 and $0.18, respectively, compared to $0.60 and $0.25 along the west coast of Florida, the means are similar. Therefore, the assessment utilizes VIMS historical mean dockside market price data as a proxy for the Florida market to predict possible changes in future market prices.

Key Output Variables

Using the data described above to parameterize the mathematical model, the analysis simulates a representative grower's expected annual profit and expected net present value (NPV) over a five-year time horizon for each county. Off-bottom oyster culture is a relatively new endeavor for the state, and Florida-specific production innovations are likely to occur in the future. Consequently, most growers will use shorter planning horizons while the industry is still adjusting to its unique environmental conditions and production methods. To calculate expected annual profit, simulated total costs are subtracted from simulated total revenue for one thousand model iterations. The formula below is calculated for each model iteration to calculate the expected NPV:

$$E[NPV] = \sum_{t=1}^{T} \frac{Revenue_t - Total\ Cost_t}{(1+r)^t}$$

where *r* is the risk-free discount rate. Individuals or firms use the Weighted Average Cost of Capital (WACC) to determine a discount rate required for an investment. The risk analysis calculates three expected NPVs with varying risk-free discount rates to account for the possible range of WACCs. The high, medium, and low cases assume a discount rate of 6%, 3%, and 1% respectively. Aquaculture and marine harvest research articles typically utilize a risk-free discount rate between 3% and 6% or the interest rate of a government issued bond for the projected time period (De Ionno et al., 2006; Clark et al., 2010; Hadelan et al., 2012; Guy et al., 2014; Jassen et al., 2018). In 2018, a 30-day and 5-year government issued bond has an approximate interest rate of 1% and 3%, respectively (DOTR, 2018). The analysis utilizes the 30-day treasury bond interest rate as the low case risk-free discount rate and the 5-year government issued bond interest rate as the base risk-free discount rate. Additionally, the analysis uses a risk-free discount rate of 6% as the upper limit based on risk-free discount rates utilized from other aquaculture and marine harvest articles.

Deterministic and Stochastic Variables

Deterministic variables are decisions made by management while stochastic variables are factors uncontrolled by the decision maker. The deterministic variables include the quantity of oysters planted; the stocking density per bag; and the quantity of each capital item used in the absence of environmental risk. The analysis assumes that a typical grower that is new to the industry begins planting 10,000 oysters at the beginning of year one. Each subsequent year, growers increase the quantity of oysters planted to a final quantity of 250,000 oysters by the beginning of year 5. Additionally, participating grower interviews determined that most oyster growers are owner-operators until they plant approximately 200,000 oysters. Virginia Cooperative Extension supports this claim reporting that additional part-time labor is required once the grower plants 200,001 to 300,000 oysters (Hudson et. al, 2012). Growers hire additional part-time labor by the day and only when demanded. After 50,000 oysters are planted, growers typically hire additional labor for one day a week, on average, for harvesting activities. Once the grower plants between 100,000 and 150,000 oysters, growers require additional labor for two days per week for harvesting and culling activities. Once 200,000 oysters are planted, growers require three days of additional labor for typical operational activities. The analysis multiplies the total time on the farm by the percentage of days in a workweek to determine the quantity of part-time labor. The percentage of days in a workweek is determined by dividing the required days of labor by 5, assuming a 5-day workweek. The quantity of part-time labor is multiplied by the wage rate to determine the labor costs. For example, if the grower plants 150,000 oysters, then the farmer requires, on average, two days of part-time labor per 5-day workweek. The total labor time spent on the farm is multiplied by 40% then multiplied by the wage rate. If an environmental risk event occurs, then the additional labor time is multiplied by the wage rate to determine additional labor costs. Capital items, such as annual boat payments and fuel costs are determined by the partial budgeting model for Levy County and Franklin County while oyster growers in Wakulla County and Escambia County incur the full costs. Additionally, the model expresses dollar values over the five-year period in real 2017-dollar amounts.

The stochastic variables include financial and environmental risk embedded within the model. Simetar randomly samples each stochastic variable's distribution using the Latin Hypercube Sampling (LHS) method. This method systematically breaks the cumulative distribution function (CDF) into equal sections based on the CDF values and selects one variable value per section per iteration.

On the financial side, there is one variable that changes with certainty over time: the expected dockside price (P_{DS}). Many factors influence market price, but it commonly follows a trend over time. As a result, the analysis generates a simple regression of each market price over time based on VIMS dockside market data listed below:

$$(6)\ \ \boldsymbol{E}[\boldsymbol{P_{DS}}] = B_0 + B_1 T + \varepsilon$$

where B_0 is the market price in period zero, B_1 is the coefficient determined by historical data, T is the period measured in calendar years, and ε is the stochastic error term. The linear regression reported an intercept of -26.310 and a coefficient for the calendar year of 0.013 (Table 3-1). Therefore, an increase in one calendar year increases the market price per oyster by $0.013 on average. The fitted linear regression for the observed VIMS dockside price values for 2005 to 2016 is illustrated in Figure 3-1.

The expected quantities available to sell into each market, (Q_{DS}), depend on stochastic variables including the mortality associated with the severity of sustained varying salinities and major storms. Based on grower interviews, approximately 90% of oysters planted at the beginning of the year reach market size by the end of 12 months. Natural mortality is a truncated GRKS distribution because it has an absolute minimum of 0 and an absolute maximum of 100 but commonly takes values that occur near the mean and within one standard deviation. Truncated GRKS distributions are similar to normal distributions but they only have three parameters: a minimum, mean, and maximum. The minimum is multiplied by -1.026 and the maximum is multiplied by 1.026 to obtain two new data values. Natural mortality does not account for additional loss from major storms or extreme salinity conditions. Furthermore, the number of major storms of a given combination of wind speed and wind direction that strike within one year is determined by a two-step process. First, the simulation determines the number of storms that occur. For example, the average number of storm strikes that occur within a 60-nautical mile radius of Levy County during a year that a storm occurs is 1.26 with a standard deviation of 0.5748. However, during simulation, the storm details take on discrete attributes of a tropical storm traveling northeast, a Category 1 hurricane traveling northeast, and a Category 1 hurricane traveling north. The probability of a storm that contains one of the attributes listed above is 18.8% in Levy County, 18.8% in Franklin County, 11% in Escambia County, and 16.1% in Wakulla County. Additionally, Table 3-2 lists the mean and standard deviation of all stochastic variables used.

In addition to affecting production output, environmental risk affects total costs. If an environmental risk event occurs, the average additional reported labor and capital costs associated with those risk events are added to the grower's total costs.

Scenarios

The analysis developed four scenarios that allow for the consideration of only environmental or market risks and a holistic scenario considering both, environmental and market risk. This allows for analyses of the KOVs caused by a change in a single type of risk per scenario among each region as well as analysis of all risk factors combined. For Scenarios 1 and 3, the analysis separates the four counties into two pairs: 1) Levy/Franklin Counties and 2) Escambia/Wakulla Counties because risk is identical within each pair for these scenarios. The analysis assumes growers located in group 1 own and operate an established hard clam farming operation prior to investing in oyster farming. Consequently, these growers do not incur startup costs, such as surveying fees and navigation signs and lights. For Scenarios 2 and 4, each county is considered individually.

For all scenarios, “normal” risk, such as thunderstorms, varying biofouling levels, and other events that occur during typical operation, is applied to representative oyster farms for each of the four main oyster-producing counties along the west coast of Florida. Normal risk affects oyster mortality rates, the quantity of labor time spent on the farm, and repairs to capital costs. For all scenarios, the stocking density is set at 250 oysters per bag, as determined by grower interviews. Table 3-2 lists the averages of each stochastic variable used during simulation, and Table 3-3 lists the value or ranges of each stochastic variable used for each scenario. In addition, the expected NPVs for each scenario are reported as a bar graph to illustrate the differences among scenarios after a five-year simulation.

The risk analysis refers to Scenario 1 as the base scenario because it only contains normal risk, and does not consider abnormal environmental or market risk. In other words, no major storms or sustained low or high salinity events occur and the market price remains at the mean for each calendar year as determined by Equation 6. This scenario provides the base level KOVs allowing for comparison with scenarios involving risk.

Scenario 2 captures the risk associated with the presence of environmental risk events along the west coast of Florida. Each environmental risk event has the potential to increase mortality and add labor costs and capital costs from gear replacement. In this scenario, if an environmental risk event occurs, then the additional mortality, labor time, and capital costs percentage is determined by a random sample from each GRKS distribution. The additional mortality percentage is multiplied by the quantity of oysters planted, and this product is subtracted from the quantity of planted oysters. The additional labor percentage is multiplied by the quantity of labor time spent on the farm to determine the additional labor required. The additional labor time provided by the employee is multiplied by the wage rate to determine the additional labor costs. Similarly, Simetar randomly selects the additional capital percentage using the LHS method and multiplies that percentage by the average costs per growing unit.

Scenario 3 analyzes the risk from changes in the dockside price. As mentioned above, a simple regression that depicts changes over time determines price. In all previous scenarios, dockside price remained at the calendar year's mean price but in Scenario 3 market price can take any value within the distribution during that year derived from the residual standard error of $0.035. The error term depicts the uncertainty in market prices over time. In this scenario, Simetar sets the stocking density at 250 oysters per bag and all other stochastic variables remain at the mean with no occurrence of a major storm or drought.

Scenario 4 considers all risk variables allowing for analysis of the most holistic view of the oyster industry within the region and comparison to all other scenarios. In Scenario 4, stocking density remains at 250 oysters per bag, there are positive probabilities of major storms and sustained salinity events, and dockside market price varies according to equation 7.

The analysis utilizes an F-test and a t-test to compare the counties in each scenario, as well as counties among different scenarios. An F-test allows for the comparisons of variances, or risk, between each county and scenario while a t-test allows for the comparisons between the expected value for each scenario and county. By running an F-test and t-test, significant differences among risk events and counties can be determined.

Break-Even and Sensitivity Analysis

The risk analysis uses the distributions listed above to analyze the risk within the oyster industry along the west coast of Florida by measuring the distributions of all KOVs. However, growers are also concerned with the percentage of oysters planted that need to be sold into the market to break even or the dockside price required to break even. A firm breaks even when the expected total revenues minus the expected total expenses equals zero. The model below calculates the expected breakeven survival of oysters a grower must sell to breakeven:

$$\boldsymbol{E[Survival\ Rate]} = \frac{E[TC] / E[P_{DS}]}{Q_{Planted,t}}$$

in which $Q_{Planted}$ represents the quantity of oysters the grower plants at the beginning of each year. Alternatively, the following formula determines the price required per oyster to break even:

$$\boldsymbol{E[Market\ Price]} = \frac{FC_t}{E[Q]} + E[VC_t]$$

where $E[Q]$ represents the expected quantity of oysters produced.

The analysis conducts a breakeven analysis on Scenarios 1 through 3 for each county to determine changes in breakeven values in the presence of various risk events. For each scenario, the relevant breakeven values are determined for years 1 through 5 resulting from additional costs incurred from environmental risk events and changes in the quantity of oysters planted as the grower establishes the oyster operation.

Next, using the variables listed above, this analysis undertakes a sensitivity analysis to determine which input variable has the greatest effect on profitability. The two input variables tested are the stocking density in the final growout bag and the price of oyster seed. The sensitivity analysis adjusts the stocking density by 50 oysters per bag from 150 to 350 oysters per bag. The sensitivity analysis then individually manipulates oyster seed cost by +/- 5%, 10%, and

15% around the mean, while keeping all other variables constant, to determine which variable generates the greatest impact on the KOVs. Comparison of the KOVs to the base level reveals the percentage change of NPV and profitability based on the change in input variables. Simetar conducts the sensitivity analysis allowing for the manipulation of a single variable during simulation. The LHS method simulates one thousand iterations from each variable. The given output reveals the base level simulation and the output of each manipulated variable.

Table 3-1. Market Price Linear Regression Results

	Beta	**Standard Error**	**t-value**	**P-value**	**F-Statistic**
Intercept	-26.310	6.18	-4.257	0.0016	18.584
Calendar Year	0.013	0.003	4.311	0.00156	
Residual Std. Error	0.0356				
R-squared	0.650				

Table 3-2. List of Stochastic Variables.

Variable	Levy County	Franklin County	Escambia County	Wakulla County
v_G	\$0.14	\$0.14	\$0.14	\$0.14
v_1	\$0.56	\$0.56	\$0.97	\$0.97
v_2	\$0.21	\$0.21	\$0.28	\$0.28
v_3	\$0.14	\$0.14	\$0.17	\$0.17
v_4	\$0.10	\$0.10	\$0.11	\$0.11
v_5	\$0.08	\$0.08	\$0.09	\$0.09
K_{High}	0.10	0.10	0.10	0.10
K_{Low}	0	0	0	0
K_{Storm}	0.33	0.33	0.33	0.33
L	0.06	0.06	0.06	0.06
L_{High}	0.26	0.26	0.26	0.26
L_{Low}	0.038	0.038	0.038	0.038
L_{Storm}	0.34	0.34	0.34	0.34
X_{NM}	0.20	0.20	0.20	0.20
$X_{Storm,i}$	0.08	0.08	0.08	0.08
X_{High}	0.10	0.10	0.10	0.10
X_{Low}	0.12	0.12	0.12	0.12
$\Pr(\text{Storm} = \text{i})$	0.19	0.19	0.11	0.16
$\Pr(\text{TS, NE})$	0.67	0.54	0.69	0.74
$\mathrm{P}r(H1, NE)$	0.14	0.29	0.08	0.17
$\mathrm{P}r(H1, N)$	0.19	0.17	0.23	0.09
$\Pr(\text{High} = \text{i})$	0.0	0.30	0.0	0.0
$\Pr(Low = i)$	0.0	0.0	0.50	0.11
$E[P_{DS,1}]$	\$0.43	\$0.43	\$0.43	\$0.43
$E[P_{DS,2}]$	\$0.45	\$0.45	\$0.45	\$0.45
$E[P_{DS,3}]$	\$0.46	\$0.46	\$0.46	\$0.46
$E[P_{DS,4}]$	\$0.47	\$0.47	\$0.47	\$0.47
$E[P_{DS,5}]$	\$0.48	\$0.48	\$0.48	\$0.48

Note: Non-dollar values are denoted as percentages.

Table 3-3. Range of Environmental and Market Risk Variables Used for Each Scenario

	Low Salinity	High Salinity	Major Storm	Baseline Mortality	Farmgate Price
Scenario 1	None	None	None	$3.6\% - 35.5\%$	Year 1: \$0.43 Year 2: \$0.45 Year 3: \$0.46 Year 4: \$0.47 Year 5: \$0.48
Scenario 2	$K_{Low} = 0\%$ $L_{Low} = 0\% - 15\%$ $X_{Low} = 0\% - 88.6\%$	$K_{High} = 0\% - 30\%$ $L_{High} = 20\% - 30\%$ $X_{High} = 0\% - 20\%$	$K_{Storm} = 0\% - 30\%$ $L_{Storm} = 20\% - 30\%$ $X_{Storm} = 0\% - 20\%$	$3.6\% - 35.5\%$	Year 1: \$0.43 Year 2: \$0.45 Year 3: \$0.46 Year 4: \$0.47 Year 5: \$0.48
Scenario 3	None	None	None	$3.6\% - 35.5\%$	Year 1: \$0.32 - \$0.55 Year 2: \$0.33 - \$0.56 Year 3: \$0.34 - \$0.58 Year 4: \$0.36 - \$0.59 Year 5: \$0.37 - \$0.60
Scenario 4	$K_{Low} = 0\%$ $L_{Low} = 0\% - 15\%$ $X_{Low} = 0\% - 88.6\%$	$K_{High} = 0\% - 30\%$ $L_{High} = 20\% - 30\%$ $X_{High} = 0\% - 20\%$	$K_{Storm} = 0\% - 30\%$ $L_{Storm} = 20\% - 30\%$ $X_{Storm} = 0\% - 20\%$	$3.6\% - 35.5\%$	Year 1: \$0.32 - \$0.55 Year 2: \$0.33 - \$0.56 Year 3: \$0.34 - \$0.58 Year 4: \$0.36 - \$0.59 Year 5: \$0.37 - \$0.60

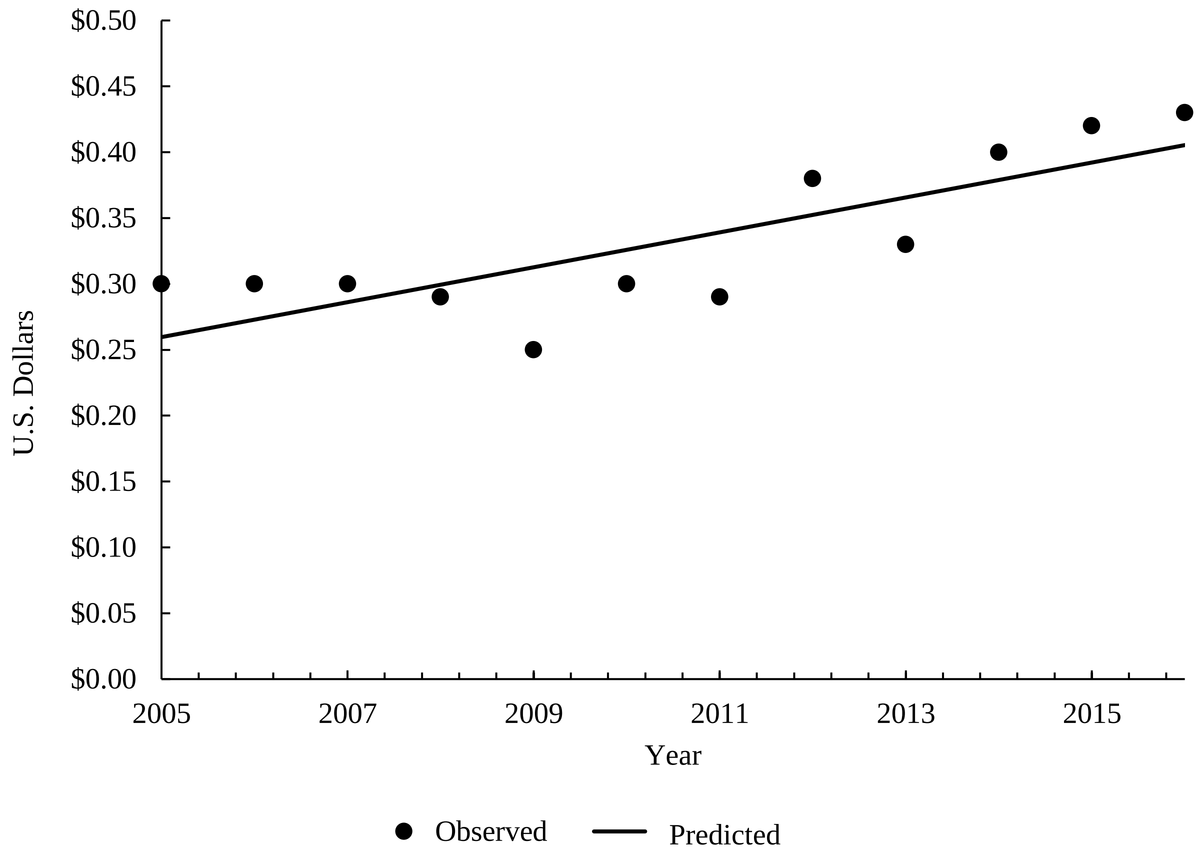


Figure 3-1. Scatter Plot with Fitted Regression Line for Observed Historical Cultured Market Prices per Oyster from the Virginia of Institute of Marine Sciences

CHAPTER 4
RESULTS

For all scenarios, a fan graph is used to illustrate each county's expected annual net income. The 5th, 25th, 75th, and 95th percentiles of annual net income are plotted on each fan graph with the expected annual net income. The range between the 25th and 75th percentile line represents the range of values net income will take 50% of the time during the simulation. Similarly, 90% of the time net income will fall in the range between the 5th and 95th percentile range. This range of potential net incomes represents the risk from each scenario for each county. The analysis simulates Net Present Value (NPV) using 1%, 3%, and 6% risk-free discount rates. All counties have a positive expected net present value for Scenarios 1 through 4. Figures 4-1 through 4-3 illustrates the expected net present value for each scenario separated by county using each risk-free discount rate.

Scenario 1

Scenario 1 applies "normal" risk to labor and capital costs and mortality from thunderstorms, varying biofouling levels, and other events that occur during typical operation. All counties have a 100% probability of a negative net income by the end of Year 1. Levy/Franklin Counties and Escambia/Wakulla Counties have a 100% and 91.93% probability of attaining a positive net income by the end of Year 2, respectively. Both counties have a 100% probability of a positive net income by the end of Year 3. Table 4-1 reports the expected net incomes and probabilities of having a negative net income for each county annually. Figures 4-4 and 4-5 illustrate Levy/Franklin Counties' and Escambia/Wakulla Counties' expected net income each year as a fan graph. As more oysters are planted the variance of net income increases, illustrating the growing risk when increasing the quantity of oysters planted (Table 4-1). Each year both regions have equal variances, but Levy/Franklin Counties have a greater expected net income compared to Escambia/Wakulla Counties.

Additionally, all counties have a 100% probability of reaching a positive NPV using a 1%, 3%, and 6% risk-free discount rate. Levy/Franklin Counties have a greater expected NPV than Escambia/Wakulla Counties due to the startup costs incurred by Escambia/Wakulla Counties and the difference in boat and fuel costs incurred and allotted to oyster production each year (Figures 4-1 through 4-3).

The breakeven oyster survival rate depends on market price, total costs, and the quantity of oysters planted. As growers in each county plant more oysters, the expected breakeven survival rate of oysters planted decreases. The expected breakeven survival rate of oysters planted for Levy/Franklin Counties in Year 1 is 129.56%, implying that they cannot obtain positive profits in the first year, and decreases to an attainable rate of 17.41% by Year 5. Similarly, Escambia/Wakulla Counties have an expected and unattainable breakeven survival rate of 232.8% oysters in Year 1 and an attainable rate of 20.39% by Year 5. The large difference in breakeven survival between counties for Year 1 is due to differences in startup costs. However, as the quantity of oysters planted increases, the difference between regions decreases due to a reduction in operational costs per oyster.

Breakeven market price depends on variable and fixed costs, the quantity of oysters planted, and the survival rate. If the quantity of oysters planted increases, then the expected breakeven price per oyster decreases. In Levy/Franklin Counties, the breakeven price is $0.78 per oyster in Year 1 and decreases each year to $0.12 per oyster by Year 5. Similarly, the expected breakeven market price per oyster in Escambia/Wakulla Counties is $1.40 per oyster in Year 1 and decreases each year to $0.14 by Year 5. Breakeven market price for both regions is greater than the highest possible market price. Therefore, no region is able to breakeven by the end of Year 1. Similar to breakeven survival, the difference between each county in Year 1 is due to differences in startup costs but decreases each year as the quantity of oysters planted increases.

Scenario 2

Scenario 2 considers the probability of each county experiencing an environmental event. Each county has different probabilities of a major storm striking and an extended low or high salinity event, as listed in Table 3-2. The probability that a county experiences two storms in a given year is 1.79% in Levy County, 1.69% in Franklin County, 0% in Escambia County, and 3.39% in Wakulla County. No county experiences 3 or more hurricanes or tropical storms in a given year. A low salinity event develops from high quantities of rainfall or an increased flow from a freshwater source, such as a stream or river. On the other hand, a high salinity event develops from low quantities of rainfall and freshwater flow. The probability of a low salinity event varies among counties. Escambia County (50%) has the highest probability of experiencing a low salinity event, followed by Wakulla County (10.53%). Levy County and Franklin County have no possibility of experiencing a low salinity event. Only Franklin County has a positive probability of a sustained high salinity event.

In this scenario, all counties have a 100% probability of a negative net income in Year 1. However, all counties have a positive expected net income by the end of Year 2. Levy County is the only county to have a 100% probability of a positive net income by the end of Year 5. Table 4-2 lists the expected net income for each county, the probability of a negative net income annually, and the variance of net income each year. Figures 4-6 through 4-9 illustrate each county's expected net income and the variance of net income values.

Franklin and Wakulla Counties are the only two counties that have statistically significantly equal expected net incomes for Scenario 2. Equal expected net incomes among Franklin and Wakulla Counties imply that environmental risk causes equal expected economic outcomes for both counties despite unique types and probabilities of each environmental risk event. Levy County has the greatest expected net income in Scenario 2 while Escambia County has the least. Since Levy County has the greatest expected net income and smallest variance, Levy County is stochastically dominant to Franklin, Escambia, and Wakulla Counties for Scenario 2. Additionally, all counties have a significantly greater variance and less expected net income compared to the same regions in Scenario 1, as expected due to the addition of environmental risk.

Overall, Levy and Franklin Counties has a 100% probability of a positive NPV for all risk-free discount rates, ceteris paribus. Escambia County has a 1.99%, 2.06%, and a 2.31%, probability of a negative NPV using a 1%, 3%, and 6% risk-free discount rate, respectively. Wakulla County has a 0.23%, 0.229%, and a 0.227% probability of a negative NPV using a 1%, 3%, and 6% risk-free discount rate, respectively. On average, Levy County has the highest expected NPV, followed by Franklin County, Wakulla County, and Escambia County.

All counties report an increase in the expected breakeven market price per oyster from Scenario 1 due to the impact of major storms. The simulation reports that Levy County has a breakeven market price per oyster of $0.81 in Year 1 and $0.14 in Year 5 while Franklin County has a breakeven market price of $0.86 in Year 1 and $0.15 in Year 5. Due to initial startup and operational costs, Escambia and Wakulla County require higher expected breakeven prices. Escambia County requires a breakeven market price of $1.63 per oyster in Year 1 and $0.19 per oyster in Year 5. Wakulla County requires a breakeven market price of $1.38 in Year 1 and

$0.14 in Year 5. Escambia County requires the greatest increase from Scenario 1 due to the relatively high probability of multiple storms striking in a given year.

Scenario 3

Scenario 3 analyzes the effect of market risk through changing market prices over time using VIMS historical market price as a proxy for the price received for Florida Gulf Coast oysters. Although market price potentially varies across locations, the model assumes that growers in all counties receive equal market prices. With constant prices across counties, the relative magnitude of expected net incomes across counties does not differ from Scenario 1. Levy/Franklin Counties receives the greatest expected net income followed by Escambia/Wakulla Counties. All counties have a 100% probability of a negative net income in Year 1. Levy/Franklin Counties have a 99.78% probability of a positive net income in Year 2 and a 100% by the end of Year 3. Escambia/Wakulla Counties have an 82.91% probability of a positive net income by the end of Year 2 and 100% by the end of Year 3. Table 4-3 reports the expected net income and probability of a negative net income for the two pairs of counties tested in Scenario 3. As expected, the risk surrounding market price increases the risk to net income relative to Scenario 1. Additionally, Figures 4-10 and 4-11 illustrate each county pair’s possible annual net incomes as a fan graph. For both county pairs, market risk is equal, with Levy/Franklin Counties having a higher probability of earning a greater net income due to lower startup and operational costs.

Each county has a greater expected net income in Scenario 3 compared to the same county in Scenario 2. The increase in expected net income from Scenario 2 to 3 is due to the possibility of receiving higher than average prices and increasing net income compared to Scenario 2 where variability only resulted in decreases in net income.

Similarly, each county has a greater variance in Scenario 2 compared to the same county in Scenario 3. Therefore, due to a greater expected net income and a smaller variance, market risk has a lesser effect on net income for each county than environmental risk events.

The expected NPV remains the same for all risk-free discount rates compared to Scenario 1, and all regions have a 100% probability of a positive NPV. Despite the variation in market price, the expected market price remains the same as in Scenario 1, causing no change in expected NPV from Scenario 1 to Scenario 3. Levy/Franklin Counties have the highest NPV for each discount rate followed by Escambia/Wakulla Counties.

Unlike environmental risk events tested in Scenarios 2, market price risk has the potential to increase net income and the NPV. Due to the probability of market price increasing above the expected values considered in Scenario 2, maximum net income and NPV is higher in Scenario 3 than in Scenario 2 for all counties during all years. Although changes in market price have the potential to decrease net income and NPV, all counties have a lower minimum NPV with the inclusion of environmental risk in Scenario 2 than with market risk in Scenario 3.

All counties have no change in expected breakeven survival for Years 1-5 compared to Scenario 1 because the expected price remains the same as in Scenario 1 and there are no changes in operational costs or mortality levels.

Scenario 4

Scenario 4 considers all risk variables, including major storms, prolonged low salinity and high salinity events, and changes in market price. This scenario is considered the most holistic case because each county may experience multiple environmental and market risk events in a given year.

All counties have lower expected net incomes for Years 1 through 5 compared to Scenario 1. Levy County has the greatest expected net income each year, followed by Franklin, Wakulla, and Escambia Counties. Similar to Scenario 1, all counties have a 100% probability of a negative net income by the end of Year 1. Only Levy County has a 100% probability of a positive net income by the end of Year 5. Franklin, Escambia, and Wakulla Counties have a 99.46%, a 97.43% and, a 99.14% probability of a positive net income by the end of Year 5. Table 4-4 reports the expected net income for each county annually and the probability of earning a negative net income. Additionally, Figures 4-12 through 4-15 illustrate each county's potential net income using a fan graph. The increased ranges of potential net income for each county encompasses the effects of environmental and market risk events.

Franklin and Wakulla Counties are the only counties to have significantly equal variances and net incomes when comparing counties within Scenario 4. Levy County has the greatest expected net income and smallest variance in Scenario 4. Therefore, Levy County is the dominant county when considering environmental and market risks simultaneously. Franklin and Wakulla Counties are stochastically dominant to Escambia County due to a greater expected net income and smaller variance. Escambia County has the lowest expected net income and greatest variance among all counties in Scenario 4. Additionally, all counties in Scenario 4 have a significantly greater variance and smaller expected net income compared to Scenarios 1 through 3.

Similar to Scenario 2, Levy and Franklin Counties have a 100% probability of a positive NPV for all discount rates analyzed. Escambia County has a 2.05%, 2.06%, and a 2.12% probability of a negative NPV using a risk-free discount rate of 1%, 3%, and 6%, respectively. Also, Wakulla County has a 0.174%, 0.175%, and a 0.177% probability of a negative NPV using a 1%, 3%, and 6% risk-free discount rate, respectively. Levy County has the greatest expected NPV value, followed by Franklin, Wakulla, and Escambia Counties. Compared to Scenario 1, all counties have a lower expected NPV for all discount rates due to the inclusion of both environmental and market risk

Sensitivity Analysis

This study includes a sensitivity analysis of the effects of two variables, oyster stocking density in final growout gear and the cost of oyster seed, on net income. The range of values considered for these variables could occur in the future as production methods and the supply of triploid oyster seed changes.

Stocking Density

The scenario analysis assumed growers utilized an average stocking density in final growout bags of 250 oysters for each scenario. However, growers are beginning to increase stocking densities to reduce the average cost of growout gear and increase the revenue per growout bag. The sensitivity analysis varies stocking density by 50 oyster increments from 150 to 350 oysters per bag assuming that changing the stocking density will not have an effect on mortality rates. The analysis simulates net income for Levy/Franklin Counties and Escambia/Wakulla Counties for each year using each discrete stocking density. For both regions, net income increases at a decreasing rate as stocking density increases. Figures 4-16 and 4-17 illustrate the expected net incomes of Levy/Franklin Counties and Escambia/Wakulla Counties each year for each stocking density.

Oyster Seed Price

This analysis utilized the most recent triploid oyster seed price, $25 for 1,000 oysters or $0.025 per oyster. Triploid oyster seed supply varies from year to year as nurseries experiment with more efficient breeding methods and increasing the supply of broodstock. As a result, the supply of triploid oyster seed varies each year, causing oyster seed prices to change constantly. The analysis adjusted oyster seed prices by positive and negative 5%, 10%, and 15% to test the effect on net income. In all counties, changes in oyster seed price do not have a large effect in the first year, due to the low quantity of seed purchased. As a grower purchases more seed, closer to Year 5, changing oyster seed prices have a greater effect on net income. Additionally, a 1% change in oyster seed price leads to a less than 1% change in net income for all counties and years tested. For example, a 15% increase in oyster seed price in Escambia County in Year 5 led to a decrease of 1.48% in net income from the base oyster seed cost. Figures 4-18 and 4-19 illustrate the effect on net income from changing oyster prices in Levy/Franklin Counties and Escambia/Wakulla Counties.

Table 4-1. Expected Net Incomes and Variances, Probabilities of Earning a Negative Net Income, and Breakeven Survival Rates and Market Prices for Scenario 1

	Year 1	Year 2	Year 3	Year 4	Year 5
			Expected Net Income		
Levy/ Franklin	($2,485.92)	$5,188.35	$27,142.52	$53,284.85	$66,181.39
Escambia/ Wakulla	($6,944.86)	$1,668.44	$23,523.28	$49,668.07	$62,565.14
			Expected Net Income Variance		
Levy/ Franklin	$81,758	$1,680,184	$14,592,915	$27,806,755	$31,365,395
Escambia/ Wakulla	$80,888	$1,740,584	$14,389,137	$27,354,559	$33,025,370
			Probability of Net Income ≤ $0		
Levy/ Franklin	100%	0%	0%	0%	0%
Escambia/ Wakulla	100%	8.07%	0%	0%	0%
			Breakeven Survival Rate		
Levy/ Franklin	129.56%	48.69%	32.52%	21.79%	17.41%
Escambia/ Wakulla	232.80%	64.50%	37.79%	25.20%	20.39%
			Breakeven Market Price		
Levy/ Franklin	$0.78	$0.30	$0.21	$0.14	$0.12
Escambia/ Wakulla	$1.40	$0.40	$0.24	$0.17	$0.14

Table 4-2. Expected Net Incomes and Variances, Probabilities of Earning a Negative Net Income, and Breakeven Market Prices for Scenario 2

	Year 1	Year 2	Year 3	Year 4	Year 5
			Expected Net Income		
Levy	($2,649.33)	$4,366.05	$24,647.87	$49,492.96	$62,073.54
Franklin	($2,798.64)	$3,618.10	$22,231.69	$45,725.65	$57,824.81
Escambia	($7,267.85)	$80.40	$18,473.94	$41,604.90	$53,265.83
Wakulla	($7,144.24)	$665.33	$20,676.58	$45,055.30	$57,582.57
			Expected Net Income Variance		
Levy	$246,396	$6,005,098	$56,599,410	$122,890,735	$138,650,997
Franklin	$349,795	$8,047,349	$75,384,844	$163,186,762	$205,359,768
Escambia	$483,977	$11,004,064	$105,199,376	$254,375,343	$342,955,057
Wakulla	$328,657	$7,453,126	$59,453,970	$168,044,830	$174,008,725
			Probability of Net Income ≤ $0		
Levy	100%	6.69%	1.97%	0.28%	0%
Franklin	100%	11.38%	1.83%	0.61%	0.51%
Escambia	100%	32.22%	7.25%	3.21%	2.58%
Wakulla	100%	22.94%	3.72%	1.17%	0.50%
			Breakeven Market Price		
Levy	$0.81	$0.33	$0.23	$0.16	$0.14
Franklin	$0.86	$0.35	$0.25	$0.18	$0.15
Escambia	$1.63	$0.47	$0.31	$0.21	$0.19
Wakulla	$1.38	$0.42	$0.27	$0.19	$0.14

Table 4-3. Expected Net Incomes and Variances, Probabilities of Earning a Negative Net Income, and Breakeven Survival Rates for Scenario 3

	Year 1	Year 2	Year 3	Year 4	Year 5
			Expected Net Income		
Levy/ Franklin	($2,485.49)	$5,186.93	$27,133.32	$53,279.37	$66,169.47
Escambia/ Wakulla	($6,946.46)	$1,668.27	$23,534.22	$49,658.29	$62,559.69
			Expected Net Income Variance		
Levy/ Franklin	$153,422	$3,342,931	$27,484,924	$58,001,633	$71,565,148
Escambia/ Wakulla	$132,260	$3,288,688	$29,900,576	$58,702,815	$72,307,976
			Probability of Net Income ≤ $0		
Levy/ Franklin	100%	0.22%	0%	0%	0%
Escambia/ Wakulla	100%	17.09%	0%	0%	0%
			Breakeven Survival Rate		
Levy/ Franklin	130.42%	49.00%	32.72%	21.90%	17.49%
Escambia/ Wakulla	234.35%	64.90%	38.02%	25.34%	20.50%

Table 4-4. Expected Net Incomes and Variances and Probabilities of Earning a Negative Net Income for Scenario 4

	Year 1	Year 2	Year 3	Year 4	Year 5
			Expected Net Income		
Levy	($2,648.79)	$4,366.28	$24,635.22	$49,477.49	$62,063.92
Franklin	($2,808.10)	$3,619.68	$22,179.94	$45,708.36	$58,184.73
Escambia	($7,268.82)	$68.75	$18,475.02	$41,575.23	$53,267.76
Wakulla	($7,066.35)	$690.89	$20,595.14	$45,457.51	$57,530.94
			Expected Net Income Variances		
Levy	$310,602	$7,559,517	$69,973,613	$150,601,953	$174,536,206
Franklin	$411,799	$9,825,170	$83,849,076	$182,478,224	$230,109,978
Escambia	$532,163	$12,247,690	$119,764,834	$283,844,643	$382,550,636
Wakulla	$287,333	$9,129,835	$78,132,507	$170,595,554	$241,573,041
			Probability of Net Income ≤ $0		
Levy	100%	7.38%	1.65%	0%	0%
Franklin	100%	12.76%	1.91%	0.60%	0.54%
Escambia	100%	38.92%	7.66%	3.26%	2.57%
Wakulla	100%	31.18%	3.50%	0.73%	0.86%

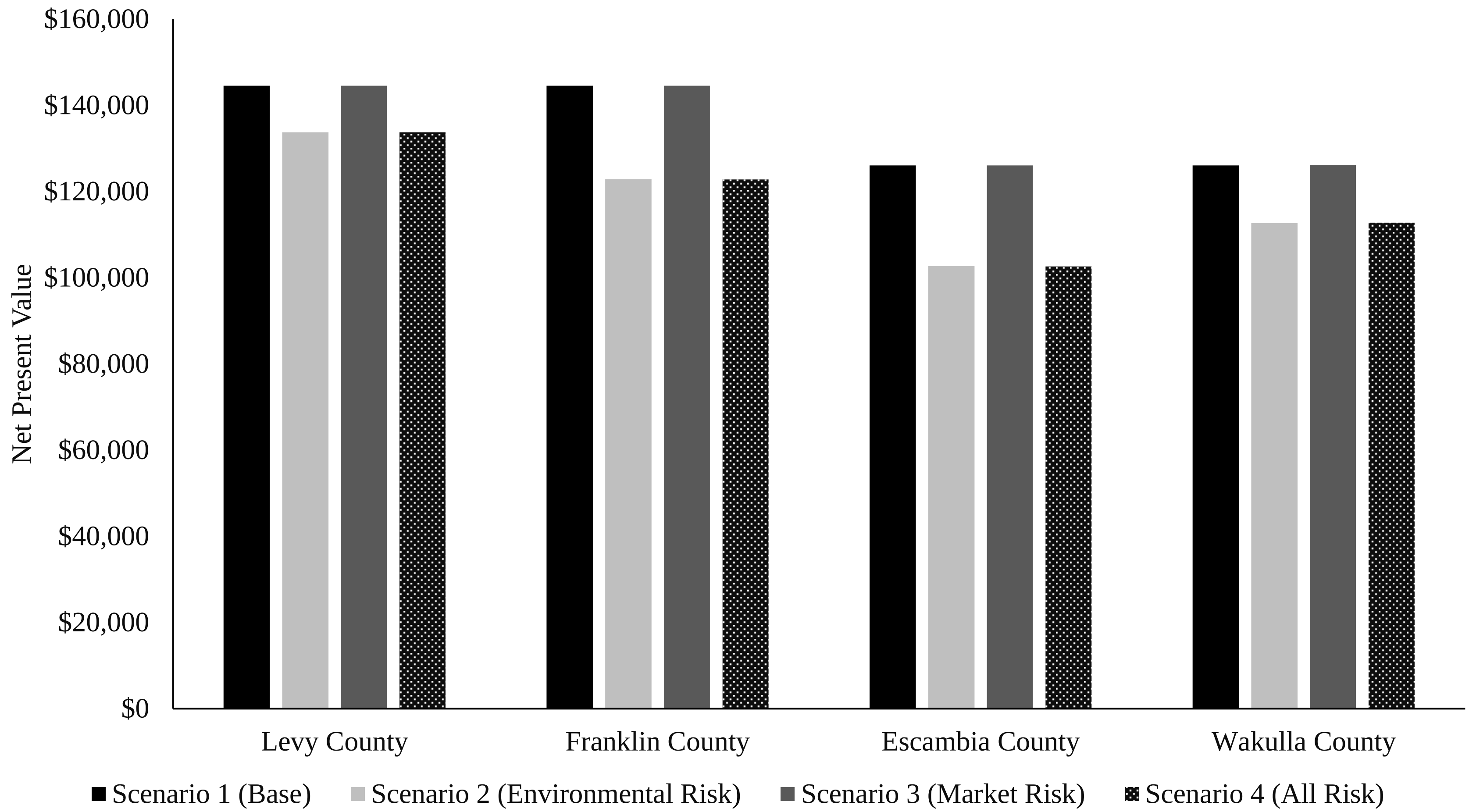


Figure 4-1. Net Present Value for All Scenarios Using a 1% Discount Rate

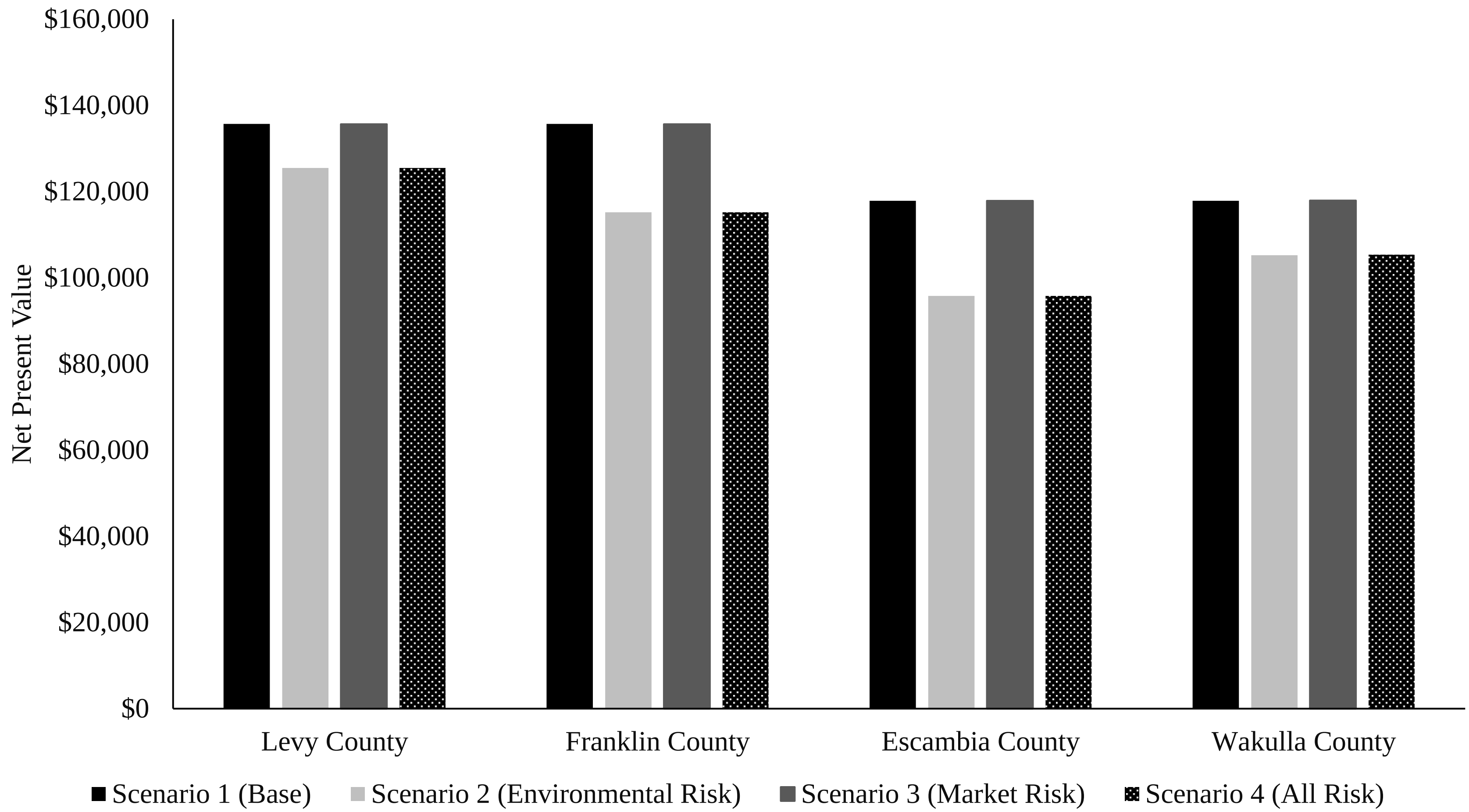


Figure 4-2. Net Present Value for All Scenarios Using a 3% Discount Rate

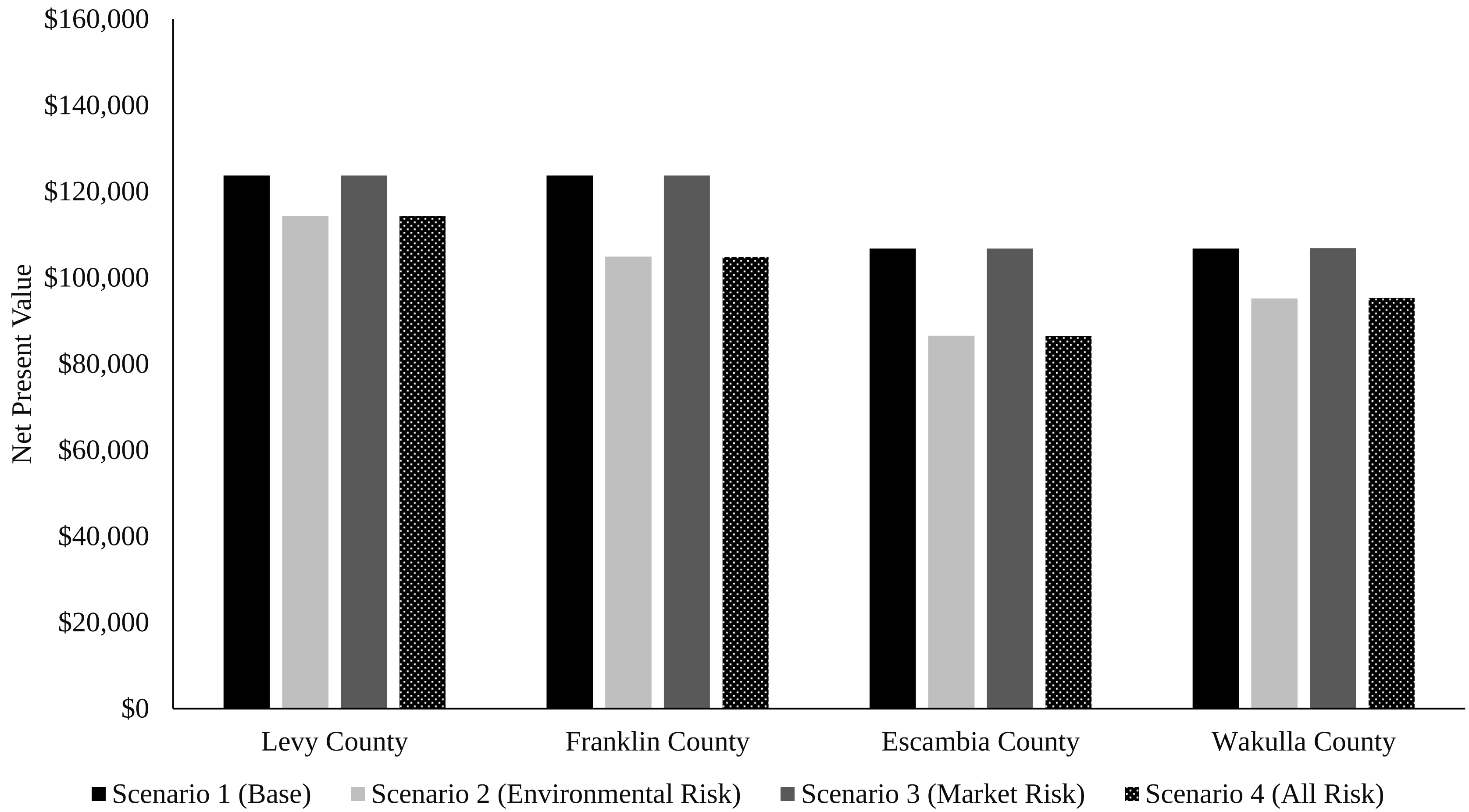


Figure 4-3. Net Present Value for All Scenarios Using a 6% Discount Rate

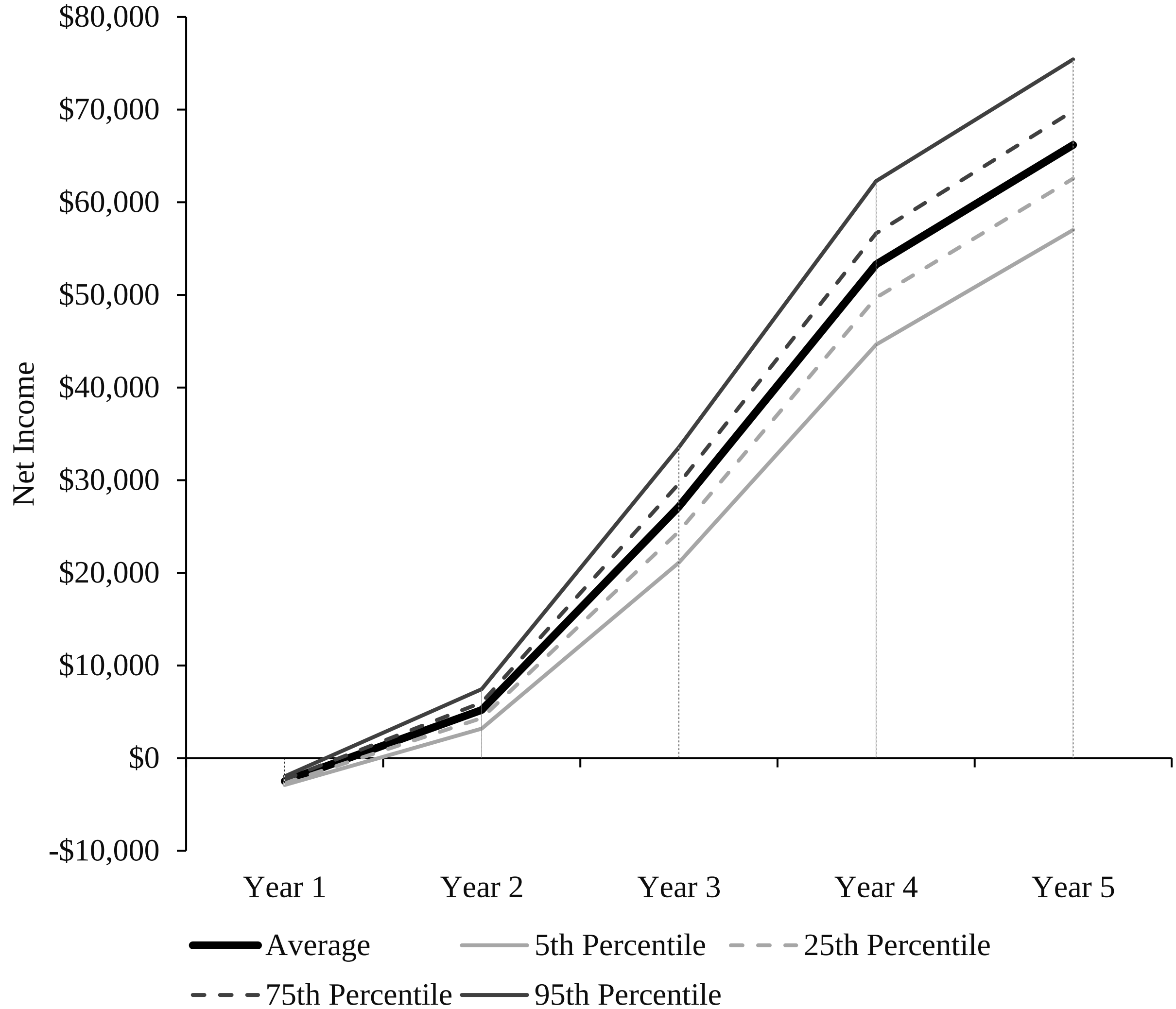


Figure 4-4. Net Income for Levy/Franklin Counties for Scenario 1

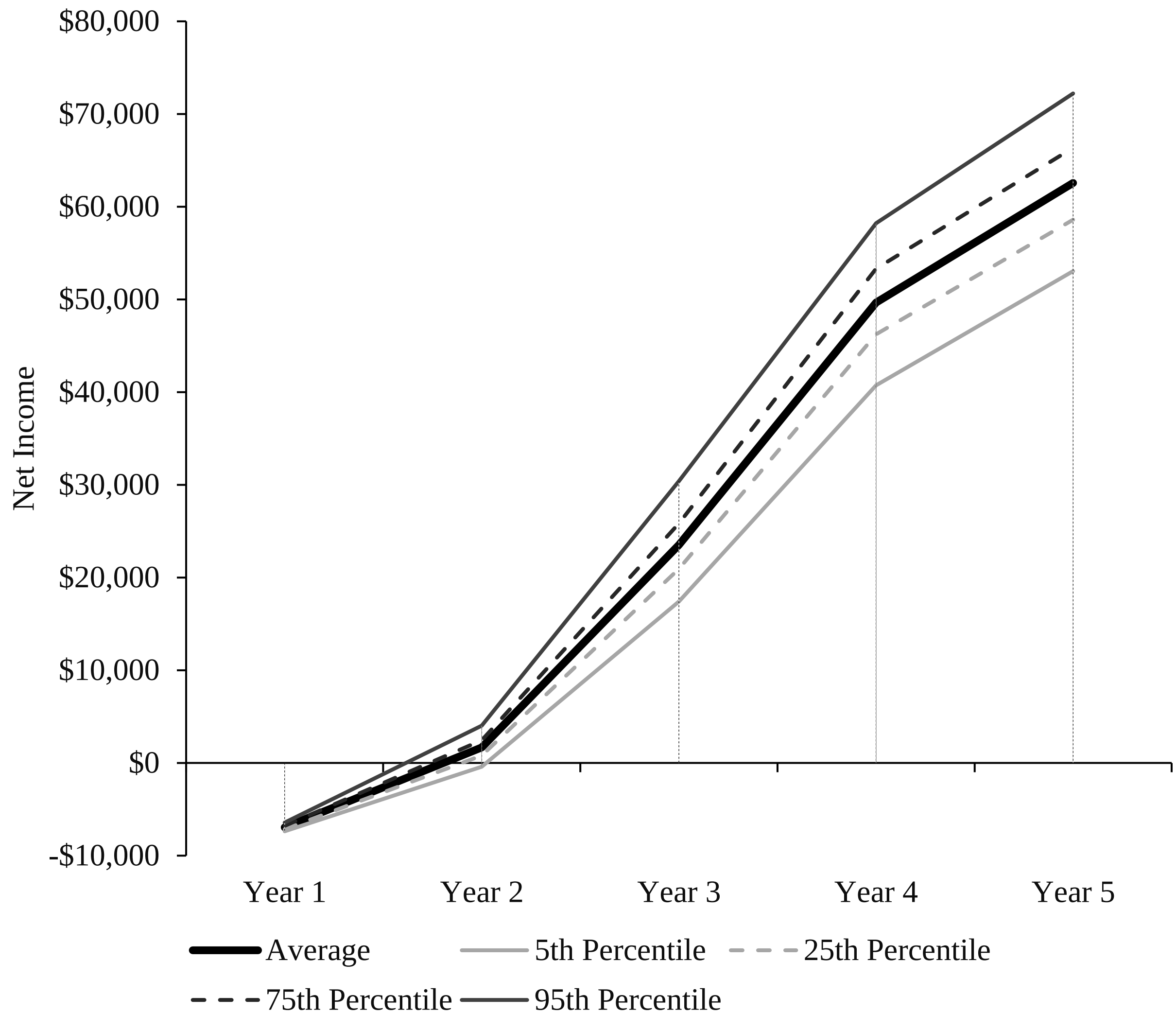


Figure 4-5. Net Income for Escambia/Wakulla Counties for Scenario 1

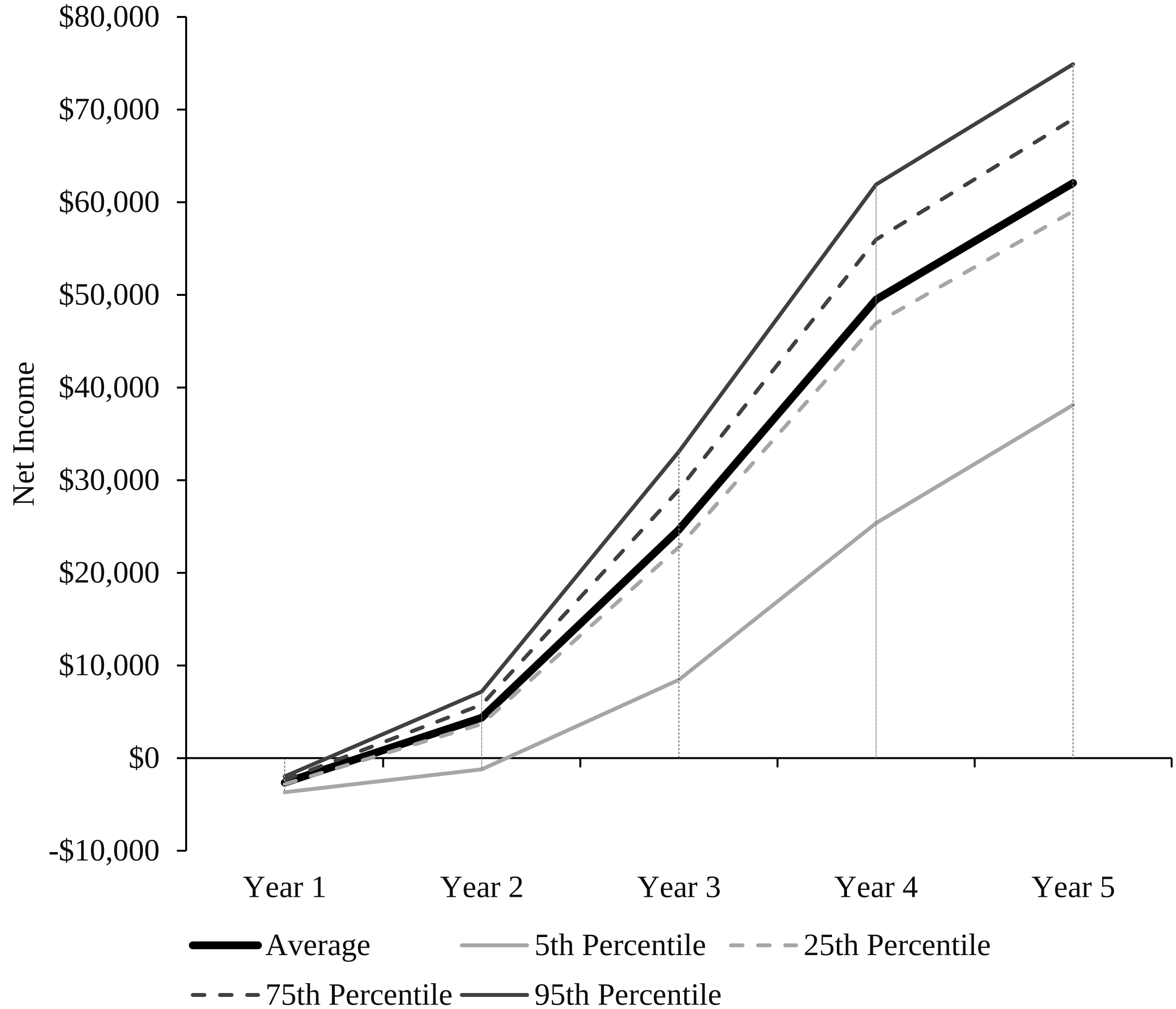


Figure 4-6. Net Income for Levy County for Scenario 2

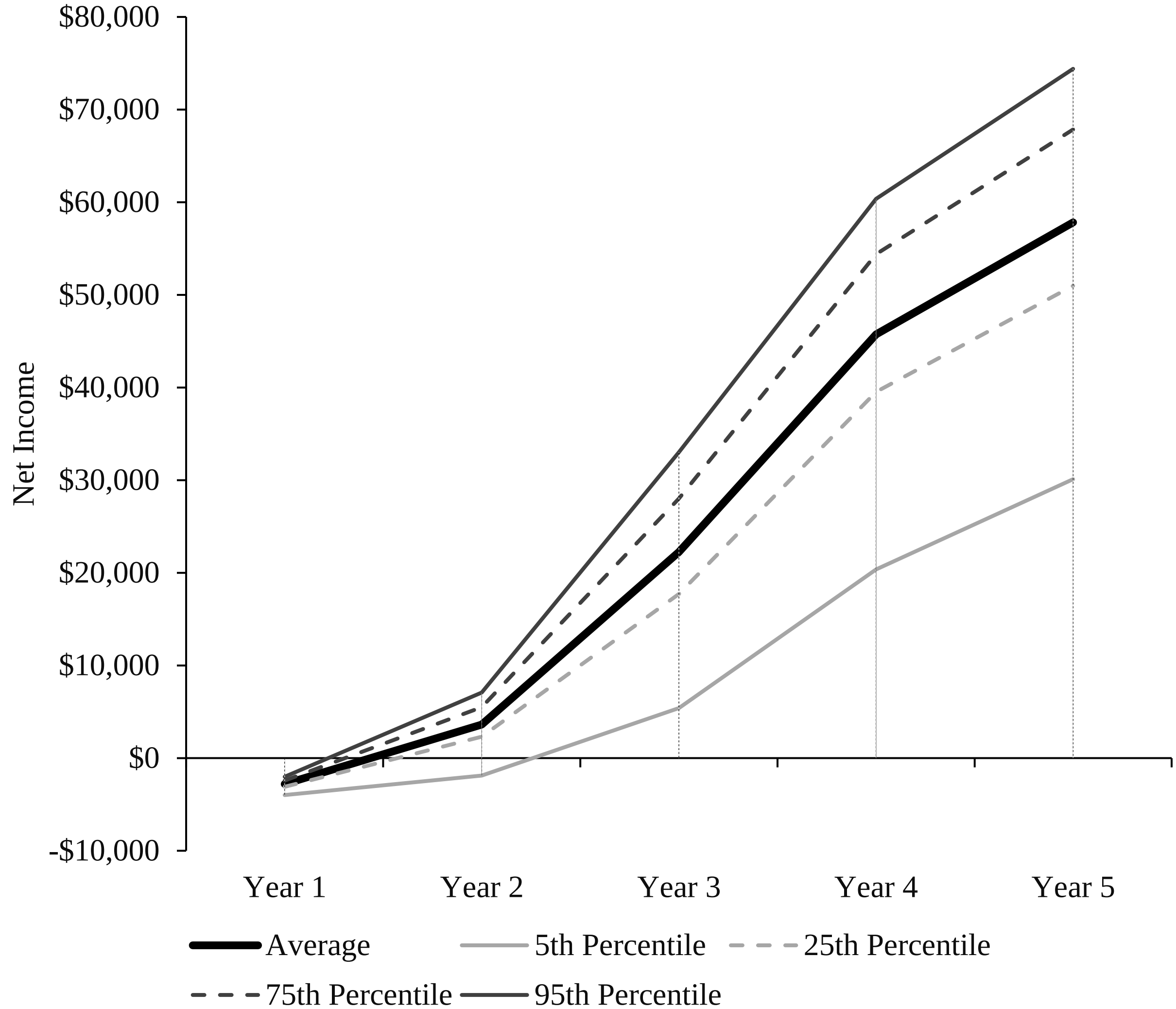


Figure 4-7. Net Income for Franklin County for Scenario 2

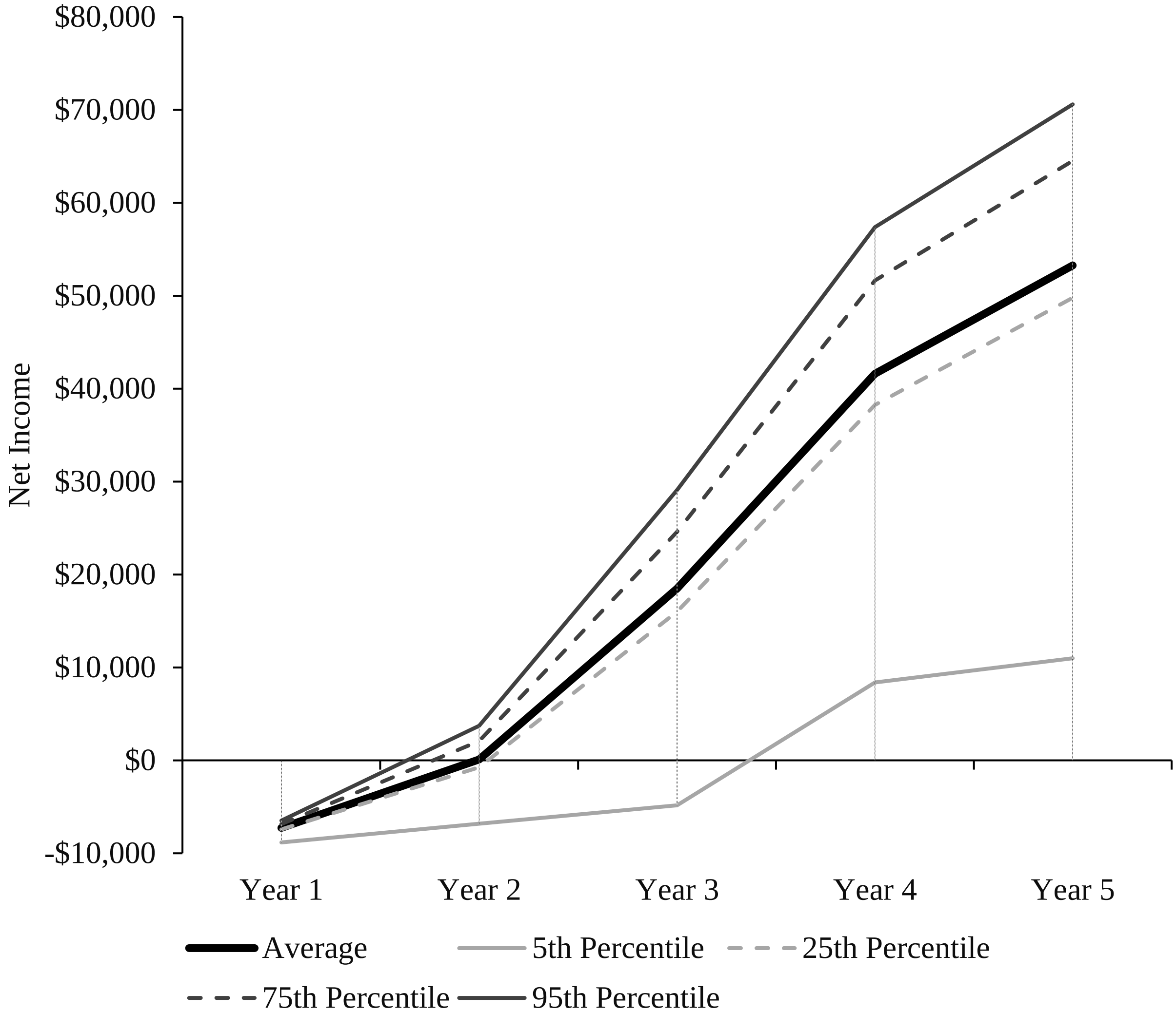


Figure 4-8. Net Income for Escambia County for Scenario 2

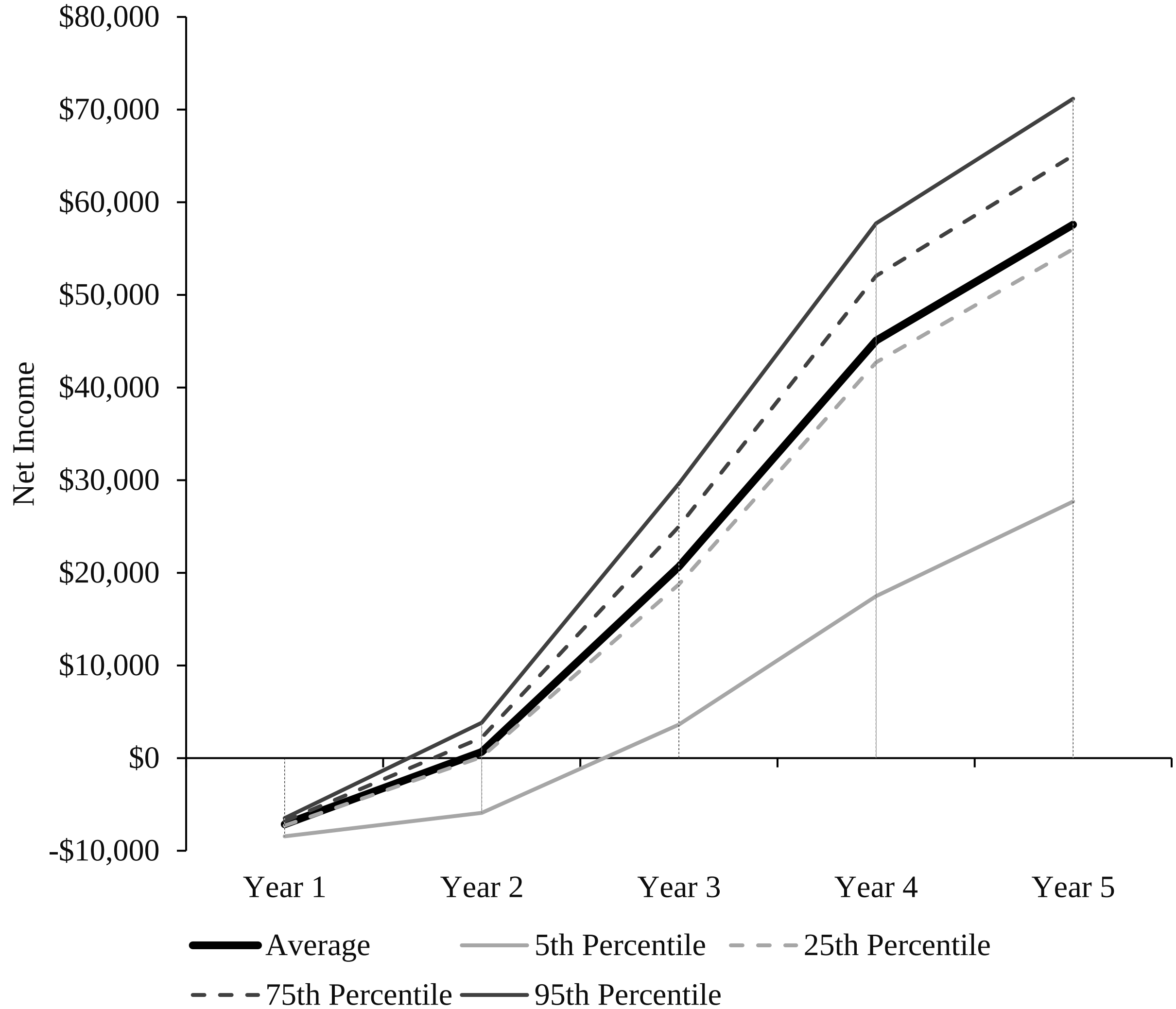


Figure 4-9. Net Income for Wakulla County for Scenario 2

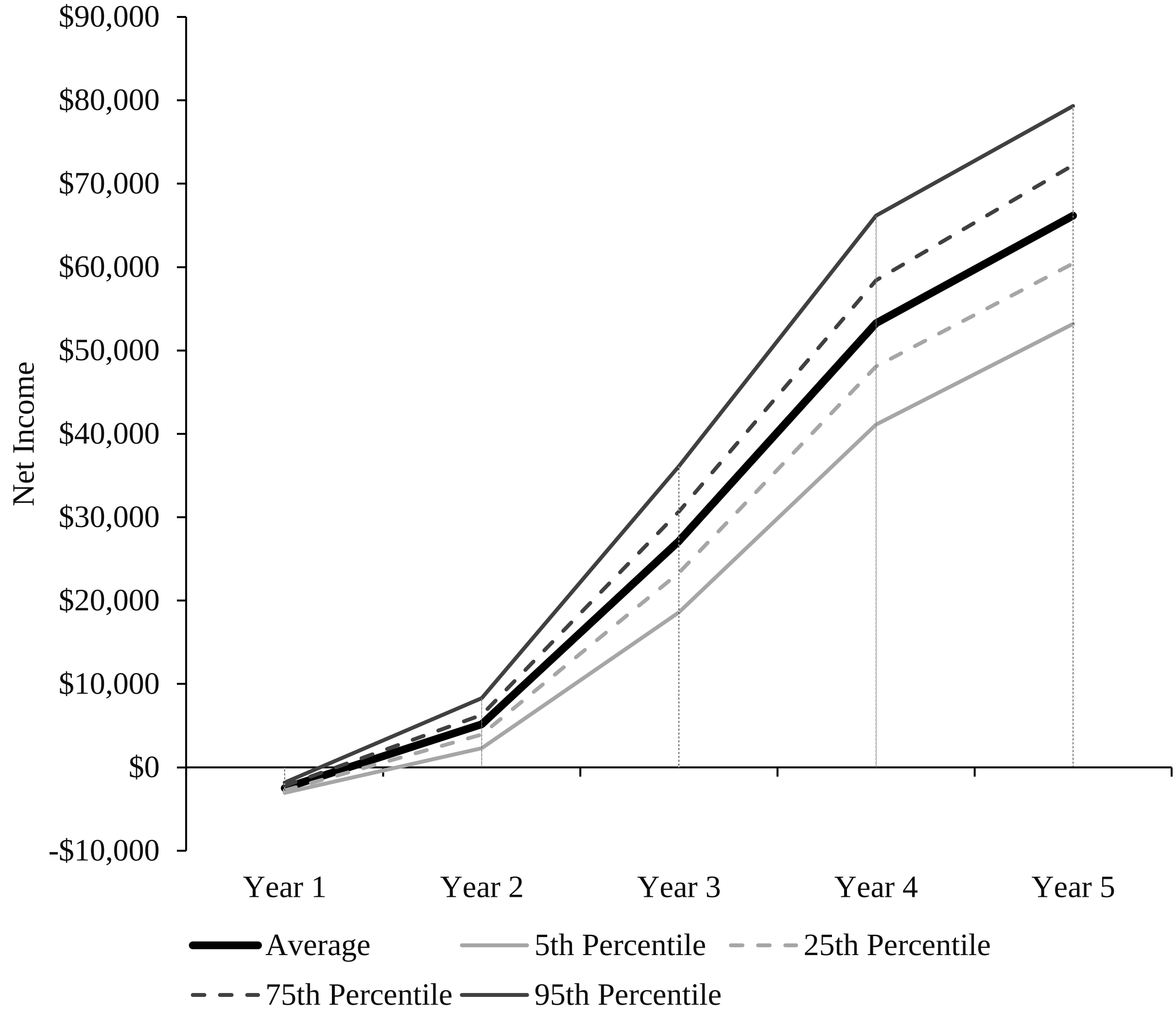


Figure 4-10. Net Income for Levy/Franklin Counties for Scenario 3

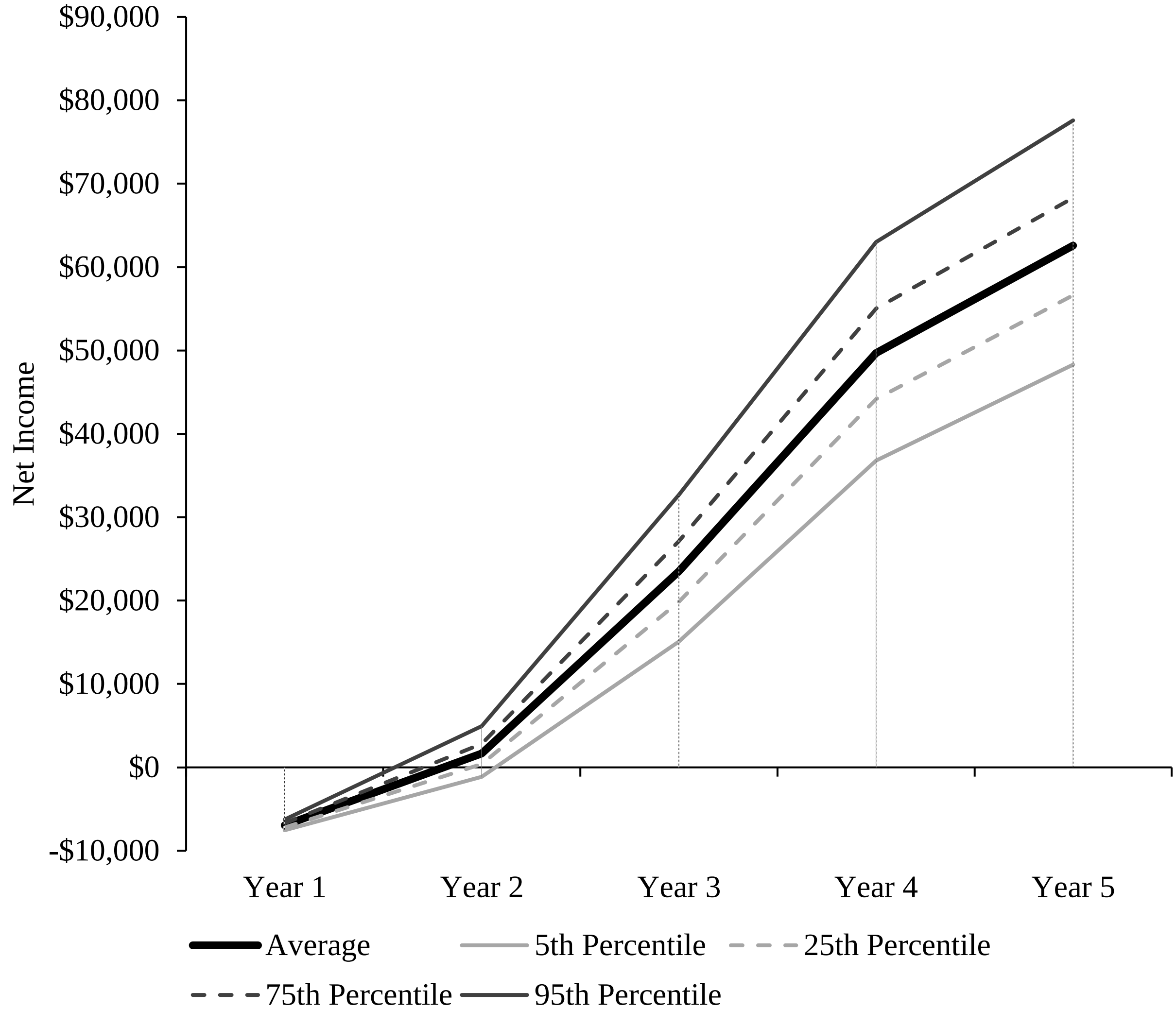


Figure 4-11. Net Income for Escambia/Wakulla Counties for Scenario 3

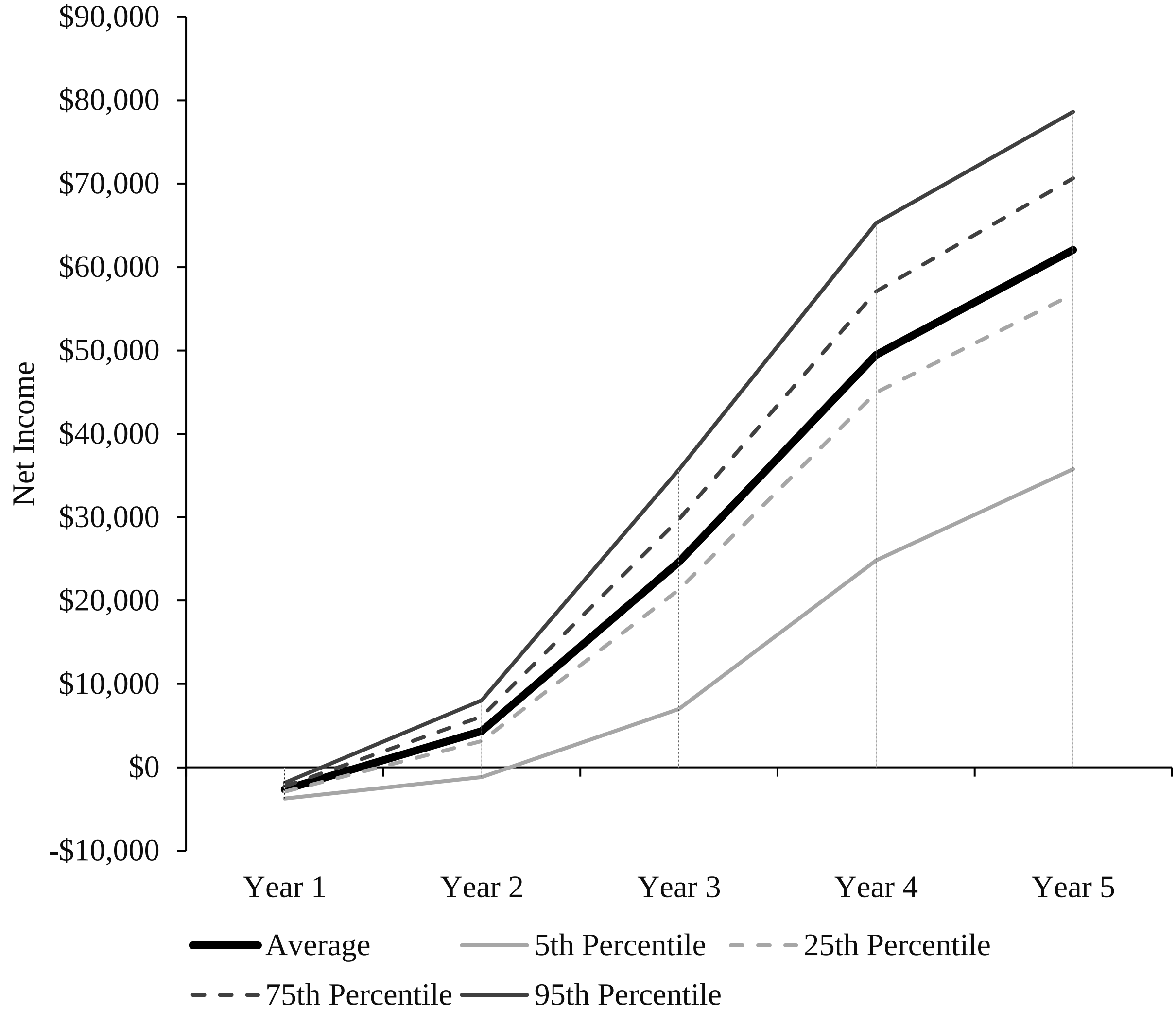


Figure 4-12. Net Income for Levy County for Scenario 4

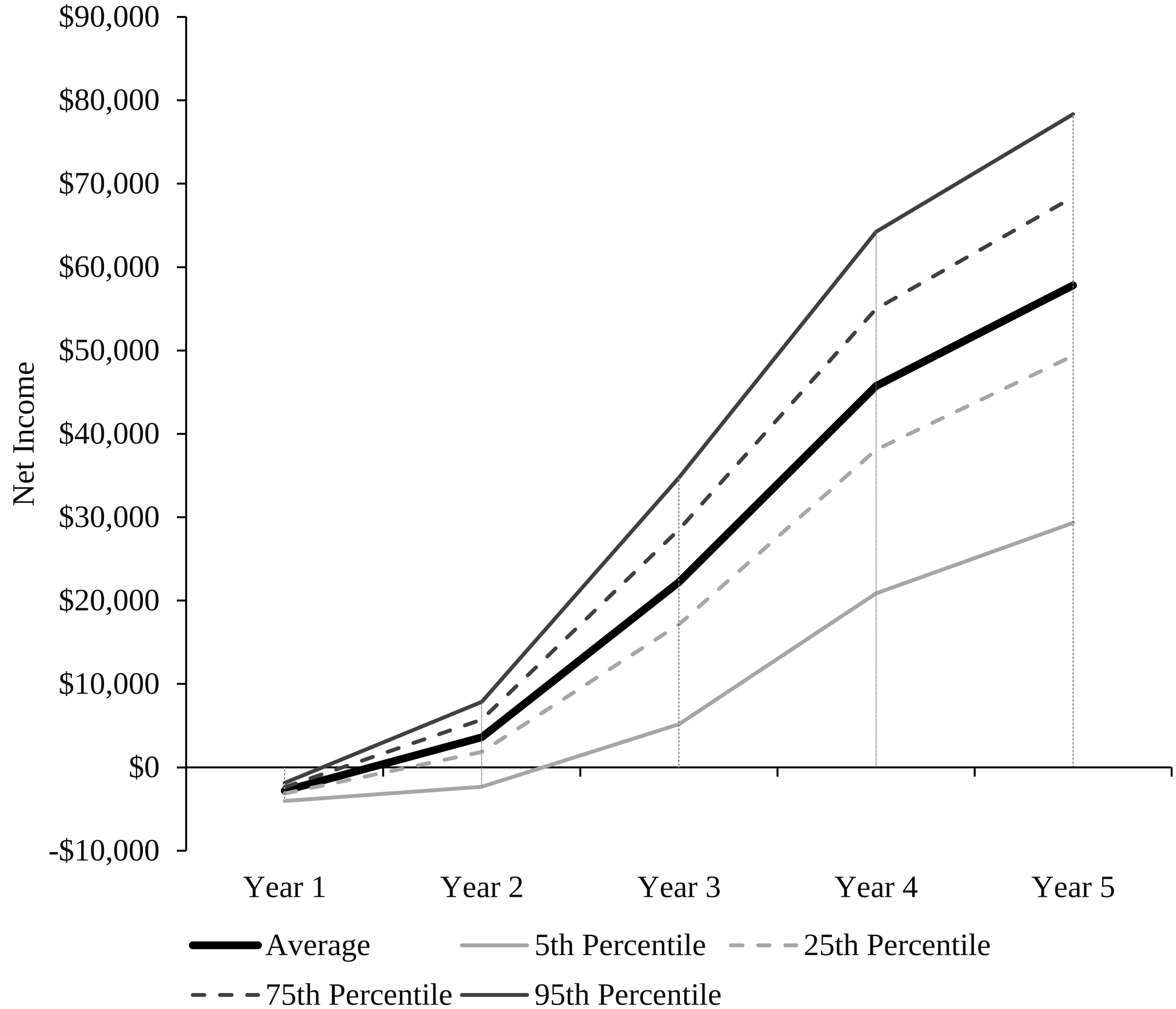


Figure 4-13. Net Income for Franklin County for Scenario 4

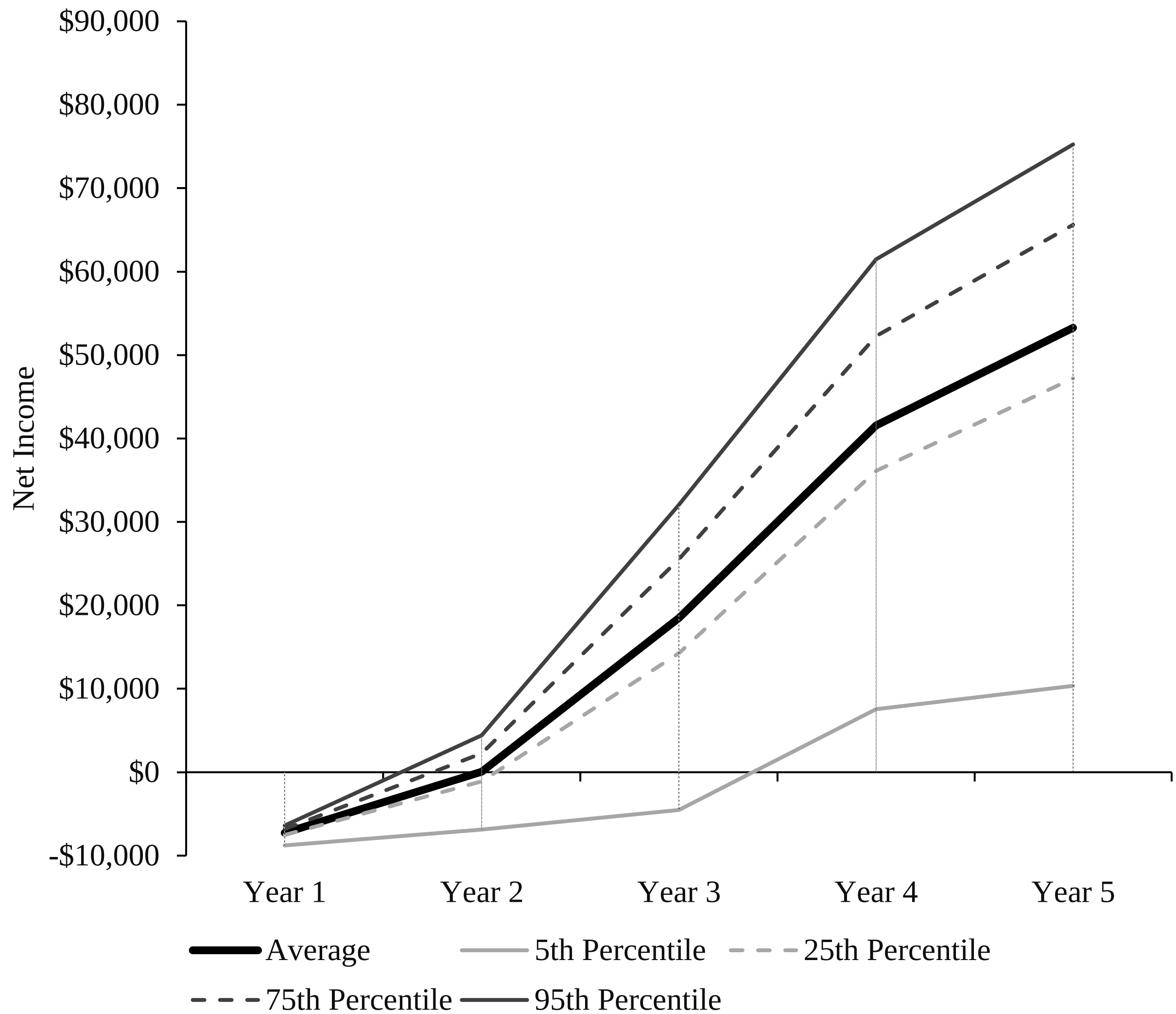


Figure 4-14. Net Income for Escambia County for Scenario 4

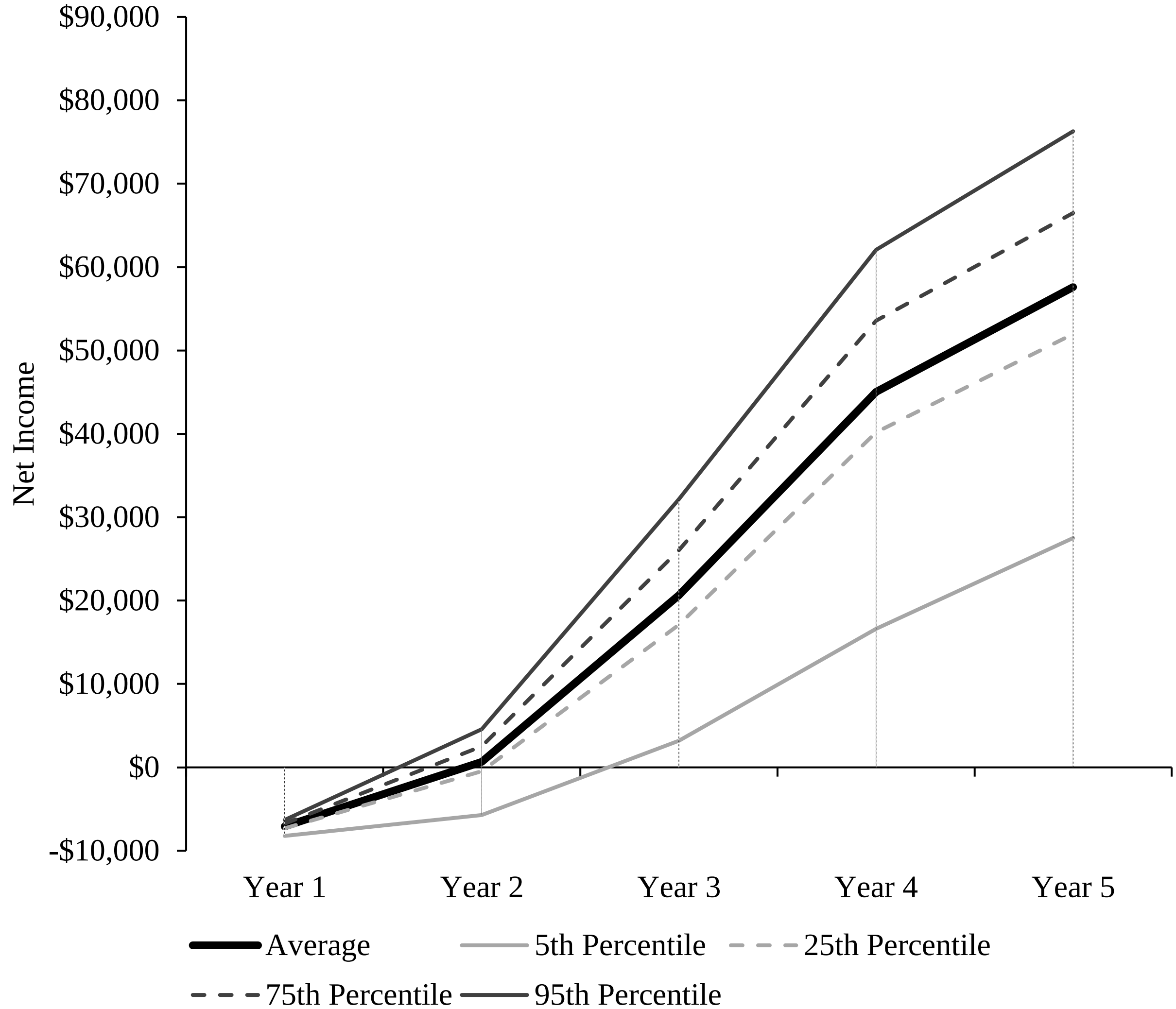


Figure 4-15. Net Income for Wakulla County for Scenario 4

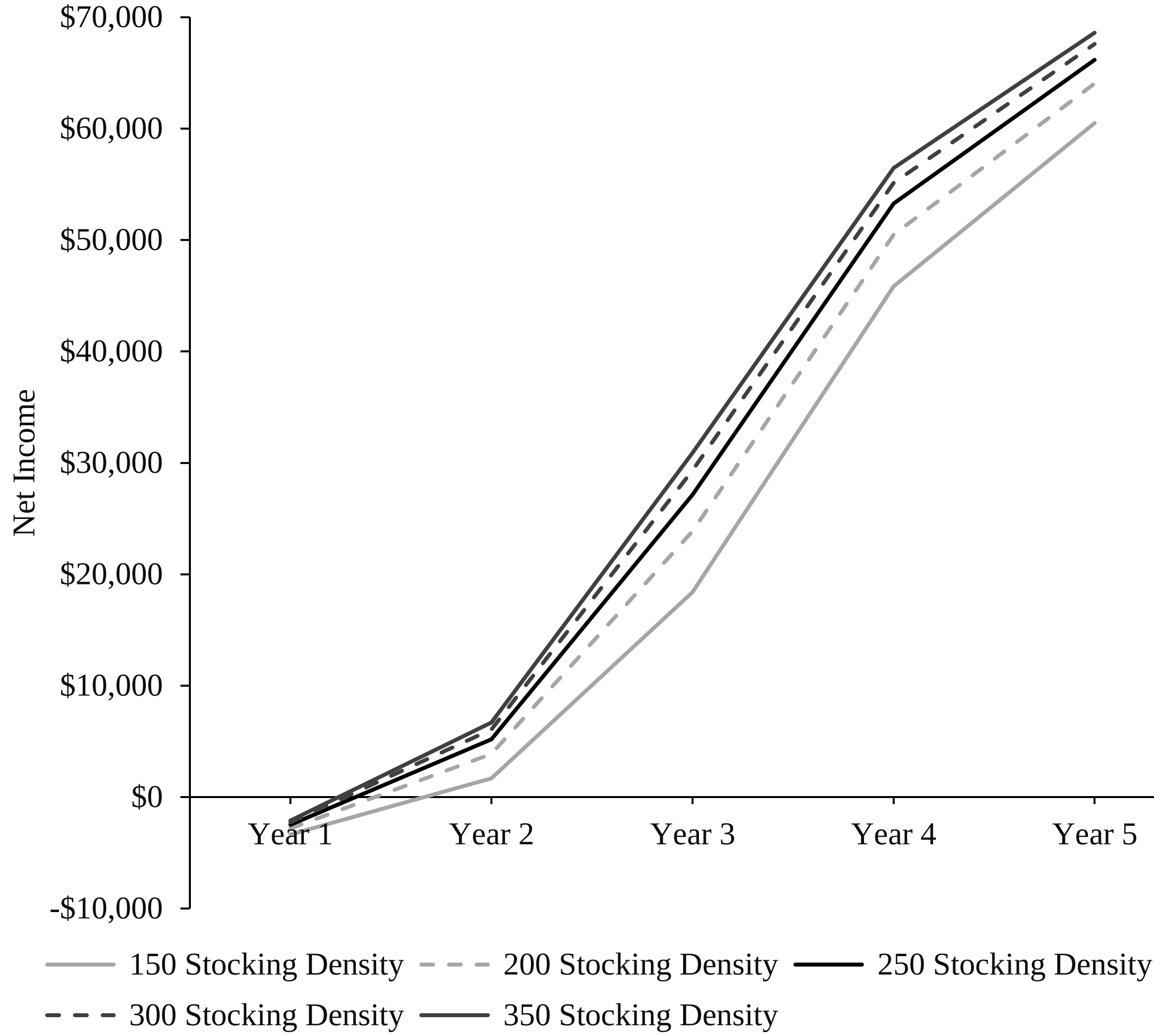


Figure 4-16. Sensitivity Analysis on Stocking Density for Levy/Franklin Counties

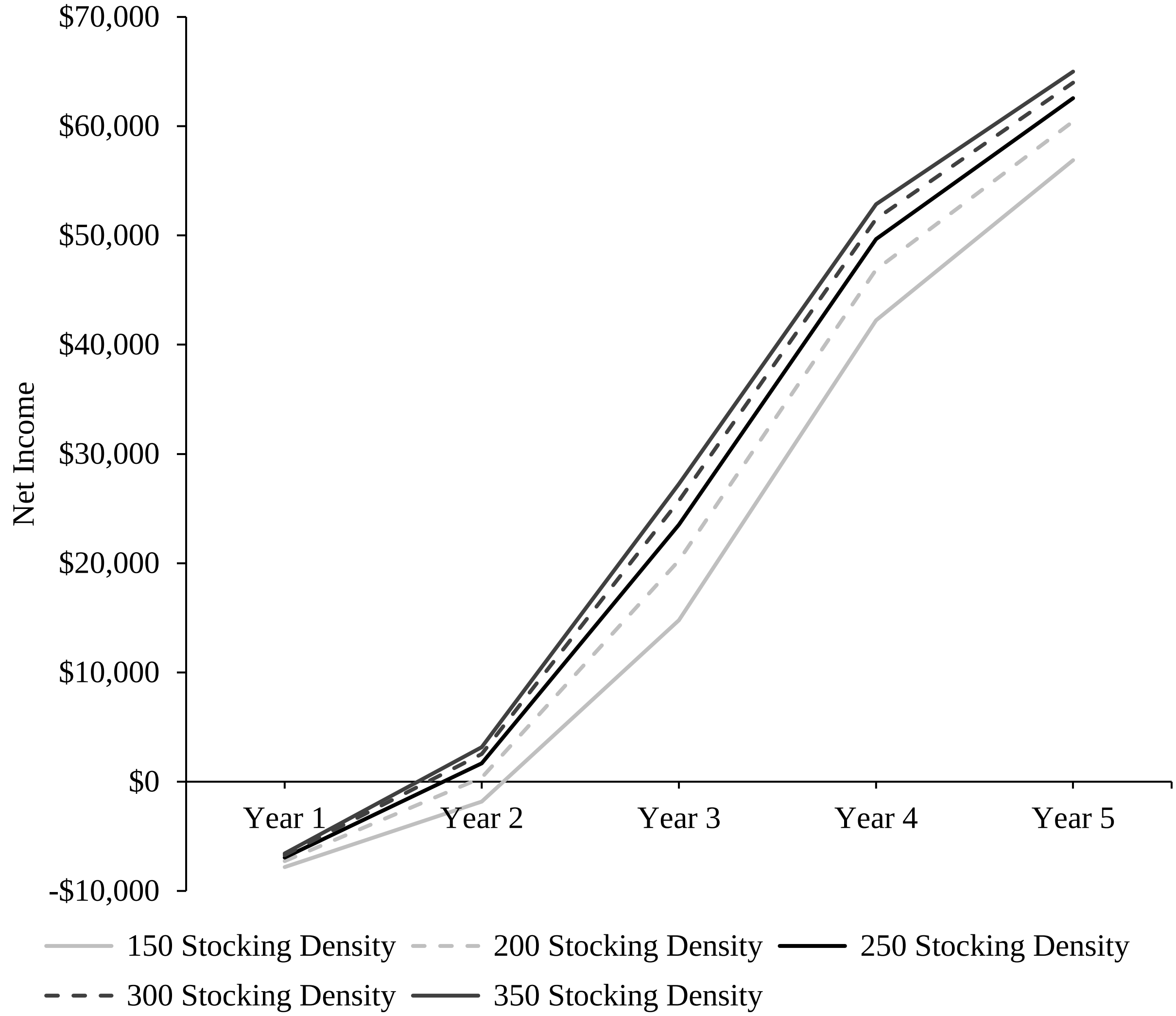


Figure 4-17. Sensitivity Analysis on Stocking Density for Escambia/Wakulla Counties

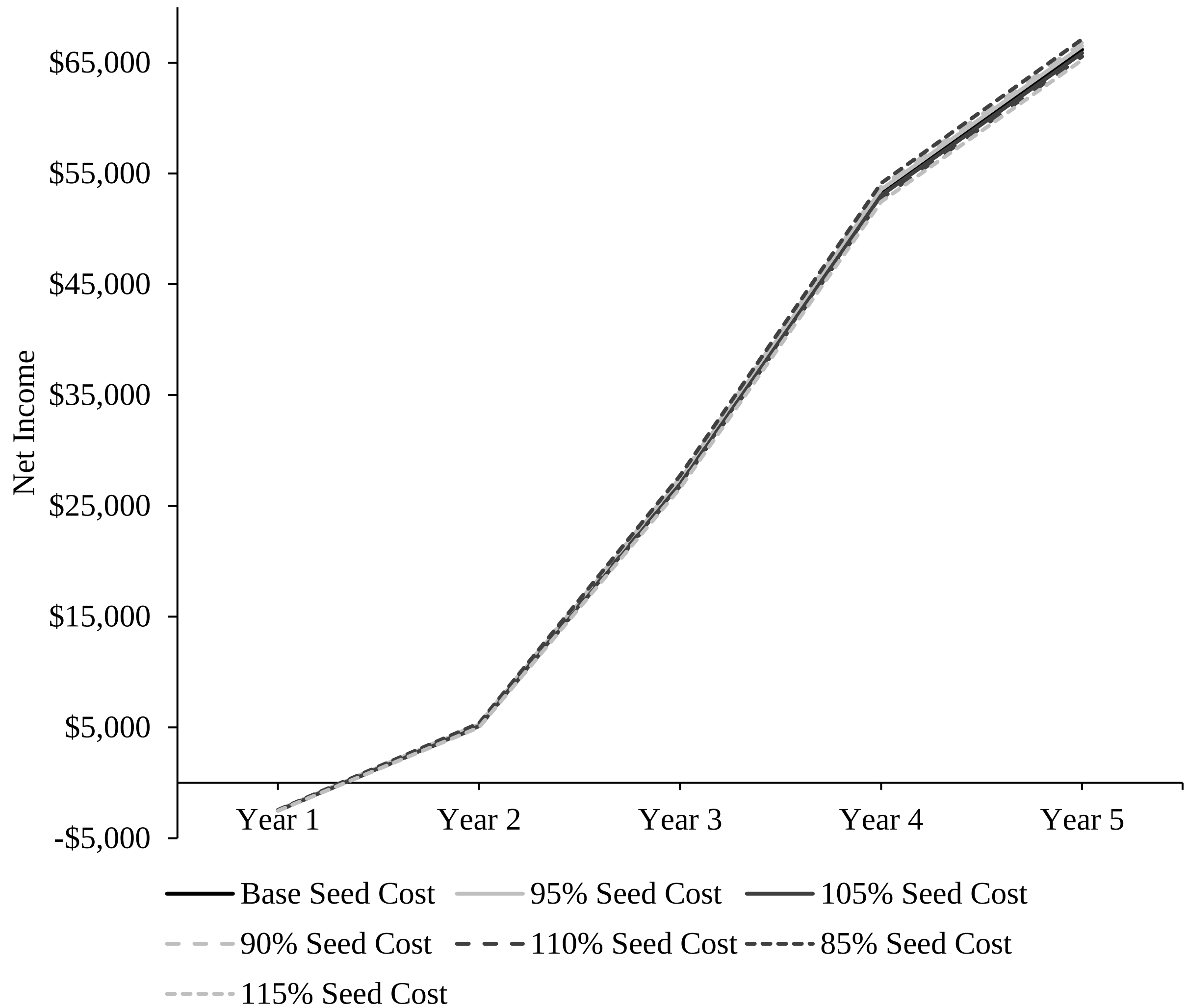


Figure 4-18. Sensitivity Analysis on Seed Cost for Levy/Franklin Counties

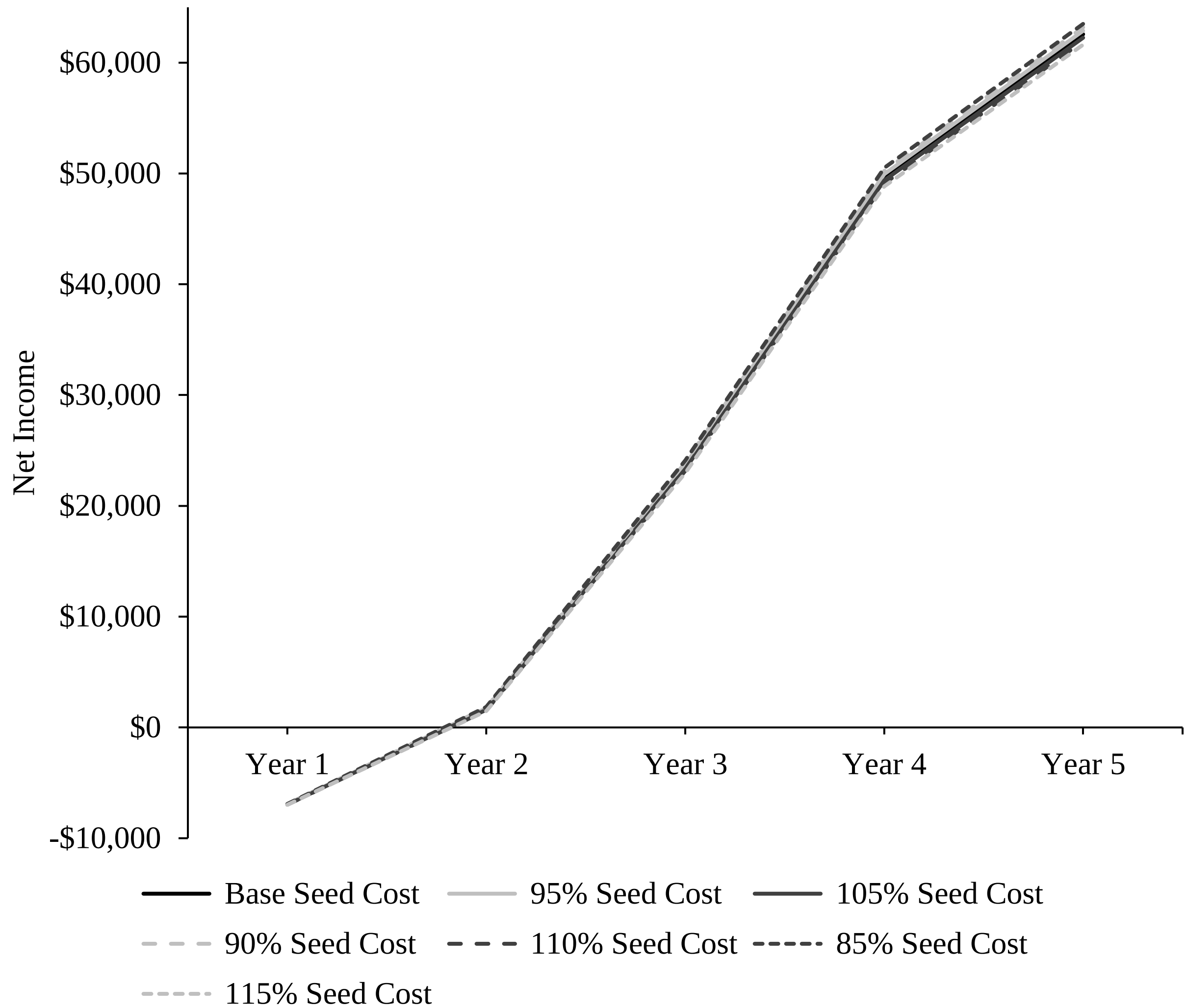


Figure 4-19. Sensitivity Analysis on Oyster Seed Cost for Escambia/Wakulla Counties

CHAPTER 5
CONCLUSION

Each county considered in the analysis has varying probability levels of each environmental event occurring, and the county possessing the highest risk for a given environmental risk event varies; no individual county experiences higher risk across all risk events. Levy County has the highest probability of a major storm occurring. Franklin County has the highest probability of a sustained high salinity event. Escambia County has the highest probability of a sustained low salinity event. Wakulla County has the highest probability of multiple storms occurring in a given year. However, all counties have a positive expected net income after the initial year of production and a positive expected NPV for all scenarios. All counties have a 97.4% probability or higher of being profitable by the end of Year 5.

A grower considering entry into the industry would most likely experience positive net income after establishment. Relative to other shellfish aquaculture net returns and other economic opportunities in these regions, the predicted net incomes by Year 5 are higher suggesting that the off-bottom oyster culture industry will likely experience growth in coming years. However, a hard clam operation can potentially earn a higher net income than predicted net incomes by Year 5. Therefore, growers in Levy and Franklin Counties may choose to initially grow hard clams prior to investing in off-bottom oyster aquaculture.

Due to increased plantings each year, there is an upward trend in expected net income for Years 1 through 5 as the expected quantity of oysters sold into the market increases. However, as plantings increase, the risk associated with net income increases. Based on results from the simulation, Levy County would be most preferred from a risk perspective, due to the higher expected net income and lower variance compared to all other counties. The analysis assumes that Levy County oyster growers share expenses with a clam culture operation reducing total costs associated with the oyster operation, and this diversification largely causes the higher expected net income. The lower variance results from smaller effects of environmental risk relative to all other counties. Escambia County has the lowest expected net income and greatest variance among counties due to the high probability of a sustained low salinity event, which has the greatest effect on mortality of the environmental risks considered.

A common risk experienced by all counties is the occurrence of a major storm event. Major storms cause an increase in labor time and capital costs. Based on interviews, growers prepare for major storms by sinking floating gear, moving gear to a location that is less likely to incur the full effects from the storm, and reinforcing gear. The preparation of a major storm results in an increase in labor time. The first major storm oyster growers experienced along the west coast of Florida, Hurricane Hermine, had the greatest increase in operational cost compared to the latter two storms. Hurricane Hermine caused growers to replace gear that was no longer usable and lose oysters in the process. However, growers adjusted production methods and gear setup to combat future hurricanes and tropical storms. The two major storms that followed Hermine caused smaller increases in operational costs relative to Hurricane Hermine as growers increased preparation. Although major storms affected each county, the storms affected net income less than sustained low or high salinity events.

Unlike other types agricultural and aquaculture production methods, shellfish aquaculture is environmentally sustainable and beneficial. Shellfish aquaculture organisms, including oysters, sequester nitrogen, feed on algae species that can potentially lead to blooms, protect the coasts from erosion, and contribute to many other ecosystem services and positive environmental externalities (Shumway et al., 2003). In addition to these positive environmental effects, oyster culture along the west coast of Florida reduces the pressure placed on over-harvested wild oyster stocks in the region and increases the ecological biodiversity. Although oyster culture produces a few negative externalities, such as visible PVC poles sticking out of the water and reductions in waterways for recreational fishers, the positive externalities generated by the plantings of the Eastern oyster potentially outweigh these negative externalities. Therefore, in addition to the net income generated by each farm, the positive environmental impact creates greater economic benefits for the region.

CHAPTER 6
LIMITATIONS AND FUTURE RESEARCH

The Florida Senate allowed the use of the water column for off-bottom shellfish aquaculture along the west coast of Florida in 2013. In the 3 to 4 years since, many gear modifications and changes in production practices have occurred. Since the beginning of this thesis study, modifications to float type and position, bag attachment gear, and growout bag setup caused constant adjustments and updates to the model. Growers are constantly making improvements to gear type to reduce total operational costs and increase growing efficiency. As a result, this assessment analyzed the current production methods but future studies will need to be updated as the industry develops.

Additionally, due to the low quantity of established oyster growers at the beginning stages of this study, only 10 growers were recruited to record labor times associated with a determined quantity of oysters and 3 growers were interviewed concerning environmental and market risk events. Since the start of the study, the number of active oyster leases and growers has increased. Although these growers are a representative sample, additional surveys should be conducted to update labor times and operational costs once the industry expands. With additional information from growers, researchers can collect better estimates of labor time and operational cost data to apply to the simulation model. Additional representative data will lead to more accurate predictions of a grower's future profitability and the off-bottom oyster culture industry trends. Also, further research should establish a growth model for a cultured triploid oyster and the effect of reduced or accelerated growth related to water quality parameters and food availability.

Since commercial triploid culture is relatively new, participating growers experienced three major storm events and one sustained low salinity event during the relatively brief time frame of this study. The analysis was only able to capture a fraction of financial effects from all possible environmental risk events. Unfortunately, the only way to obtain accurate estimates of future environmental events is for growers to experience such events and report damages. When environmental events occur, documented reports need to be recorded and applied to the simulation model to increase the accuracy of financial predictions. Also, the water temperature interacts with sustained high and low salinity events, which can alter impacts. If water temperatures are high, then sustained abnormal salinity events will have a greater impact on oysters due to increased metabolism and energy requirements. Therefore, to increase the accuracy of mortality estimates associated with high and low salinity events, future research should consider the probabilities of the simultaneous occurrence of both metrics interactively. This is particularly important given predictions of rising ocean temperatures.

Throughout this assessment, the Virginia Institute of Marine Science's market data is utilized as a proxy for Florida Gulf Coast cultured oyster prices. Although the mean for 2016 and 2017 Florida cultured market prices were similar, Virginia has an established market and historically received a higher price for oysters compared to wild-harvested Gulf oysters. Each county in the study was assigned equal market prices based on VIMS historical data. However, realistically, each county in the study could obtain different market prices due to the existence of established cooperatives, subsidies, and other market factors, each of which can impact price. As each county records future annual average market prices, researchers will have historical data to create an individual market trend for each county. Therefore, records need to be established to log annual market prices based on county.

Despite the limitations discussed above, this is the most accurate baseline study of the financial effects from environmental and market risk events for off-bottom triploid oysters along the west coast of Florida. Additional risk events that researchers could consider include red tide, varying water temperatures, and food availability. Other scenarios that could be considered include varying stocking densities and using alternative gear types.

APPENDIX A
LOGBOOK PAGES

Planting

Date	Number of Bags Planted		Bag Mesh Size	Est. Time
	3N	2N		

Fouling Control

Date	Method	Number of Bags Planted		Est. Time
		3N	2N	

Transfer to Additional and/or Larger Bag Sizes

Date	# of Bags Pulled				# of Bags Returned				Est. Time
	3N	Mesh Size	2N	Mesh Size	3N	Mesh Size	2N	Mesh Size	

Culling/Sorting

Date	Number of Bags Pulled		Number of Bags Returned		Est. Time
	3N	2N	3N	2N	

Harvesting

Date	Number of Bags Pulled		Number of Bags Returned		Est. Time
	3N	2N	3N	2N	

Miscellaneous

Date	Description of Activity				Est. Time

APPENDIX B
INDIVIDUAL GROWER QUESTIONNAIRE

Farm Background:

1. **Do you use on-bottom or off-bottom gear?**
    a. For example, floating cages, floating bags, on-bottom cages, on-bottom bags, etc.
2. **What oyster seed size do you prefer for initial stocking (planting)?**
3. **Based on your answer above, what bag mesh sizes do you typically use to growout your oysters?**
    a. 9mm, 12mm, 14mm
4. **How do you determine the quantity of oysters placed in the different bag sizes?**
    a. For example, individual counting, volume (5-gallon bucket), bag height (one-third full), etc.
5. **Based on the answers above, how many oysters do you typically stock per growout bag size?**
6. **At any given time, how many oysters are on your lease?**
7. **Approximately how many number bags is that?**
8. **Based your oyster grower experience, what is the average mortality per growing unit per year?**
    a. For example, 10%, 20%, 30% of stocking density dies within one year
9. **Are there any years that you have experienced exceptionally high or low mortalities?**
10. **If so, what did you experience?**

Oyster Unit Costs:

1. **What is your estimated average cost per growing unit?**
    a. including all equipment, i.e. zip ties, ropes, pucks, etc.
2. **Are there any additional costs incurred in deploying your growing unit?**
    a. i.e. long line rope, anchor, etc.
3. **What is the average wage rate paid to labor?**

Market Information:

1. **What is your target market size per oyster?**
    i. For example, 2.5 inches, 3 inches, etc.
2. **From planting, how long does it take for all of your oysters to be sold?**

3. **From being placed in the final grow out bag, how long does it take for a majority of oysters to be sold and what is that estimated percentage?**
    i. For example, from being placed in the final grow out bag it takes 6 months for approximately 80% of oysters to be market size?
4. **From your experience, what is the average market price for your half-shell oysters?**
5. **What percentage are sold for a higher price because of better shell-appearance and size? And what is the higher price?**
    i. For example, 20% are sold for a higher price with an average price of 1 dollar per oyster
6. **What percentage of oysters per bag are sold into the premium half-shell market and the conventional half-shell market?**

Environmental Mortality Information:

1. **What has the greatest effect on your crop and farm regarding a storm?**
    a. Storm Surge
    b. Windspeed and Wind direction
    c. Rainfall
    d. Other:
2. **What wind direction from a storm and/or weather event has the…**
    a. greatest effect on your farm?
    b. least effect on your farm?
3. **What percentage of your oyster crop do you estimate was lost due to…**
    a. Strong Storms from Cold Fronts
    b. Hurricane Hermine
    c. Hurricane Colin
    d. Hurricane Irma
    e. Hurricane Harvey
4. **What category hurricane do you estimate would cause complete loss of your crop?**
5. **What percentage of your oysters do you estimate would be lost from a drought resulting in an extended period of salinities greater than 30 ppt?**
    a. regarding the increased mortality from predators, diseases, and increased biofouling sets
6. **What percentage of your oysters do you estimated would be lost from a period of excessive rainfall resulting in extended periods of salinities less than 10 ppt?**

Environmental Costs Information?

1. **What is the estimated additional labor and capital due to…**
    i. For example, an additional 3 hours to repair 40 bags (including replacing rope, repairing bags, etc.)
    b. Strong Storms from Cold Fronts

c. Hurricane Hermine
d. Hurricane Colin
e. Hurricane Irma
f. Hurricane Harvey

2. **What is the estimated additional labor and capital related to drought resulting in excessive salinities of greater than 30 ppt?**
    - **i.** For example, an additional 4 hours from increased sorting and de-biofouling techniques

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BIOGRAPHICAL SKETCH

Russel Dame earned his Associate of Arts Degree at Palm Beach State College in 2014 prior to transferring to University of Florida's Food and Resource Economics Department. Russel graduated with his Bachelor of Science and Master of Science degrees from the Food and Resource Department in 2016 and 2018, respectively. He will attend Oregon State University in the fall of 2018 to continue his education in hopes to obtain a Ph.D. in the Applied Economics Department with a concentration in natural resources and environmental economics.