THE VALUE OF FRESH WATER AS AN ECONOMIC INPUT: EVIDENCE FROM FLORIDA OYSTER FISHERIES

by

Caleb Eliot Dahl

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Applied Economics

MONTANA STATE UNIVERSITY
Bozeman, Montana

May 2019

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Richard Ready, for his guidance throughout the thesis process. I am appreciative of Dr. Randal Rucker and Dr. Brock Smith for being on my committee and providing insightful comments. I would also like to thank my parents for their constant support and encouragement. Last but not least, shoutout to the BBs.

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ABBREVIATIONS AND ACRONYMS

ACF Basin: Apalachicola-Chattahoochee-Flint River Basin

cfs: Cubic Feet per Second

cms: Cubic Meters per Second

Corps: United States Army Corps of Engineers

CPUE: Catch per Unit Effort

FWC: Florida Fish and Wildlife Conservation Commission

HpH: Harvest per Hour

HpL: Harvest per License

HpT: Harvest per Trip

Q1: Quarter One

Q2: Quarter Two

Q3: Quarter Three

Q4: Quarter Four

USGS: United States Geological Survey

ABSTRACT

Natural resources contribute to a number of processes that humans depend on for economic benefits. A notable example is fisheries. Fishery productivity is largely dictated by environmental factors. When an ecosystem is altered, the effect on its fisheries can be catastrophic. As development intensifies throughout the world, an increasing number of fisheries are affected by environmental change driven by human behavior. A relevant example is Florida's oyster industry in the Gulf of Mexico, including the famous Apalachicola Bay fishery. As development and population have increased in the surrounding region, the river system that drains into the Florida Gulf has seen diminished water supply. Oysters rely on a particular mix of fresh and saltwater, so changes in the fresh water level affects the ecosystem and the fishing industry. In this thesis, I analyze the effect and value of freshwater input in the oyster fisheries of the Florida Gulf. I find that the effect of freshwater inflow on oyster productivity varies by season, with quarter three flow being of primary importance. Depending on the county and valuation method, I find a standard deviation change in freshwater inflow to be worth between $318,650.98 and $834,004.81 over two years in the context of oyster fisheries. While this specific situation is of particular interest, this work also contributes to the broader literature regarding the role and value of natural resources as economic inputs.

CHAPTER ONE

INTRODUCTION

The goal of this thesis is to evaluate the effect of freshwater inflow on oyster fisheries on Florida’s Gulf Coast and to estimate the value of fresh water as an economic input. Fisheries are defined by the health of the ecosystem of which they are a part of. Because fisheries support human use, their value is of economic interest. Oysters grow in brackish water, which means freshwater input is necessary for oyster production. As a result, fresh water can be considered an input in the fishery production function. An ongoing water dispute in the Southeast United States has limited fresh water availability which has resulted in diminished freshwater inflow to the bays throughout the Gulf of Mexico. At the same time, oyster harvest has dropped precipitously, particularly in the past decade. This drop-off is highlighted by the collapse of the fishery in Apalachicola Bay, the state’s most productive oyster harvest area. Using Florida Fish and Wildlife Conservation Commission (FWC) harvest data over a 30 year period, I estimate the economic value of fresh water in Florida oyster fisheries, providing insight to the consequences of the water dispute and environmental instability in general.

Estuaries are brackish wetlands formed at the intersection of river and open sea. Estuaries provide substantial environmental and economic value. Environmentally, estuaries act as “enormous filters,” removing pollutants and debris from water (NOAA 2017a). Economically, nearly 70 percent of commercial fish harvest in the United States comes from estuaries, worth $4.3 billion annually (NOAA, 2017b; NOAA, 2018).

Despite their high productivity, estuaries are extremely fragile. Minor changes in the environment or human behavior can profoundly alter the ecosystem and dramatically reduce its productivity (NOAA, 2018). One such alteration is fluctuation in the flow of rivers that feed estuaries. Estuaries rely on rivers to regulate water salinity levels. When river flow diminishes, estuarine salinity rises, affecting estuarine wildlife.

Of particular interest in this thesis is Apalachicola Bay, a large estuary located where the Apalachicola River enters the Gulf of Mexico in the Florida Panhandle. In a state with ever-developing coastlines, Apalachicola Bay is notable both for its lack of human influence and its remarkable productivity, even by the standard of estuaries. Estuaries are essential to wildlife in the region as "more than 95 percent of all species harvested commercially [in the Gulf of Mexico]…spend a portion of their life in estuarine waters" (FDEP, 2019). Perhaps no species is as important to the region economically, environmentally, and culturally as the eastern oyster (*Crassotrea virginica*). Apalachicola Bay's unique tasting bivalves are nationally famous and accounted for 10 percent of harvest in the United States as recently as 2012 (Pillion, 2014). The Apalachicola Bay fishery is a multi-million dollar industry and supports employment for thousands of local residents. Environmentally, oysters enhance their ecosystem by filtering up to 50 gallons of water per oyster per day (CBF, 2019). Like other species in estuaries, oysters are highly susceptible to environmental changes, including variation in salinity. Over the past few decades, this vulnerability has become apparent as a regional battle for water resources has resulted in diminished inflow to the Gulf and uncertainty for the once-thriving fishery.

The diplomatic and legal conflict between Alabama, Florida, and Georgia – dubbed the “Tri-State Water War” – centers around their shared water resource, the Apalachicola-Chattahoochee-Flint (ACF) River Basin. The system was once considered “drought-proof,” but water has become scarce as the region’s population and economic activity have grown (Feldman, 2009). As a result, each state is battling to maintain its access to the watershed, which each relies on for a variety of uses.

The majority of existing work regarding the value of natural resources focuses on the demand side, such as willingness to pay and hedonic pricing methods. The value of natural resources on the supply side is less researched, but has received more focus in recent years. Multiple works estimate the value of habitat, such as mangrove and wetland area, to fisheries (Lynne, Conroy, & Prochaska, 1981; Barbier, 1994; Bell, 1997). The work of Barbier and various co-authors is of particular importance because of their use of a dynamic fishery production model (Barbier & Strand, 1998; Barbier, Strand, & Sathirathai, 2002; Barbier, 2007; Kennedy & Barbier, 2016). A similar dynamic model is used in this work.

The majority of Florida oysters are produced in Apalachicola Bay in Franklin County, but harvest occurs statewide. Some harvest occurs in the Atlantic Ocean on Florida’s east coast, but this analysis will focus on Gulf fisheries because the Gulf and Atlantic are inherently different ecosystems. The ACF water dispute motivated this work, but the ACF is not the only source of fresh water in the Gulf. This analysis is not limited to counties that receive fresh water from the ACF system. Instead, multiple counties are analyzed to determine the effect of freshwater inflow on oyster productivity and determine if that effect is consistent throughout the state's oyster fisheries.

Data have been obtained from FWC detailing quarterly oyster harvest and fishing effort levels by landing county from 1986-2018. Oyster harvest occurs statewide, but landings are inconsistent over time in many regions. That is, some counties report harvest in some years, but not others. It is unclear if this inconsistency is due to poor reporting or lack of harvest. Therefore, in this work only counties that report harvest consistently over the data period are considered, due to the likely structural differences between fisheries in consistently reported counties and inconsistently reported counties. Spatially, only counties on Florida's West Coast are considered. The counties included in the final dataset are Bay, Franklin, Levy, and Wakulla County.

Two econometric specifications are used in this thesis. The first includes catch per unit effort (CPUE) as a proxy for fishery stock to evaluate the relationship between freshwater inflows and oyster productivity. The second model utilizes an adapted form of the dynamic model used by Barbier and Strand (1998) to estimate the value of fresh water in its capacity as an input in oyster production. Differences between the two specifications are discussed at further length in Chapter Six. From these specifications, I find that quarter three flow has a significant, positive effect on stock and harvest in the following year. I estimate a standard deviation of average quarter three flow to be worth as much as $318,650.98, depending on the county.

The motivation for this thesis is threefold. First, this work provides a relatively novel addition to the literature on the valuation of natural resources. Multiple works have considered the economic value of general fishery habitat in fish production, but only Kennedy and Barbier (2016) have specifically examined the value of freshwater inflow. In this capacity this thesis contributes to the general natural resource economics literature. Second, this work is highly relevant given the ongoing legal dispute regarding ACF water allocation. The 2018 Supreme Court ruling in *Florida v. Georgia* ensured the conflict will continue for at least the near future barring an unexpected compromise. An ongoing struggle for Florida in the legal proceedings is its ability to show “clear and convincing evidence that ‘the benefits of apportionment substantially outweigh the harm that could result’” (Oyez, n.d.). In this vein, this thesis serves to quantify the monetary consequences of reduced fresh water availability for Florida oyster fisheries. Finally, in 2013, the Apalachicola Bay fishery was declared collapsed after a precipitous fall in harvest over the preceding years. (FWC, 2013). The exact cause of the collapse is unclear, but it is possible that variation in freshwater input was a contributing factor. Given the magnitude of the fishery, the situation is of interest from an economic perspective.

This thesis proceeds as follows. Chapter Two presents background on Florida oyster fisheries and the Tri-State Water War. In Chapter Three, economic and biological literature on fisheries, resource value, and estuarine productivity is reviewed. Economic theory of the fishery in general and the role of habitat in particular is introduced in Chapter Four. The data and dataset construction are presented in Chapter Five. The methodology and econometric models are described in Chapter Six. Chapter Seven presents the empirical results from estimating the role and value of fresh water as an input to oyster fisheries. Chapter Eight closes this thesis and includes a summary of results and implications.

CHAPTER TWO

BACKGROUND

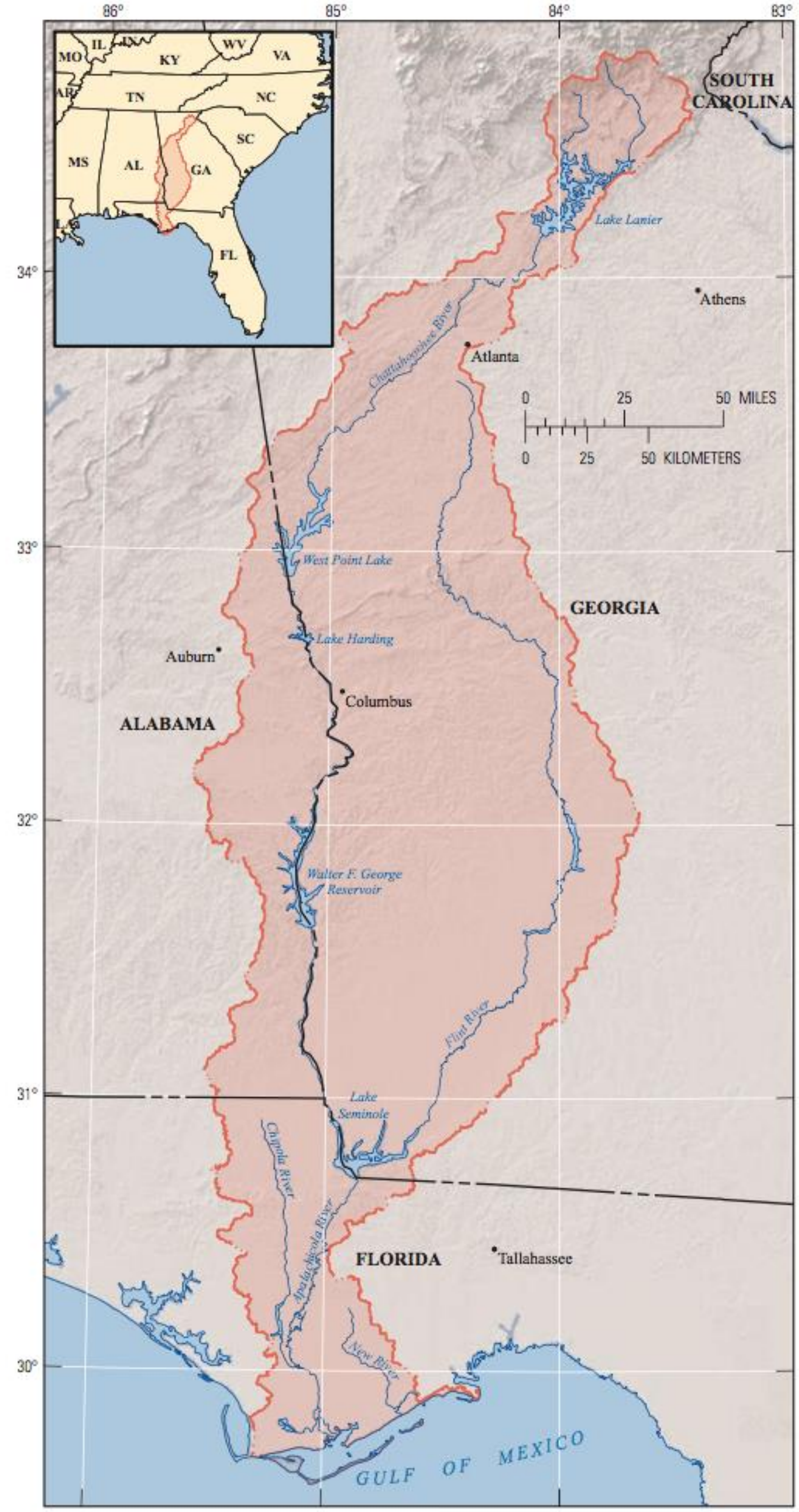
ACF Basin

Florida's Gulf Coast is an anomaly in a state known for tourism and waterfront high-rises. Development is largely concentrated to the south, and north of Tampa the coast is largely rural wetland, spotted by estuaries and bays (FWS, 2017). The region is noted for its thriving inshore fisheries, including oyster. The most productive and well-known oyster fishery in Florida, and perhaps the Southeast, is Apalachicola Bay.

Apalachicola Bay is formed at the output of the Apalachicola River, the largest river in Florida by discharge (NWFWMD, 2017). The Apalachicola River is formed by the confluence of the Chattahoochee and Flint Rivers at the Florida-Georgia border and anchors the immense Apalachicola-Chattahoochee-Flint River Basin (Figure 1). Water use in the basin is controlled by the U.S. Army Corps of Engineers. The population served by the ACF was nearly 4 million in 2010, much of which is concentrated in and around Atlanta (Lawrence, 2016). Both the Chattahoochee and Flint River originate in North Georgia and run roughly parallel for hundreds of miles before converging. The two rivers are dissimilar in multiple ways and highlight the complicated nature of water allocation in the region.

First, the Chattahoochee and Flint differ in their paths to the Gulf. The Chattahoochee is heavily impeded by 13 dams used to regulate flow, generate power, and

Figure 1: Apalachicola-Chattahoochee-Flint River Basin (USGS, n.d.)



reserve water in case of drought. One of these reservoirs, Lake Seminole, is located just below the Florida border and serves as the beginning of the Apalachicola River (Lawrence, 2016). Water released at the dam that creates Lake Seminole, Jim Woodruff Lock and Dam, is therefore the main determinant of flow level in the Apalachicola River. Conversely, the Flint River flows almost unimpeded until meeting the Chattahoochee. This is possible due to its path through primarily rural regions, originating south of Atlanta and largely avoiding municipalities en route to the Gulf.

Water withdrawals are naturally defined by each river's location. The Chattahoochee runs through Atlanta before turning westward toward Alabama, forming roughly half of the Alabama-Georgia border. Due to the high population concentration, about half of the water withdrawn from the Chattahoochee in 2010 was by "public water suppliers" (Lawrence, 2016). This amounted to 483 million gallons per day (Mgal/d), the majority of which was used in the Upper Chattahoochee River region, which includes Atlanta (Lawrence, 2016). An equivalent amount was withdrawn by "self-supplied users" and used largely for power generation and industry (Lawrence, 2016). In contrast, most of the water withdrawn from the Flint River is for agriculture. South Georgia is home to a strong agricultural industry, growing a variety of crops such as pecans, cotton, and tobacco (USDA, 2019). Roughly 500 Mgal/d was withdrawn from the Flint for agricultural use in 2010 (Lawrence, 2016). The nature of this use – irrigation – highlights a major theme in ACF water allocation. Demand for water from the basin is highly correlated with precipitation in the region. When water supply is low, water demand from the basin is high. This means that drought years are particularly difficult for the entities that rely on the basin for water supply.

It is important to note that water withdrawn from the ACF system is not necessarily permanently removed from the rivers. In 2010, roughly a third of the 1,645 Mgal/d used was returned to the river system (Lawrence, 2016). This is possible because of water treatment and non-consumptive uses like energy production.

Although the dispute over the ACF Basin motivated this work, not all freshwater inflow to the Gulf is from the ACF. A number of smaller river systems discharge throughout the Gulf Coast. This is useful for analysis because it allows the effect of fresh water to be analyzed in multiple oyster fisheries. Four counties are included in this analysis – Bay, Franklin, Levy, and Wakulla County – all in Florida. Of these, Franklin and Wakulla County receive fresh water from the ACF, while Bay and Levy County do not. I include counties outside the ACF system to identify the effect of ACF flow against non-ACF flow.

Legal Climate

In 1990, the ACF River Basin's population was 2.6 million. In 2010, the population had grown to almost 4 million (Lawrence, 2016). Increased population has strained the basin's water supply and sparked battles among Alabama, Florida, and Georgia as each attempts to maintain access to the water supply on which it depends. Legally, each state is entitled to as much water as it needs. In practice, the sum of "needs" exceeds the ACF's supply. Alabama, Florida, and Georgia – like most other states in the eastern U.S. – adhere to riparian water rights.[1] Yet “the ACF itself has for all practical purposes no defined Law of the River” (Ruhl, 2003).[2]

The three states utilize the rivers in a variety of ways. Alabama uses the basin for hydropower and municipal use, accounting for nine percent of total withdrawals (Couch, Hopkins, and Hardy, 1996). Florida withdraws an equal percent for a variety of uses, but predominantly relies on the basin for its freshwater inflows to support the productivity of Apalachicola Bay. Georgia accounts for a massive 82 percent of withdrawals, using the water for municipal supply, hydropower, and agricultural irrigation (Couch et al., 1996; Ruhl, 2005). A portion of withdrawals are treated and returned to the river system, but in general the more water withdrawn upstream, the lower flows are downstream.

Despite the fact that no formal agreement regarding allocation of the ACF exists, there is precedent regarding interstate water use in past Supreme Court rulings. The basin primarily lies in Georgia, home to 90 percent of the basin’s population (Couch et al., 1996). Per *Idaho ex rel. Evans v. Oregon,* however, this does not give Georgia any more right to the resource than Alabama or Florida. The Court asserts that “a State may not preserve solely for its own inhabitants natural resources located within its borders” (Ruhl, 2005). Further, “no state has inherent priority, absolute or presumptive, over another state in the use of water from an interstate stream” (Ruhl, 2005). States also “have the affirmative duty to take reasonable steps to conserve prospective water use…as a

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[1] Under riparian water rights, “water belongs to the person whose land borders a body of water” (Ryan, 2009).

[2] “Law of the River” refers to water rights for the Colorado River, consisting of “numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines” (USBR, 2008).

condition of making a successful claim to a fair share of an interstate water" (Ruhl, 2005).

The states are not the only parties involved in the ongoing legal dispute. The U.S. Army Corps of Engineers, tasked with regulating water supply via dams throughout the basin, has found itself at the center of the battle. The Corps' mission in regard to water management is broad – not only is it responsible for controlling water supply, but also counts environmental protection among its numerous goals (Carter, 2018). At times, such as in the case of the ACF, maintaining water supply appears contradictory to environmental wellbeing because increasing the amount of water stored in reservoirs results in ecological strain elsewhere, and vice-versa. The Corps enjoys greater autonomy than other government agencies because it has a role in planning its projects, but it is still at the mercy of the United States Congress in regard to funding and project assignments (Carter, 2018). Municipalities wishing to increase their water withdrawals must seek permission from the Corps in the form of a permit (Carter, 2018). Requests by Georgia following drought years in the 1980's were the impetus for legal action in the Tri-State Water War (Ruhl, 2005). The Corps follows a set of guidelines for storing and releasing water at dams. The policy for releasing water to Apalachicola River is summarized in *Florida v. Georgia* (2018). In general, the Corps allows "most additional water that enters the Basin" to enter the Apalachicola River (*Florida v. Georgia*, 2018). However, "in certain circumstances the Corps will artificially increase or decrease the amount of water [released] to ensure that 5,000 cubic feet per second flows into the Apalachicola River" (*Florida v. Georgia*, 2018). This is the current standard, but over time the Corps has modified its manual to allow for lower releases when it deems necessary, such as during extreme drought. Regardless, these guidelines show that in general the amount of water released to the Gulf is similar to the amount that reaches the southernmost dam. Important to this analysis, there is no evidence that the Corps adjusts the amount of fresh water released based on measured oyster abundance or oyster harvest levels. Kennedy and Barbier (2016) support this in noting that "during periods of crisis, the ecological health of coastal areas (and [the] value of any associated economic activities) are given low priority."

Ruhl (2003) describes the methods by which interstate water disputes can be resolved. One option is for the states involved to negotiate an agreement, or "Compact," amongst themselves and submit it to the United States Congress for authorization. This method is the most flexible option, which has proven to be as much of a downside as a benefit. Alabama, Florida, and Georgia sought this route during the 1990's and early 2000's, but eventually negotiations stalled and legal action continued (ARC, 2019a). The other options require the involvement of the federal government, either through Congressional legislation or a Supreme Court ruling. Ruhl correctly predicted in 2003 that Congressional intervention is "unlikely," which left only the Supreme Court. Interstate property disputes are unique in that they fall under the Supreme Court's original jurisdiction.[3] This means that a state can directly ask the Supreme Court to hear its case. In 2013, Florida brought suit against Georgia over its water use, which became

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[3] Original jurisdiction refers to "a court's power to hear and decide a case before any appellate review" (LII, 2007). The Constitution asserts that only the Supreme Court can settle legal action between states (LII, 2007).

the 2018 Supreme Court case *Florida v. Georgia*.

Tri-State Water War

The history of the Tri-State Water War is now briefly summarized. Litigation did not begin until 1990, but it can be argued that turmoil was inevitable once Buford Dam was completed in 1956. Buford Dam impounds the Chattahoochee River to create Lake Lanier, which Atlanta uses for recreation and municipal water supply. This supply is inherently tenuous because "the Chattahoochee River is the smallest river basin providing the most water supply for any metropolitan area in the United States" (Hull, 2000). Additional dams were built downriver on the Chattahoochee in the ensuing years. In the 1970s, a study was commissioned to determine a long-term plan for Atlanta's water use (ARC, 2019a). This study indicates water supply was already an issue almost 50 years ago. The proposed action from the study was for an additional dam to be built below Buford Dam to "capture peaking hydropower releases from Buford Dam" (ARC, 2019a). This dam was planned, but ultimately not built. Instead, in 1989 the Corps decided to allocate more water to Atlanta and its suburbs (ARC, 2019a). This led Alabama to sue the Corps in 1990.

In 1992, the states and Corps came to an agreement known as a Memorandum of Understanding.[4] Alabama agreed to suspend its lawsuit provided the states and Corps worked to find an equitable water allocation arrangement (ARC, 2019a). In 1997, the states agreed to develop an "interstate compact," but then failed to agree on how the

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[4] "A document that records the details of an agreement between two companies or organizations, which has not yet been legally approved" (Cambridge University Press, 2019).

water was to be allocated. Of particular note, this compact allowed "water suppliers in Metro Atlanta [to] increase withdrawals to meet reasonable increases in demand, which all parties understood would occur" (ARC, 2019a). After minimal progress toward an allocation resolution, Alabama left the compact in 2007, continuing its prior legal action. Over the next five years, a number of legal decisions and reversals were made. Highlights include the dismissal of Florida's lawsuit that the Corps allocation decisions were not permitted by the Endangered Species Act and the ruling that the Corps "has the legal authority to grant Georgia's entire water supply request, which would allow withdrawals from Lake Lanier and the Chattahoochee River of 705 million gallons per day" (ARC, 2019a).

The next chapter of the dispute was the Supreme Court case *Florida v. Georgia*. In 2014, the Supreme Court approved Florida's request for a suit seeking equitable apportionment over Georgia's water use (ARC, 2019b). As is practice in an original jurisdiction case, the Supreme Court appointed a Special Master to hear the case and suggest a ruling (LII, 2007). After multiple years of preparation and hearings, the Special Master ruled that although Florida appeared to have been affected by Georgia's water use, "Florida [had] not proven by clear and convincing evidence that any injury could be remedied without the US Army Corps of Engineers as a party to the case" (ARC, 2019b). That is, Florida was not suing the correct entity because Georgia's water use was authorized by the Corps. The Supreme Court heard additional arguments before deciding whether to follow the Special Master's recommendation. Ultimately, the Court ruled 5-4 that "the Special Master applied too strict a standard when he determined that the Court would not be able to fashion an appropriate equitable decree" (*Florida v. Georgia*, 2018). This decision remanded the case back to the Special Master (although a new Special Master was appointed). The Special Master is now tasked with answering the question, "would the amount of extra water that reaches the Apalachicola River significantly redress the economic and ecological harm that Florida has suffered?" (*Florida v. Georgia*, 2018). Each state submitted additional materials in early 2019, so it is possible that there will soon be a ruling after almost 30 years of legal sparring with minimal results.

Florida v. Georgia is a fascinating case, but the legal environment surrounding the ACF Basin is outside the scope of this thesis beyond providing context for the ensuing economic analysis. Specifically, this thesis was inspired in part by an integral aspect of the legal battle: equitable apportionment. Equitable apportionment is a legal doctrine used to determine water and other natural resource disputes between states. The doctrine calls for a practical distribution of shared resources based on "the benefits, harms, and efficiencies of competing uses" (*Colorado v. New Mexico*, 1984). The importance of freshwater inflow to Apalachicola Bay has been considered biologically, but to my knowledge no academic works have empirically examined the situation from an economic perspective. Further, biological analyses have been limited to Apalachicola Bay without examining if a relationship between freshwater inflow and fishery productivity extends to other harvest areas.

The environmental and legal implications of the Tri-State Water War are clear, but how is the dispute over the ACF's allocation related to economics? As Ruhl (2003) notes, “increasingly today we understand that ecological injury in fact *is* economic injury.”[5] Beyond the intrinsic value of the environment, ecosystems provide humans with a multitude of economic benefits. These benefits includes food, fuel, building material, and much more (Daily et al., 1997). Indeed, without ecosystems to filter air and protect from natural disasters, humans could not survive (EPA, 2018). In recent years the importance of ecosystem services has become more widely recognized, leading to increased research on the value of ecosystems. This thesis uses the Tri-State Water War as a lens through which to contribute to the economic literature on ecosystem services and value. Both the relationship between fresh water and oyster productivity and the value of fresh water as an economic input to Florida oyster fisheries are analyzed.

Florida Oyster Production

Oyster harvest in Florida has changed remarkably little over the past hundred years. Harvesters are known as “oystermen” and are indeed generally male. Working from simple wooden boats equipped with outboard motors, harvesters use long tongs to scoop oysters from the bay’s floor. Tongs are typically around 12 feet long, with wooden handles and metal tines at the end that are used to grasp oysters (Becnel, 2008). The primary oyster harvest methods in Gulf States are tonging and dredging. Florida is unique in that tonging is the only harvest method allowed (MASGLP, 2014). Harvesters generally work in teams of two, with one tonging while the other culls the haul (FWC, 2013).[6] As oyster stock has diminished, the crew makeup has apparently changed as well.

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[5] Emphasis by Ruhl.

[6] In this context, culling refers to separating and returning undersized oysters to the water.

In the past, one “tonger” could “keep two cullers busy all day long” (Barnes, 2018). Oystermen do not sell their haul directly to consumers. Instead, oystermen sell to licensed wholesale dealers, who then sell to the public. Wholesale dealers are important because they are responsible for submitting “trip tickets,” which provide information about an oysterman’s harvest and create the FWC dataset used in this analysis. Dealers and trip tickets are discussed further in the data section of this thesis.

There are few requirements to become an oysterman in Florida. To legally harvest oysters, an individual must purchase a Saltwater Products Licenses (SPL) from FWC and complete Shellfish Harvester Training. There are three types of SPL’s: individual, vessel, and crew.[7] The licenses cost $50, $100, and $150, respectively, for Florida residents (FWC, 2019b). The Shellfish Harvester Training teaches “sanitary shellfish harvesting, handling, and transportation practices (FWC, 2019a). The course is required to obtain a free Shellfish Endorsement and must be completed annually (FWC, 2019a).[8] Both online and in-person training is offered, with multiple sessions available per year.[9]

Harvest costs beyond the legal requirements are similarly minimal. The basic equipment necessary to harvest oysters in Florida is tongs and a boat. Becnel (2008) describes the no-frills nature of an oysterman’s supplies: one particular oysterman “owns a $1,300 boat with a $6,000 motor. A pair of tongs costs $250 and lasts about four years. Instead of an anchor, most oystermen toss out an old crankshaft.” It should be noted that

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[7] An individual SPL authorizes the holder to fish commercially. A vessel SPL allows all passengers on a specific vessel to fish commercially. A crew SPL authorizes the holder and all passengers on *any* legal vessel to fish commercially, as long as the license holder is present (FWC, 2019c).

[8] To harvest in Apalachicola Bay, oystermen must possess an Apalachicola Bay Oyster Harvesting License (ABOHL). The requirements are the same as for the Shellfish Endorsement, but the ABOHL costs $100 (FDACS, 2019a).

[9] The course can be completed in a single day.

in coastal communities, a relatively high proportion of the population already owns a boat, the most expensive requirement for oyster harvesting. Beyond tongs and a boat, the primary remaining expense is fuel, typically gasoline. Oystermen generally do not travel on the water extensively, allowing the current to move the boat (Bragg, 2002). Therefore, gas expenses are expected to be relatively minor.

Although the costs associated with oyster harvest are low, so too is revenue from commercial oyster harvest. In the four counties analyzed in this work, the average dockside value per pound of in-shell oysters from 1988-2017 was $0.45 (2017 dollars).[10] Based on Ensley's (2015) anecdotal report of prices, the retail price of oysters is currently around $1.25, up from around $0.40 in previous years. Using the calculated average harvest per trip from the data, roughly 10 bags, a day of work yields an average of $270 in revenue. Assuming two crew members per boat and equally shared revenue, each crew member earns $135 per day before costs. This calculation likely overestimates the typical daily revenue because value per pound is highly skewed over time due to scarcity resulting from the fishery collapse, which inflates the average value over the data period. At any rate, it is clear from this estimate that "nobody gets rich tonging" (Becnel, 2008).

Harvesters are subject to regulations set by FWC limiting harvest amount and oyster size. A "bag" is defined as either "two five-gallon buckets, one ten-gallon bucket or 60 lbs. of oysters in the shell" (FWC, 2019d). In most counties, the bag limit is 20 bags per vessel per day. The bag limit is currently lower in Bay and Franklin County at 10 and two bags per day, respectively. In Franklin County, this is due to the oyster fishery

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[10] Prices have risen drastically in recent years likely due to the Apalachicola Bay fishery collapse. The median value per pound over the same period was $0.36.

collapse in Apalachicola Bay. The lower limit in Bay County appears to be due to an active habitat restoration project. FWC publishes fishery regulation changes over time and based on that information it appears the statewide bag limit has typically been 15 or 20 bags per day (FWC, 2019e). The notable exception is from 1999-2014 when the bag limit was removed in Apalachicola Bay. Interestingly, it does not appear that the bag limit is binding. From the data available, the average bags per trip is typically around half of the current bag limit. Oystermen must also obey the minimum size limit mandated by FWC, currently three inches. Bycatch is inevitable, but undersized oysters must be "immediately" returned to the area they were drawn from (FWC, 2019e). Often oysters are tightly attached to one another; in this case a small number of undersized oysters can be kept if "separation would destroy either oyster" (FWC, 2019e).

There is also seasonal regulation on oyster harvest. The typical harvest season extends from early fall to late spring. Since 1991, the statewide season has begun October 1 and concluded June 30 (FWC, 2019e). This start date applied to all counties initially except for Dixie and Levy County, where the season is September 1 to May 31. In 1994-1995, Wakulla County switched to the September 1 start date, and Franklin County followed suit in 2005-2006 (FWC, 2019e). Currently the "winter season" runs from September 1 to May 31 in Dixie, Franklin, Levy, and Wakulla County, and October 1 to June 30 in the remainder of the state (FWC, 2019e). There is also a summer season in Franklin County. The summer season covers the dates not included in the winter season.[11] Franklin County is the only county with a summer season throughout the data

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[11] That is, July 1-September 30 before the 2005 change, June 1-August 31 since.

period. Oysters reproduce in the summer, so the harvest amount and quality are generally lower during this season (FWC, 2013). This is discussed further in the data section of this thesis.

Another way FWC regulates commercial oyster harvest is by limiting the days of the week oystermen can harvest. In the 1990's, harvest was not allowed on Fridays, Saturdays, and Sundays (FWC, 2019e). It is unclear if this was the intent, but limiting harvest to weekdays makes it logistically difficult to harvest as a second job. That said, Becnel (2008) notes that "lots of people have second jobs," although the actual proportion of harvesters that do is unclear. Reiley (2018) indicates that harvesters may find work harvesting other species from the Gulf, such as shrimp. The limitation on weekend harvesting was adjusted multiple times throughout the 1990's due to "certain circumstances," effectively eliminated in 2006, and officially lifted in 2012 (FWC, 2019e). However, day restrictions have been reinstated since the collapse of the Apalachicola Bay fishery in 2013.

Given the low barriers to entry for oyster harvest in Florida, the fishery is considered open access in this work. Field (2008) defines an open access fishery as a fishery in which "anybody who [wants] to buy or build a boat and go fishing essentially [has] the 'right' to do so." License fees and harvest regulations prevent commercial oyster harvest in Florida from being open access in the purest form, but anyone who wishes to satisfy the legal requirements to obtain a commercial oyster license is allowed to do so.[12] Additionally, harvest areas are published online and are easily found by

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[12] This extends beyond just Florida residents. Residents of other states and nonresident aliens are allowed to obtain a Saltwater Products License, albeit at a higher price than Florida residents pay.

would-be-harvesters. There are no “secret spots” for knowledgeable harvesters to exploit. Further, it does not appear that a limit has ever been placed on the number of licenses issued. The implications of open access are discussed in detail later in this thesis and dictate some assumptions relied upon in the analysis section.

Recreational oyster harvest occurs as well. Many regulations are the same as for commercial oyster harvest. This includes season dates and the three-inch size minimum. That is, season dates of September 1 to May 31 in Dixie, Franklin, Levy, and Wakulla County, and October 1 to June 30 in the rest of the state (FWC, 2019f). There is no summer season for recreational oyster harvest. In Franklin County, recreational harvesters are currently limited to a five-gallon bucket of oysters daily, per vessel. In the rest of the state, recreational harvesters may keep two 60-pound sacks per vessel daily (FWC, 2019f). In the past, the limit in Franklin County was also two bags (FWC, 2019e). Recreational harvesters are limited to the same harvest regions as commercial oystermen, but “commercial and recreational harvest by any person during the same day is prohibited” (FWC, 2019d). Recreational oyster harvest data are not available, but recreational harvest does not appear to have a major effect on stock levels. The current bag limits show that the recreational harvest limit is just a tenth of the commercial harvest limit, and recreational harvest cannot be sold. Further, Becnel (2008) notes that “there is nothing glamorous about oystering.” Harvest areas are clearly delineated, and it requires little skill to scoop oysters once a reef is located. In this sense, oyster harvest appears to lack the excitement of other fishing pursuits, which likely further limits the appeal of recreational harvest. Based on the apparently limited impact of recreational harvest on oyster abundance and commercial harvest, recreational harvest is not considered in the analysis section of this thesis.

Florida’s oyster aquaculture industry is also not a focus of this work but will be summarized now for completeness. Oyster aquaculture in Florida was first introduced in the 1990’s, but the industry is still in its infancy. Growers have had little success due to a combination of ineffective methods and high costs (IFAS, 2017). As a result, in 2012 oysters accounted for less than two percent of Florida aquaculture mollusk sales, well behind clams (USDA, 2013). That could change, however, as wild catch diminishes. As wild oyster supply falls and prices rise, farmed oysters could become more competitive in the market (IFAS, 2017). Farmers typically allow seed to develop in a nursery onshore then move oysters to the water, growing the oysters in cages to protect from predation (FDACS, 2019b). In the past, aquaculture leases allowed cages on the water floor only. Productivity was low under these circumstances due largely to high predation. Recently, the state government lifted the rule limiting cages to the bottom, allowing for floating cages “providing the oysters some protection from predators and greater access to nutrients as they grow” (FLGov, n.d). When mature, farmed oysters are harvested and sold to licensed seafood dealers (FDACS, 2019c).

An aquaculture lease is required to farm oysters in Florida. Farmers submit an application and $200 fee to Florida Department of Agricultural and Consumer services (FDACS) who survey the proposed site before approving requests (FDACS, 2019c). Leaseholders pay annual fees depending on the type of lease. Bottom leases allow use of up to six inches above the water floor and cost “$16.73 per acre and fraction of an acre,” plus a $10 surcharge per acre (FDACS, 2019c). Water column leases grant the leaseholder access to the entire depth of the water and cost "$33.46 per acre and fraction of an acre," plus a $10 surcharge per acre (FDACS, 2019c). Leases are currently available in 10 counties. Farmers must also apply for an Aquaculture Certificate of Registration, which costs $100 annually, and adhere to the FDACS Aquaculture Best Management Practices (FDACS, 2019d). First time applicants must provide FDACS with a plan and timeline for lease development. Like commercial harvesters, farmers must complete the Shellfish Harvester Education Training annually to receive the Aquaculture Certificate of Registration (FDACS, 2019d).

Beyond administrative and financial barriers, a limitation to oyster aquaculture is public perception, particularly in Franklin County, home to Apalachicola Bay. The region has a rich history of wild oyster production, and the introduction of modern "farming" is hugely unpopular. This is because, as Reiley (2018) explains, "a slick farming industry…could render the Florida oysterman finally, permanently extinct." To this end, local government has limited aquaculture leases in Franklin County waters in the interest of protecting Apalachicola Bay's wild oyster fishery (Reiley, 2018). This has incentivized would-be oyster farmers to go elsewhere to establish leases. Based on a map of leases published by FDACS (2019c), oyster aquaculture leases are concentrated in Levy, Dixie, and Wakulla County, with a few in Southwest Florida. In this analysis, aquaculture is not expected have a major impact on commercial harvest because oyster aquaculture is relatively undeveloped in Florida. In the coming years, aquaculture could provide greater competition to Florida’s wild oyster fisheries, especially if wild harvest continues to dwindle.

Figures 2 and 3 show the relationship between statewide harvest and harvest effort over the data period. Of particular note in these figures is the massive drop in harvest in 2012, after which the Apalachicola Bay fishery was declared collapsed. The Deepwater Horizon oil spill happened in 2010, leaking oil throughout the Gulf. Oil did not reach the majority of Florida’s Gulf Coast, but there is anecdotal concern that fear of approaching oil lead to relaxed harvest regulations and overfishing, possibly contributing to the collapse by diminishing recruitment and oyster bar area (Downs, 2018). The validity of this is unclear and is not be considered in this thesis, but it is worth noting that the oil spill is a factor that may have affected oyster productivity. Figures 2 and 3 also show that harvest is closely related to harvest effort, but the collapse appears to be driven by diminished harvest, not diminished effort. Figure 4 shows a slight downward trend in Apalachicola River flow over time, though not nearly as drastic as the fall in harvest.

Biology

The eastern oyster is found throughout the U.S Atlantic Coast and Gulf of Mexico. The species is native to the East Coast and is also farmed there and in Washington State. Oysters were once plentiful in the waters of the United States, but overfishing and other human behavior such as pollution has resulted in modern harvest levels that are just a fraction of past yield (MDSG, n.d.; NOAA, n.d.).

Oysters grow quickly in Florida, reaching harvestable size (three inches) within

Figure 2: Total Florida Trips and Oyster Harvest (Pounds, in-Shell), 1987-2017

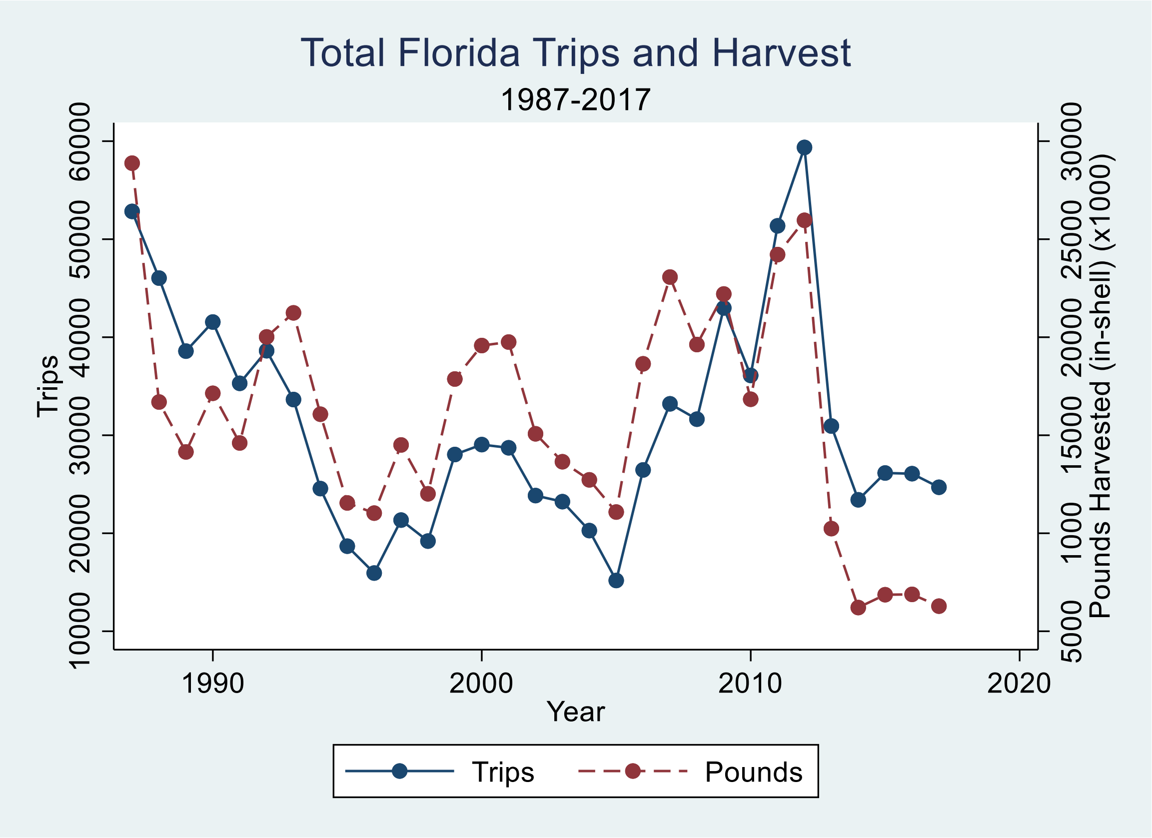


Figure 3: Total Florida Hours Fished and Oyster Harvest (Pounds, in-Shell), 1987-2017

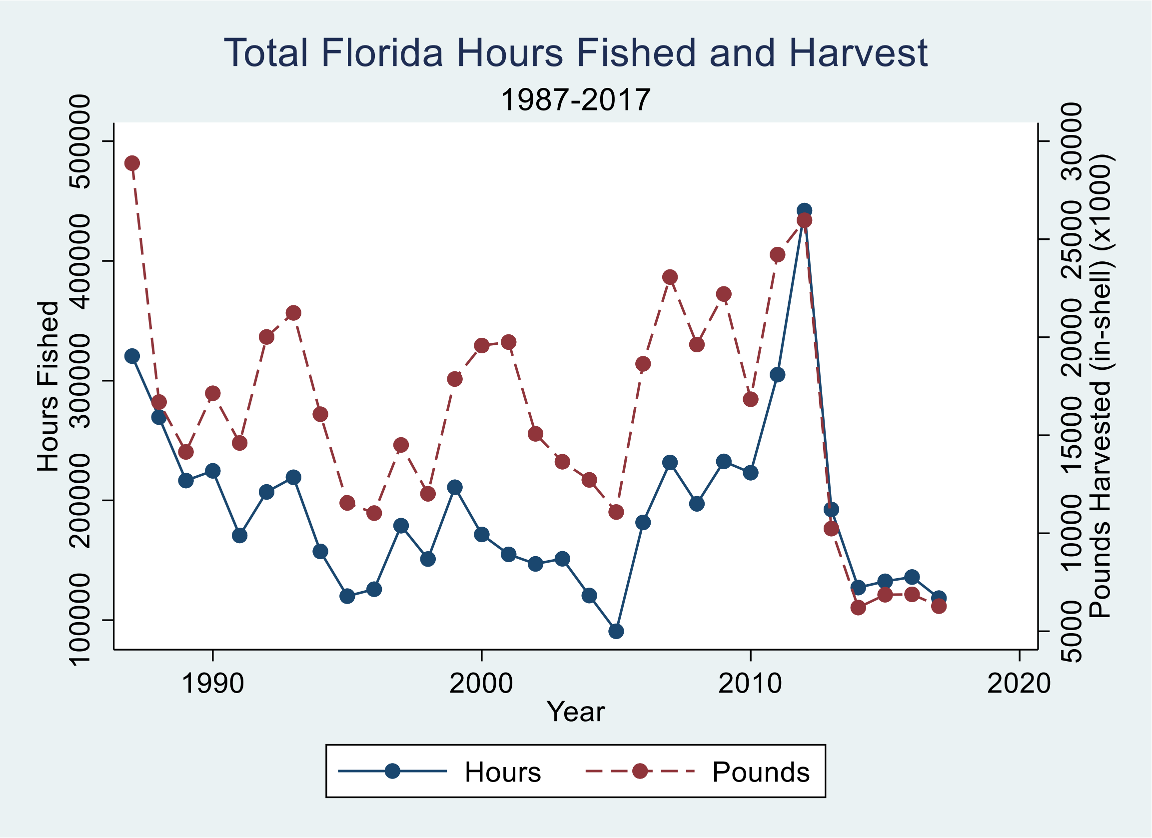
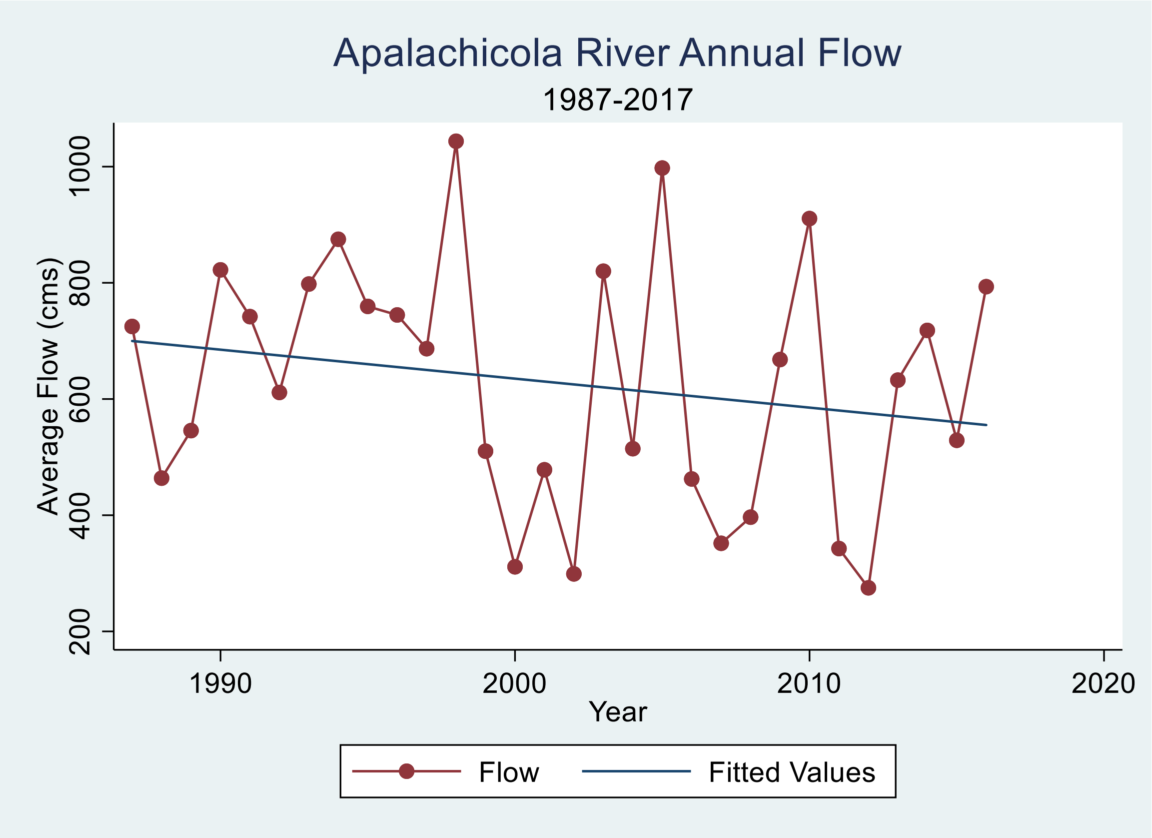


Figure 4: Average Annual Flow, Apalachicola River, 1987-2017



two years (FWRI, 2018). This rapid maturation can largely be attributed to high water temperature, which increases growth rate (NOAA, n.d.). In contrast, oysters in Maryland and Virginia can take as long as five years to reach the same harvest size (NOAA, n.d.). Reproduction is also dictated by temperature. Oysters spawn when water temperature reaches the mid-60s, generally beginning in the spring and lasting until early fall (NOAA, n.d.). Eggs hatch in the water within a day of fertilization, beginning the larval stage which typically does not last longer than a month (NOAA, n.d.). During this period, larvae “remain free-swimming while undergoing 2 more larval stages before settling and becoming adults” (USF Water Institute, 2019). These stages are the veliger and pediveliger larvae, respectively. As the name implies, during these stages the larvae grow a foot which is “used to attach to a hard substrate” (NOAA, n.d.). The shell begins to develop in these stages as well. Once settled, oysters are known as “spat” (USF Water Institute, 2019). The juvenile oysters then begin the process of maturation. All oysters are male initially but transition to females over time, sometimes alternating repeatedly between sexes (FWRI, 2018).

Once an oyster settles, it remains in that location for the entirety of its life. Oysters are filter feeders and eat a variety of microscopic organisms including algae and bacteria (Lorio and Malone, 1994). In the process, oysters filter water. Water filtration enhances the overall ecosystem and illustrates a benefit of oyster abundance beyond a productive commercial fishery. It is estimated that a single oyster can filter between two and 50 gallons of water a day (FWC, 2013; CBF, 2019). This in turn enhances the productivity of surrounding organisms and can reduce environmental degradation (FWC, 2013).

Salinity is measured in parts per thousand (ppt). Fresh water salinity is below 0.5 ppt while ocean water is roughly 35 ppt (NOAA, 2017c). The salinity of brackish water in estuaries lies between these values. Oysters can tolerate a wide range of salinity, between five and 40 ppt for mature oysters and 10 and 27.5 ppt for larvae (NOAA, n.d.). The "optimum range is 14-28 [ppt]" (NOAA, n.d.). Despite the broad range of tolerance, salinity affects oysters in several ways. First, oysters require salinity higher than 10 ppt to spawn (FWRI, 2018). There is also evidence that oyster growth increases with increases in salinity (Lorio & Malone, 1994). Clearly, high salinity is not inherently bad for oyster populations, ceteris paribus. The negative effects of high salinity are the predation and disease that flourish in high salinity environments.

Gulf oysters have numerous predators, including but not limited to conch, black drum, crabs, snails, and whelk. Of particular concern currently is the Florida rock snail (*Stramonita haemastoma*), also known as the southern oyster drill (FWC, 2013). As the name suggests, oyster drills "secrete an enzyme to soften an oyster's shell, then drill pin-sized holes through the shell" to feed on the meat of an oyster (CBP, 2019). Zachary and Haven (1973) find evidence that low salinity is fatal for oyster drills. It is unclear the exact range of salinity oyster drills can survive in, but there appears to be a positive relationship between salinity and oyster drill population (FWC, 2013). Oysters can survive outside of their ideal salinity range (to a point), but elevated salinity is an environmental stressor. This stress combined with higher predator populations serves to "exacerbate the level and intensity of predation by weakening oysters" (FWC, 2013).

Another mortality factor associated with high salinity is disease. Dermo (*Perikinsus marinus*) is a parasite that is particularly harmful to oyster populations. Havens et al. (2013) note that dermo is relatively common and only becomes a major issue when "severe." The severity of dermo largely depends on high temperature and salinity (FWC, 2013). Ewart and Ford (1994) argue that dermo severity is dictated more by salinity than temperature in the Gulf of Mexico. As a result, dermo is thought to be most devastating in the summer when flow magnitude is lowest and temperature highest (FWC, 2013). For this reason, it is expected that freshwater inflow in the summer will be most important to oyster stock levels. This is discussed further in the analysis section of this thesis.

Oyster harvest affects oysters beyond the obvious reduction in population. There are reports that oysters "can live up to 25-30 years and reach a maximum size of 11.8 inches" (FWRI, 2018). Commercial fishing results in very few oysters reaching the maximum size or age, however. It appears most oysters are harvested soon after reaching maturity, especially in high-harvest areas. Harvest and evolving tastes also affect oyster reefs, the hard bottom that oysters attach to. Discarded oyster shell is an ideal material for reefs, and in the past, the shells from processed oysters were largely returned to the water. As the popularity of eating oysters raw has increased, fewer shells have been recycled to regenerate reefs (Reiley, 2018). Reef degradation affects both oysters and the ecosystem as a whole because a variety of fish and other marine organisms live and feed at oyster reefs (FWC, 2013). To counteract the lack of shells for reefs, the State of Florida has paid residents to dump rock and other material into bays as a substitute. The long-term effectiveness of this strategy is unclear.

CHAPTER THREE

LITERATURE REVIEW

This literature review addresses both economic and, to a lesser extent, biological works. The economic section examines works on fishery economics and natural resource valuation. The biological section covers literature on estuarine productivity and the role of river flow in ecosystems. Both oyster productivity and ecosystem productivity in general are addressed.

Economic Literature

The foremost works on the economics of fisheries are by Gordon (1954) and Schaefer (1954; 1957). Their works and associated models remain widely-cited in the field of natural resource economics.

Gordon (1954) discusses the implications of fishery management on fishery production and population. Gordon considers demersal fish[13] in his analysis, but the work can be applied to oysters as well. An open access fishery is a common-property resource,[14] which means that an individual cannot secure the economic rent associated with future harvest because there is no individual ownership. If a particular harvest area is highly productive, a fisherman cannot claim it for himself. Instead, if harvesters are free to move between fishing areas, the economic rent from fishing disappears over time

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[13] Demersal fish are "bottom-dwelling" and include flounder and halibut (Gordon, 1954).

[14] Common-property resources are "owned and managed collectively by a community or society rather than by individuals" (OECD, 2001).

because harvesters fish in the area where average productivity is highest. Therefore, harvest occurs until average cost is equal to average revenue, at which point open access equilibrium is reached. Gordon identifies the lack of economic rent as the reason that fishermen do not become rich from commercial harvesting. Low earnings are exacerbated by the fact that commercial fishermen "[live] often in isolated communities, with little knowledge of conditions or opportunities elsewhere; educationally and often romantically tied to the seas; and [lack] the savings necessary to provide a 'stake'" (Gordon, 1954).[15] Gordon goes on to show that the fishing effort at open access equilibrium in a common-resource fishery will be higher than the social optimum effort level, resulting in equilibrium harvest that is higher than the social optimum harvest level. In this case, Gordon assumes the social optimum effort level is where the difference between total revenue and total cost is maximized.[16] The social optimum effort level results in economic rent, while the open access equilibrium effort level does not. The primary takeaway from Gordon's work is that in a common-property fishery without regulation, the equilibrium harvest level results in total revenue equal to total cost, yielding zero economic profit. The zero-profit condition is relevant in the analysis section of this thesis and is discussed further at that point. It should be noted that Gordon assumes fishery labor to be homogeneous. This assumption is reasonable in this context because tonging is the only harvest method allowed in Florida. Though experienced harvesters may be

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[15] This description is strikingly applicable to commercial oyster harvesters in Florida. See Becnel (2008) and Evans (2015) for popular press articles that provide background on oyster harvesters.

[16] This is traditionally the optimal production level for a monopoly but in this case is considered the socially optimal level as well, assuming price is exogenous. See Gordon (1954) for more detail.

slightly more efficient than newcomers, there is little technological advantage to be gained from a certain boat or tongs.

Schaefer (1954) presents a fishery population model that accounts for the effects of harvest. Schaefer begins by assuming fishery populations evolve according to a logistic function. Harvest acts to temper the population growth rate, resulting in a “rate of change in the stock [that is] less than the natural rate of increase by an amount equal to the rate of catching fish” (Schaefer, 1954). Therefore, ceteris paribus, the intensity of harvest dictates whether a fishery population increases, decreases, or stays constant over time. Equilibrium harvest is the level at which harvest entirely offsets fishery growth, resulting in constant fish stock. The “maximum equilibrium catch,” then, is the maximum harvest level that perfectly offsets population growth (Schaefer, 1954). This is also known as the maximum sustainable yield.

Schaefer (1957) builds upon Gordon’s (1954) work, but diverges in a few ways. First, Schaefer argues that Gordon is incorrect in his assumption that the relationship between population and harvest is linear. Schaefer instead suggests that equilibrium harvest is maximized “at some intermediate level of fishing effort” (Schaefer, 1957). This is because fish populations are “self-regulating” (Schaefer, 1957). Although Schaefer critiques Gordon’s definition of socially optimal harvest, he confirms that effort and harvest in an open access fishery will exceed that in a socially optimal equilibrium. Whether open access harvest surpasses or falls short of the maximum sustainable yield depends on the per unit cost of effort. When “unit price is sufficiently high relative to unit cost" of effort, the open access equilibrium harvest effort level will result in harvests above the maximum sustainable yield harvest level (Schaefer, 1957).

Together Gordon (1954) and Schaefer's (1954; 1957) works form the basis of the Gordon-Schaefer population model. The majority of the following works use a variation of this model to estimate the value of fishery habitat. The Gordon-Schaefer model and relevant adjustments and derivations is discussed at greater length in the theory section of this thesis.

A growing literature attempts to value natural resources as inputs to fishery production. Barbier (2000) refers to this method as the "production function approach." Some methods of analysis used in this thesis are drawn from this literature. For the most part, the natural resource in question – in this thesis, fresh water – is a function of the fishery habitat. In this case, fresh water is not the only determinant of oyster habitat availability, but is a primary determinant of oyster habitat *quality*. When habitat quality improves, oyster productivity is expected to increase, and vice-versa.

One of the earliest attempts to value natural resources as inputs to production is the work of Lynne, Conroy, and Prochaska (1981). The authors focus their analysis on Florida's blue crab fisheries in the Gulf of Mexico. Blue crabs live in estuaries and marshland throughout the Gulf Coast of Florida. This paper is one of the first economic works to "isolate the effects and contributions of the human actors as compared to the contribution of the [habitat]" (Lynne et al., 1981). The authors draw upon the Gordon-Schaefer population model to develop a regression to estimate the effect of marsh area and fishing effort on the harvest rate of blue crabs. Barbier (2000) describes the approach of Lynne et al. as “essentially halfway between the ‘static’ and ‘dynamic’ approaches” that are discussed later in this section. Lynne et al. use the regression results to estimate the marginal product generated by an additional unit of marsh habitat. At the mean effort level in the data period, the authors estimate that an additional acre of marsh yields 2.3 pounds of blue crab harvest annually worth around $0.30 (Lynne et al. do not specify what “year dollars” are used). Although total marsh area exceeded 500,000 acres in 1974, this estimate is lower than expected by the authors.

Ellis and Fisher (1986) continue the work of Lynne et al. (1981) and model the production of blue crabs with a Cobb-Douglas production function. The authors then solve the cost-minimization optimization problem to estimate changes in consumer and producer welfare. Using the same data as Lynne et al. (1981), Ellis and Fisher estimate the value of an increase in marsh acreage from 25,000 to 100,000 to be nearly $200,000 (again, dollar year unknown). Ellis and Fisher’s work is also notable in that it introduces preliminary methods for a dynamic valuation model because of “the intertemporal nature of growth and depletion of natural resource stocks.” As is discussed, the “dynamic model” has since become popular in the literature and is used in the analysis section of this thesis.

Freeman (1991) builds upon the work of Lynne et al. (1981) and Ellis and Fisher (1986). This work is important because it is apparently the first to consider the implications of fishery management on resource valuation estimates. Specifically, Freeman considers the zero-profit condition that results in an open access fishery. That is, total revenue is expected to equal total cost in the long-run. Freeman uses this condition to calculate a unit cost of effort (measured by traps per year) equal to $63 per trap using the same blue crab data as Lynne et al. (1981) and Ellis and Fisher (1986). Freeman then estimates the value of wetland acreage increasing from 25,000 to 100,000 to be $166,245, about $30,000 less than the estimate made by Ellis and Fisher (1986) for the same change in acreage under socially optimal regulation. Results for a variety of acreage changes are presented. When demand for the species in question (in this case, blue crab) is inelastic, Freeman finds that marsh area is more valuable under open access than socially optimal regulation. The results indicate the opposite is true when demand for crabs is elastic.

Bell (1997) emulates Ellis and Fisher (1986) in his use of a Cobb-Douglas production function but departs from the existing literature to examine recreational fisheries instead of commercial fisheries. The habitat Bell considers is wetlands on the East and West Coast of Florida and the type of fish is finfish. Bell estimates that a marginal acre of wetland is worth $6,471 on Florida’s East Coast and $981 on Florida’s West Coast (1984 dollars). Bell attributes the difference in value by coast to the fact that there are more acres of wetlands on Florida’s West Coast than on the East Coast. Bell estimates consumer surplus and willingness to pay for wetlands to derive the value approximation.

The work of Barbier and Strand (1998) appears to be the first use of the valuation referred to as the “dynamic approach” (Barbier, 2000). The need for a dynamic fishery production model was first identified by Ellis and Fisher (1986) due to the fact that fishery production is highly intertemporal. Barbier’s use of the dynamic model marks a departure from the “static approach” employed by Ellis and Fisher (1986), Freeman

(1991), and to an extent, Lynne et al. (1981). The dynamic model used by Barbier and Strand is used in this analysis, so the model and associated derivations are shown in the theory section of this thesis. For now, the context and results are presented.

Barbier and Strand (1998) examine the commercial shrimp fishery in Campeche, Mexico from 1980-1990. Following Freeman (1991), Barbier and Strand account for the fact that the shrimp fishery is open access. The habitat considered is mangrove area and the effort metric is total fishing boats. Barbier and Strand derive a regression from the Gordon-Schaefer model and use the price data to calculate the zero-profit per unit cost in each year of the data period. They then solve for the marginal product and value of an additional km^2 of mangrove area using the regression results, price and harvest data, and derived per unit cost. Barbier and Strand estimate that the average marginal harvest from an additional km^2 of mangrove area over the data period is over 24,000 pounds of shrimp worth an average of $139,352 in revenue annually. The authors note that the magnitude of mangrove destruction over the data period is small, so the results may underestimate the effect of mangrove loss on the shrimp fishery if deforestation continues at a greater rate.

Barbier, Strand, and Sathirathai (2002) further the literature by incorporating elasticity of demand into the dynamic model. The habitat of interest is mangrove area in Thailand and both demersal fish and shellfish are considered. Barbier et al. estimate a loss of 3,000 hectares of mangrove area to be worth between $12,000 and $408,000 annually at demand elasticities of -10 and -0.1, respectively. The vast majority of this value comes from shellfish harvest. The results show that valuation estimates are higher when demand is highly inelastic than when demand is highly elastic. This means that the method used by Barbier and Strand (1998), on which the method used in this thesis is based, can be thought of as a conservative estimate of habitat value because it assumes infinitely elastic demand. In reality, the demand for oysters and other seafood products is almost certainly not infinitely elastic.

Kennedy and Barbier (2016) appear to be the first to consider fresh water specifically as an input to fishery production. Kennedy and Barbier focus on blue crab fisheries in Georgia. This work is of particular interest because the variation in freshwater inflow to blue crab harvest areas is driven by the same factors contributing to the water dispute over the ACF Basin. These factors include increased population and demand for water in the watershed in question, specifically in Atlanta. Kennedy and Barbier note that "like most US states, Georgia does not consider coastal ecosystem resource needs when setting minimum flow rates" (Kennedy and Barbier, 2016). Like oysters, the productivity of blue crab fisheries is affected by salinity due its effect on both reproduction and adult health. Another way Kennedy and Barbier's work is relevant to this thesis is that they too consider multiple harvest areas, in this case three sounds and the associated rivers. Kennedy and Barbier's analysis differs slightly in that they have access to crab abundance and salinity data collected by the Georgia Department of Natural Resources (GDNR). Kennedy and Barbier utilize a seemingly unrelated regressions (SUR) empirical approach to analyze the effect of salinity on crab stock and recruitment. The effect of stock on harvest is then estimated, along with the relationship between harvest profit and fishing effort. The results indicate a negative relationship between salinity and both stock and juvenile recruitment. Kennedy and Barbier also estimate the value of freshwater inflow using a policy simulation that assumes river flow must be maintained at or above the 25th percentile of historic average flow. After showing that the relationship between river flow and salinity is negative, Kennedy and Barbier estimate the value of fresh water to be between \$0.63 and \$6.97 per acre-foot depending on the sound. The time horizon at which the acre-foot measurement is estimated is unclear, but assuming it is acre-feet per year the equivalent value in cubic meters per second is between \$16,000 and \$180,000 annually, depending on the sound.

Barbier and various co-authors have also analyzed the value of other ecosystem services such as storm protection, flood control, and groundwater recharge (Barbier, 1994; Barbier, 2007, Barbier et al. 2011). Although these works are not particularly relevant to the analysis in this thesis, they underscore the fact that there is economic value derived from natural resources and ecosystems beyond commercial fishing. The value of habitat as an input to fishery production is just one aspect of the importance of ecosystem health.

Biological Literature

Biological literature on the productivity of estuarine ecosystems and the role of fresh water will now be reviewed, albeit more briefly than the economic literature. The purpose of including biological works in this literature review is to illustrate the determinants of estuarine productivity and the times that organisms are specifically susceptible to variation in habitat, specifically salinity. Oysters are of most interest in this thesis, but given the linkages between estuarine organisms, estuarine productivity at a broad level will also be discussed.

The importance of salinity in oyster production has been understood for many years. Copeland (1966) identifies fresh water “flushing” to be an important regulator of dermo prevalence. Copeland also acknowledges that too much fresh water can also be problematic for oyster abundance. Loneragan and Bunn (1997) identify a positive relationship between freshwater inflow and multiple estuarine species in Australia. Loneragan and Bunn note that the mechanism associated with freshwater inflow that results in increased productivity may vary by species. That is, fresh water may support the population of one species by increasing reproduction, while benefiting another species through decreased disease prevalence.

A number of works focus on the Florida Gulf specifically. Wilber (1992) attempts to identify the effect of freshwater inflow from the Apalachicola River on oyster productivity in Apalachicola Bay. Although biological in focus, Wilber’s work provides interesting insight to the relationship between flow and productivity in the region that is of most interest in this thesis. Wilber finds that oyster productivity, measured by catch per unit effort, diminishes when flow was low two years prior. Low flow is defined as the lowest flow over a given number of days in a year, ranging from one to 120 consecutive days. Wilber also finds that oyster productivity is low in years with sustained high flows. This supports Copeland’s (1966) assertion that oysters are susceptible to both high and low salinity. Meeter, Livingston, and Woodsum (1979) also find a positive correlation between freshwater inflow and oyster harvest. The same relationship appears to hold for crab and shrimp harvest. Additionally, Meeter et al. find that construction of dams throughout the ACF Basin does not have an effect on flow cycles.

Livingston, Niu, Lewis, and Woodsum (1997) find that normal variation in flow does not have a major effect on productivity in Apalachicola Bay, but abnormal variation, such as droughts, causes an increase then drop off in herbivore abundance. This in turn results in a similar population pattern for carnivores. Chanton and Lewis (2002) provide additional insights into the effects of high and low flow. They find that flow alteration in either direction can be problematic, “especially during the low-flow period when the estuary is dependent on input of dissolved nutrients to maintain a high level of primary productivity” (Chanton and Lewis, 2002).

Multiple works have attempted to model oyster population dynamics in Apalachicola Bay, including Livingston et al. (2000) and Wang et al. (2008). Livingston et al. predict oyster mortality based on surveys and the proximity of oyster beds to freshwater inflow. They find that both oyster population density and salinity fluctuation influence oyster mortality. Wang et al. compare two reefs in Apalachicola Bay, one of which is closer to freshwater input than the other. They find that oyster growth is highest in the summer when salinity and temperature are high. This supports the idea that increased salinity can actually be beneficial to oyster growth while also increasing oyster mortality. This suggests a tradeoff between high and low flow in the summer. High flow may curtail disease and predation, but at the expense of individual oyster growth rates.

There also exists literature regarding river flow management. An aspect of the Tri-State Water War is the discussion over what flow level is required to maintain “normal” oyster productivity. One suggestion is a minimum flow requirement. Arthington et al. (2006) reject this broad policy approach and advocate for river-specific determinations of adequate flow level. Poff et al. (1997) suggests flow magnitude is not the only determinant of ecosystem health. Instead, they present “five critical components of the flow regime…magnitude, frequency, duration, timing, and rate of change of hydrologic conditions” (Poff et al., 1997). This reinforces the complicated interaction between fresh water and ecosystem productivity. Finally, Richter et al. (2003) present a six-step process for establishing “an ecologically sustainable water management program.” Richter et al. argue that this plan is feasible in most situations, but stakeholders should act quickly to increase the likelihood that such a program is successful.

The preceding review of the biological literature on estuarine productivity serves to establish the expected importance of freshwater inflow. The ensuing analysis is intended to provide further evidence of the relationship between freshwater inflow and oyster fishery productivity from an economic perspective. This analysis will also provide insight to whether the effects of fresh water persist beyond Apalachicola Bay. Based on these results, the value of fresh water as an input to oyster production is estimated.

This thesis contributes to the economic literature in multiple ways. First, despite several existing works focusing on fisheries in the Gulf of Mexico, it appears no economic work has considered the value of fresh water as an input to Florida’s oyster fisheries. In addition, this thesis estimates the effect of freshwater input on fishery productivity under differing assumptions regarding harvester behavior. As is discussed in the empirical section, these differing assumptions about behavior serve as the extreme bounds of actual harvester behavior. Finally, this thesis provides relevant economic insight to the ongoing water dispute and legal proceedings.

CHAPTER FOUR

THEORY

The first regression used in this thesis – Regression 1 – directly estimates the impact of freshwater inflow on stock abundance, based on the following model of oyster biology.

$$X_t = X_{t-1} + g(W_{t-z}, P_{t-z}, T_{t-z}) - h_t \tag{1}$$

Stock in the current period, X_t, is equal to stock in the previous period, X_{t-1}, plus growth g, net of harvest h_t. Stock in a period is initially the final stock in the previous period, which is then supplemented by stock growth and diminished by harvest. Growth is a function of a variety of environmental factors, including freshwater inflow (W_{t-z}), precipitation (P_{t-z},) and temperature (T_{t-z}), all in some previous period $t-z$. Current period stock is highly influenced by stock in the previous period. Freshwater inflow is assumed to influence oyster stock through its effect on the prevalence of predation and disease. The relationship between both predation and disease and oyster stock growth is assumed to be negative; therefore, the relationship between freshwater input and growth is assumed to be positive. Precipitation – another form of freshwater input to oyster habitat areas – is assumed to influence stock in the same way. Temperature is assumed to influence oyster stock through its effect on disease and reproduction. Of these habitat determinants, freshwater flow is of primary interest in this thesis.

Regression 1 is based on the relationships detailed in Equation 1. For the sake of simplicity, the relationship between the habitat determinants and stock is assumed to be linear. In Regression 1, X_t is represented by CPUE, which is valid based on Equation 2a. Harvest is not included in Regression 1 due to stock being modeled as CPUE. The notation for previous period $t - z$ is explained further in Chapter Six.

Regression 2 is now presented as follows. The Gordon-Schaefer model models the evolution of fishery population with respect to growth and harvest. Using the same notation as in Equation 1, oyster population grows according to:

$$O_t = rX_t\left(1 - \frac{X_t}{K}\right) \tag{2}$$

O_t is the biological growth rate of oysters in time t according to r, the intrinsic growth rate,[17] X_t, the existing oyster stock in time t, and K, the ecosystem carrying capacity.[18] Harvest tempers the growth rate according to:

$$h_t = qE_tX_t \tag{3}$$

$$X_t = \frac{h_t}{qE_t} \tag{3a}$$

Equation 3 and 3a are equivalent. h_t is the harvest of oysters in time t according to q, the catchability coefficient of oysters, E_t, the amount of harvest effort in time t, and oyster stock. Equation 3a is included to show that in the Gordon-Schaefer model, oyster stock is equal to catch per unit effort, dependent on the catchability coefficient. From Equation 3, it is clear that a positive relationship exists between both fishing effort and harvest and oyster stock and harvest. Then, the evolution of oyster stock over time can be written as:

$$X_{t+1} - X_t = O(X_t) - h(X_t, E_t) \tag{4}$$

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[17] The intrinsic growth rate is “the reproduction rate less the death rate” (Thompson & Post, 2017).

[18] The carrying capacity of an ecosystem is “the population size reached at equilibrium” (Dias, 1996). That is, the maximum sustainable population of an organism in a particular ecosystem.

Equation 4 can be thought of as the oyster production function over time, which is a function of current oyster stock and harvest effort. This standard model can now be adapted to account for habitat – in this case freshwater inflow – as an input to production.

The clearest depiction of this process is by Barbier and Strand (1998). Barbier and Strand’s method is as follows.

Assuming carrying capacity is a function of freshwater inflow W_t, Equation 2 can be reformulated as:

$$O_t = rK(W_t)X_t\left(1 - \frac{X_t}{K(W_t)}\right) \qquad (5)$$

W_t represents freshwater inflow in time t. Foley et al. (2009) and Armstrong, Foley, and Kahui (2016) show that the added $K(W_t)$ term is implied by Barbier and Strand’s (1998) derivation.[19] When freshwater inflow is incorporated, Equation 4 becomes:

$$X_{t+1} - X_t = O(X_t, W_t) - h(X_t, E_t) \qquad (6)$$

Substituting Equation 3 and 5 into Equation 6 and rearranging yields:

$$X_{t+1} - X_t = [r(K(W_t) - X_t) - qE_t]X_t \qquad (7)$$

Because harvest in Florida Gulf oyster fisheries is assumed to be open access, the evolution of harvest effort can be modeled as:

$$E_{t+1} - E_t = \delta[ph(X_t, E_t) - cE_t] \qquad (8)$$ [20]

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[19] The inclusion of this term means that the logistic growth function in this analysis differs from the “standard” Gordon-Schaefer model. This additional term is included to model habitat (freshwater input) as affecting both carrying capacity and the intrinsic growth rate (Foley et al., 2009). Because the effect of freshwater input on the intrinsic growth rate is multiplicative through carrying capacity, it is implied that fresh water influences carrying capacity and the intrinsic growth rate exactly the same. In reality this is unlikely, but the relationship is modeled in this way for simplicity.

[20] The adjustment coefficient δ determines the rate at which equilibrium is reached.

Where p is the dockside price of oysters and c is the cost per unit of harvest effort. Equation 8 shows that harvest effort responds to profits. Solving for steady-state oyster stock and harvest effort yields:

$$X = \frac{c}{pq}, \text{ when } E_{t+1} = E_t = E \tag{9}$$

$$E = \frac{r(K(W)-X)}{q}, \text{ when } X_{t+1} = X_t = X \tag{10}$$

Equation 9 shows that in equilibrium, stock does not depend on freshwater inflow. The steady-states in Equation 9 and 10 are based on the assumption that “in equilibrium…stock and the level of fishing effort are…constant over time,” assuming freshwater inflow is also in equilibrium (Barbier & Strand, 1998).

For simplicity, the relationship between freshwater inflow and carrying capacity is assumed to be linear and is specified as:

$$K(W) = a + bW, \text{ where } a > 0, b > 0 \tag{11}$$

Where a and b are constants. The relationship between habitat and carrying capacity is modeled differently in Equation 11 than by Barbier and Strand (1998), who omit the constant a. Barbier and Strand’s approach assumes habitat – in this case, freshwater inflow – is “essential,” while I model freshwater inflow as a “facultative” habitat (Foley et al., 2012). The essential habitat approach assumes that if the amount of habitat is zero, the carrying capacity is zero. The facultative habitat approach assumes that the carrying capacity remains nonzero if the amount of habitat is zero. The facultative habitat approach is more appropriate when relating oyster carrying capacity to fresh water because oysters can survive in pure ocean water. Substituting Equation 11 into Equation 10 yields:

$$E = \frac{r((a+bW)-X)}{q} \tag{12}$$

Taking the partial derivative of E in Equation 12 with respect to freshwater inflow W, yields:

$$\frac{\partial E}{\partial W} = \frac{rb}{q} > 0 \tag{13}$$

Equation 13 is expected to be positive based on economic intuition. That is, harvest effort increases as freshwater inflow increases. Equation 13 can be rewritten as:

$$\partial E = \frac{rb}{q} \cdot \partial W \tag{13a}$$

Substituting Equation 9 and 13a into the partial derivative of h in Equation 3, with respect to E:

$$\partial h = q \cdot \partial E \cdot X = r \cdot b \cdot X \cdot \partial W = \frac{rbc}{pq} \cdot \partial W \tag{14}$$

A positive relationship is therefore predicted between freshwater inflow and harvest. That is, $\frac{\partial h}{\partial W} > 0$. This relationship is consistent with the biological literature, which suggests oyster productivity increases as freshwater inflow increases, at least over a range of freshwater input levels. Equation 14 is rewritten as:

$$p \cdot \partial h = \frac{rbc}{q} \cdot \partial W \tag{14a}$$

Equation 14a shows the change in revenue from oyster harvest as freshwater input changes. Holding dockside price p constant, the relationship between freshwater inflow and harvest revenue is expected to be positive.

Substituting Equation 3a into Equation 10 and rearranging for h:

$$h = qEK(W) - \frac{(qE)^2}{r} \tag{15}$$

Now, substituting Equation 11 into Equation 15:

$$h = qaE + qbEW - \frac{q^2E^2}{r} \tag{15a}$$

Equations 15a shows that harvest is expected to increase as effort increases, but at a decreasing rate over time. Finally, Equation 15a can be rewritten as the regression:

$$Harvest_t = \beta_1 Effort_t + \beta_2 Effort_t \cdot Inflow_t + \beta_3 Effort_t \cdot Effort_t + \mu_t \tag{16}$$

Where $\beta_1 = qa$, $\beta_2 = qb$, $\beta_3 = \frac{q^2}{r}$, and μ_t is an independent and identically distributed (i.i.d.) error term. This regression can be adapted to fit the structure of my data, which is discussed in the empirical section. Now, Equation 14 and 14a are rewritten based on the regression coefficients:

$$\partial h = -\frac{c\beta_2}{p\beta_3} \cdot \partial W \tag{17}$$

$$p \cdot \partial h = -\frac{c\beta_2}{\beta_3} \cdot \partial W \tag{17a}$$

Gordon (1954) proposes that in the long-run, open access oyster harvest will continue until average revenue equals average cost. That is, the average revenue from the oysters harvested with one unit of effort will equal the average per unit cost of that one unit of effort, at which point open access equilibrium is reached. Harvest revenue exactly offsets the costs of harvest, i.e., there is zero economic rent. Because each variable in Equation 17 and 17a is identified by either the data or from running the regression in Equation 16, the per unit cost that yields zero economic rent in a period can be easily estimated:

$$p_t \cdot h_t = c_t \cdot E_t \tag{18}$$

Where p_t is the dockside price per pound of oysters, h_t is oyster harvest measured in pounds, c_t is the per unit cost of harvest effort, and E_t is the quantity of effort, all in time t and assuming the fishery is in open access equilibrium. Equation 18 simply equates total revenue with total cost, allowing me to solve for the per unit cost of effort that yields zero profit. Every variable in Equation 17 and 17a is now known, so I solve these equations to yield the change in harvest and revenue, respectively, from a marginal change in freshwater inflow.

The two regressions rely on different assumptions about harvest effort. Equation 3 in the above derivation shows that in this model, effort is assumed to increase when stock increases, and vice versa. Specifically, it is assumed that fishing effort responds perfectly to changes in stock to satisfy the zero-profit condition. The other regression model uses CPUE as the dependent variable and therefore – if changes in CPUE are indicative of changes in stock – it is assumed that effort does not respond “perfectly” to changes in stock. That is, the fishery is not in open access equilibrium. This distinction is explained further in Chapter Six.

CHAPTER FIVE

DATA AND DATASET CONSTRCTION

Data

The primary data sources for this analysis are Florida Fish and Wildlife Conservation Commission (FWC) commercial trip ticket data and United States Geological Survey (USGS) river discharge data. Other data including weather data from PRISM Climate Group are included as well.

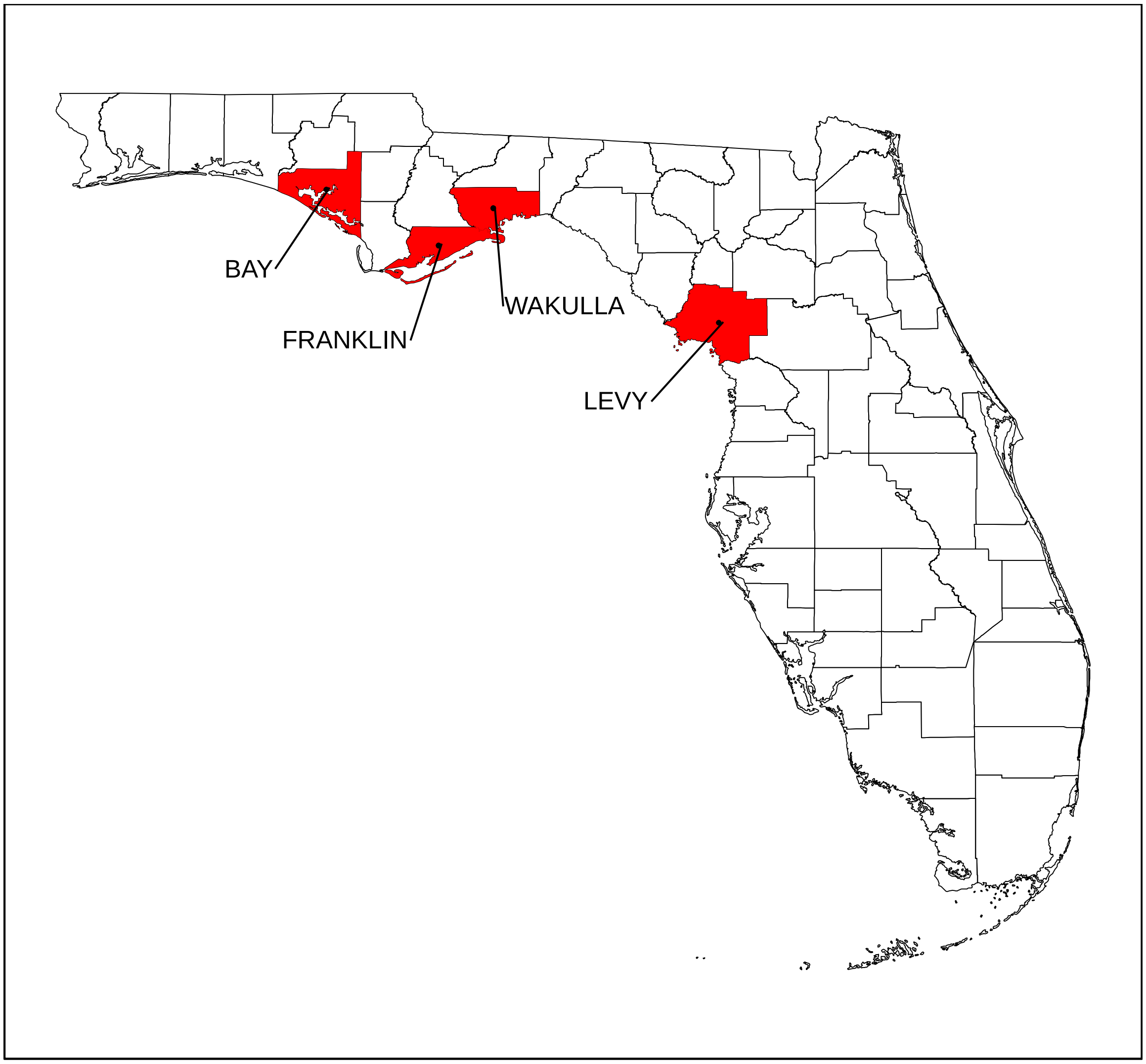
FWC has maintained commercial fish harvest records since 1984 through its trip ticket program. The oyster harvest data range from 1986-2018 and were provided at the quarterly-county or daily-county level, depending on the variable. The trip ticket program was established to maintain records of harvest and fishing effort. Trip tickets are completed by licensed seafood dealers when they make a purchase from a commercial harvester (FWC, 2002). To ensure legal harvesting, the dealer is required to confirm the harvester is legally licensed each time a purchase is made. The dealer and harvester each keep a copy of the ticket while a third copy is submitted to FWC. In the event that a harvester fishes from a dealer-owned boat, a trip ticket still must be completed (FWC, 2019g). Dealers may submit tickets either on paper or through a computer program. FWC reports that 80 percent of commercial tickets (all fisheries) are submitted by computer. It is not clear what proportion of oyster harvest is reported manually versus electronically.

The same trip ticket format is used for all commercially harvested species, but the data reported vary somewhat. In general, pounds, effort (hours or days), fishing gear, data, vessel ID, license number, crew members, unit price or overall value, dealer, and county are recorded. The most relevant fields for oyster harvest are pounds, county landed, value, and time fished. These values have been recorded consistently throughout the entirety of the data period. Pounds landed, trips, and harvest value are supplied at the quarterly-county level. Hours fished and trips are supplied at the daily-county level, as well as other effort metrics such as number of crew and licenses.

Oysters are harvested throughout Florida. The raw FWC data include landings for nearly every coastal county and even some landlocked counties. However, harvest is concentrated in a small number of counties. Many counties appear only sporadically throughout the dataset. It is unclear whether this is due to an absence of harvest in some periods or to a lack of reporting. Only counties that have data reported for 30 of the 33 years of the data period are included in the final dataset because it is possible that harvest in inconsistently reporting counties is fundamentally different than harvest in counties that consistently report landings. This leaves four counties: Bay County, Franklin County, Levy County, and Wakulla County, shown in Figure 5. Apalachicola Bay is located in Franklin County.

The FWC harvest and effort data were supplied at two time levels: quarterly and daily. I have aggregated the daily effort data to the broadest time level – quarterly – using Stata. This yields hours fished, number of crew, licenses, and trips at the quarterly-county level. This license aggregation is not useful because it is a count of every time any license holder harvests. I compare my quarterly aggregation of daily trips to the provided quarterly-county trips data. In general, the values are similar, however, I chose to use the

Figure 5: Map of Counties in Final Dataset (MyFlorida, 2003).



quarterly trips data values provided by FWC because they may account for errors beyond my knowledge. Number of crew data – the number of harvesters on the vessel for a given trip – were considered as an effort metric, but ultimately discarded for two reasons. First, there is little variation in crew size per boat over time. Second, number of crew data have only been recorded since 2000, about half of the harvest data period. Number of licenses was also discarded as an effort metric because it is considered to be an unreliable measure. It is unreliable because it measures effort at a very broad scale. For example, a harvester could purchase a license, then not harvest a single time. Data on the activity of each individual license are unavailable, so licenses are not a useful metric of effort.

The data provided span the period from 1986 to 2018. Per personal communication with FWC, there was an exemption in place in 1986 that allowed harvesters to decline reporting fishing effort metrics. Therefore, 1986 is dropped from the dataset. 2018 data are preliminary, so 2018 is dropped as well. This results in the final dataset ranging from 1987-2017. As is discussed further, a one year lag is applied to the harvest and flow data, so ultimately the relationship is estimated from 1988-2017.

Catch per unit effort is used as a proxy for oyster stock. I generate two CPUE variables: harvest per trip (HpT) and harvest per hour (HpH). These variables are simply pounds harvested in a quarter divided by the relevant effort value for that period. I calculate the natural logarithm of each CPUE variable as well. I do this so a log-log regression can be specified.

Estimated harvest value is included for each quarterly data observation in the original dataset. These value data are based on the reports from trip tickets. Each value measurement is converted to 2017 dollars using the Consumer Price Index. The resulting deflated quarterly values are then divided by pounds harvested in the corresponding quarter to create a value per pound variable. This measure is considered the dockside price for oysters in each quarter.

Freshwater inflow data are sourced from USGS gage recordings. Each of the four counties in the final dataset contains one or multiple rivers or streams that supply fresh water to the county's harvest areas. These water bodies are Econfina Creek in Bay County, Apalachicola River in Franklin County, Suwannee River in Levy County, and Ochlocknee River and St. Marks River in Wakulla County. Using the USGS National Information System Mapper, the gage on each river located closest to its outlet to the Gulf of Mexico (typically the southernmost gage) that has recorded data for the entire data period is used (USGS, 2017). It should be noted that this approach does not perfectly account for all freshwater input in each county. For example, small creeks may discharge into the bays in addition to the major rivers included in this dataset. Such a measure is at best beyond the scope of this thesis and at worst impossible due to the data available. That said, care was taken to include data that are as representative of actual freshwater input to each harvest area as possible while avoiding imputed values wherever possible.

The USGS gage data are sourced from the following gages: site number 02359500 Econfina Creek near Bennett, FL, site number 02359170 Apalachicola River near Sumatra, FL, site number 02323500 Suwannee River near Wilcox, FL, site number 02330000 Ochlockonee River near Bloxham, FL, and site number 02326900 St. Marks River near Newport, FL. I obtained monthly average discharge data measured in cubic feet per second (cfs). To match the harvest and effort data, I aggregated the average monthly discharge (flow) to quarterly average flow in cfs. I then converted the values from cfs to cubic meters per second (cms) by multiplying each value by the conversion factor.[21] I converted to cms to increase the magnitude of a single unit of flow to allow for easier interpretation of regression coefficients compared to cfs. Finally, I took the natural logarithm of each quarterly average flow value to fit a log-log regression specification. For Wakulla County, where two river flows are used, the only difference in this process is that the two river flows are summed before the values are aggregated to the quarterly level.

The USGS flow data are generally well reported, but some missing values exist for monthly flows at various gage sites. To account for this, missing values are imputed based on the flow value at a nearby flow station, preferably on the same river but occasionally on another river. The correlation is calculated between monthly flow values on the river of interest with missing values and the nearby river. In every case the correlation between monthly flow is at least 0.7 and often nears 0.9. A simple regression is then estimated to determine the relationship between the two rivers of interest and the values for the relevant missing quarters are then calculated. This process is repeated for each river with missing values. Overall, very few flow values need to be imputed, so the missing data are not expected to have a major effect on the results. Missing values exist for the harvest data as well, but there is no reliable method of imputing harvest levels. Therefore, quarters with missing harvest data are dropped from the analysis.

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[21] One cfs is equal to about 0.0283 cms.

I obtained weather data from PRISM Climate Group. PRISM data are presented as a map of the entire United States gridded as four km^2 cells. I selected the cell closest to the center of all harvest areas in each county. I obtained the mean monthly temperature in degrees Fahrenheit and total monthly precipitation in inches for each cell. I then aggregated the monthly values to a quarterly average for temperature and a quarterly sum for precipitation.

Data Considerations

Trip tickets are reported by dealers, so it is possible that measurement error exists in the harvest and effort data. This measurement error could be either unintentional or intentional. An example of an unintentional reporting error is a typo on a trip ticket. This measurement error is likely random and therefore should bias the coefficients toward zero. An example of intentional measurement error is a dealer purchasing 2,000 pounds of oysters but only reporting 1,000 pounds. This misreporting would result in underestimating pounds harvested and, assuming effort is unchanged, CPUE, used as the dependent variable in Regression 1. Intentional misreporting is certainly possible, but there is no evidence it occurs at all, much less on a widespread scale. FWC occasionally audits dealers to ensure accurate reporting and penalties exist for inaccurate reporting. Further, FWC (2013) suggest that anecdotal evidence shows “[dealers] limit landings to ten bags per fisher daily in a form of self-regulation based on market demand.” If this is true, it is counterintuitive that dealers would simultaneously intentionally underreport their purchases. With this in mind, it is assumed that harvest is accurately reported in general. It is also possible that measurement error exists in the effort data. For example, harvesters may misremember how many hours they were on the water. Although this measurement error may be random as well, it is slightly more concerning, especially for the hours fished data. If harvesters consistently misreport effort data, the empirical results could be biased. That said, there is little to be done about this potential measurement error beyond considering it when viewing the empirical results. It is expected that measurement error would be less of an issue for trip and license data because it is less granular. That is, it is more likely that a harvester could misreport the number of hours fished than the number of trips fished because if a harvester is selling to a dealer, they must have completed a trip, whether it lasted five hours or eight hours. With this in mind, the inclusion of multiple effort variables serves as a robustness check in the event that measurement error exists for a particular effort variable. Finally, there is also the possibility of measurement error in the county harvest data. The county reported is the county the harvest is “landed” in, not necessarily the county whose waters it was harvested in. Due to regulations that require oysters to be sold relatively quickly after being caught, it is unlikely that harvesters often travel to other counties to sell their catch, although it may happen at times. In the event that harvesters do routinely sell in a different county than they harvest, it is possible that CPUE is not affected greatly due to the similarity in CPUE by county shown in the following section. At any rate, it is difficult to definitively determine whether this or other measurement error exists. Based on knowledge of the industry and data collection detailed above, it is assumed that measurement error is not a major issue in these data.

Summary Statistics

Relevant summary statistics, by county-quarter, are now presented. Summary statistics for Bay, Franklin, Levy, and Wakulla County are found in Tables 1, 2, 3, and 4, respectively. These tables show that although harvest and total harvest effort varies substantially by county, the CPUE metrics are reasonably similar. This supports Gordon's (1954) assertion that in an open access fishery, harvesters will harvest in the area where "average productivity" is highest. In doing so, economic rent dissipates. In this context, the similar CPUE metrics show that harvesters are unable to harvest a higher quantity of oysters per unit of effort in any area compared to another. That is, harvesters cannot obtain a higher amount of harvest per unit cost of effort. Another thing to note is the weather variables across counties. Although all four counties are relatively close to one another, the summary statistics show that weather does vary by county. This variation supports the inclusion of weather variables in the empirical models, detailed in Chapter Six.

Table 1: Bay County Summary Statistics by Quarter, 1987-2017

Quarter 1

	N	mean	sd	min	max
Pounds (in-shell)	27	276,954.30	308,697.80	449.83	1,090,000.00
Sacks	27	5,541.20	6,176.31	9.00	21,857.80
Value (2017 $)	27	108,029.40	107,076.40	140.13	425,075.50
Value per Pound (2017 $)	27	0.48	0.24	0.23	1.02
Trips	27	458.41	432.83	1.00	1,286.00
Harvest per Trip (HpT)	27	546.77	199.27	222.67	981.83
Licenses	27	46.22	41.66	1.00	145.00
Harvest per License (HpL)	27	4,479.18	2,950.83	449.83	11,035.09
Total Fishing Hours	27	2,822.56	3,263.59	6.00	12,404.00
Harvest per Hour (HpH)	27	104.48	43.53	27.25	240.82
Flow (cms)	31	15.52	3.13	9.82	22.12
Total Precipitation (in.)	31	15.69	5.68	6.82	28.83
Mean Temperature (F)	31	56.60	2.48	50.80	61.53

Quarter 2

	N	mean	sd	min	max
Pounds (in-shell)	27	254,676.70	290,612.40	199.92	956,188.80
Sacks	27	5,095.47	5,814.46	4.00	19,131.06
Value (2017 $)	27	105,025.60	115,904.50	93.42	447,410.60
Value per Pound (2017 $)	27	0.50	0.22	0.21	1.01
Trips	27	473.00	488.53	1.00	1,638.00
Harvest per Trip (HpT)	27	469.95	214.37	62.48	872.78
Licenses	27	38.96	38.13	1.00	124.00
Harvest per License (HpL)	27	5,109.75	3,522.58	199.92	12,661.84
Total Fishing Hours	27	2,971.63	3,791.50	3.00	12,679.00
Harvest per Hour (HpH)	27	93.77	51.08	11.90	237.48
Flow (cms)	31	14.76	3.64	8.28	24.11
Total Precipitation (in.)	31	12.21	5.53	4.40	24.57
Mean Temperature (F)	31	74.07	1.57	70.43	77.33

Table 1 cont.: Bay County Summary Statistics by Quarter, 1987-2017

Quarter 3

	N	mean	sd	min	max
Pounds (in-shell)	18	208,706.80	253,447.50	99.96	752,671.30
Sacks	18	4,175.73	5,070.88	2.00	15,059.16
Value (2017 $)	18	75,478.35	93,685.22	59.78	338,293.90
Value per Pound (2017 $)	18	0.51	0.27	0.21	1.02
Trips	18	367.50	411.06	1.00	1,300.00
Harvest per Trip (HpT)	18	557.55	226.16	99.96	1,048.53
Licenses	18	35.83	31.85	1.00	92.00
Harvest per License (HpL)	18	5,292.71	3,716.17	99.96	12,711.82
Total Fishing Hours	18	2,513.39	2,817.72	3.00	8070.00
Harvest per Hour (HpH)	18	109.67	56.88	2.27	223.53
Flow (cms)	31	15.27	3.59	9.45	24.07
Total Precipitation (in.)	31	20.55	7.04	12.24	40.14
Mean Temperature (F)	31	81.23	1.01	78.83	83.37

Quarter 4

	N	mean	sd	min	max
Pounds (in-shell)	29	282,204.20	384,546.20	199.92	1,440,000.00
Sacks	29	5,646.23	7,693.85	4.00	28,758.34
Value (2017 $)	29	108,526.60	127,696.50	83.04	445,519.80
Value per Pound (2017 $)	29	0.53	0.25	0.23	1.08
Trips	29	465.03	531.45	1.00	1,754.00
Harvest per Trip (HpT)	29	491.22	209.71	108.29	819.48
Licenses	29	39.72	40.24	1.00	137.00
Harvest per License (HpL)	29	4,853.13	3,946.49	199.92	14,373.69
Total Fishing Hours	29	2,926.10	3,932.77	5.00	14,784.00
Harvest per Hour (HpH)	29	90.95	39.32	25.30	190.50
Flow (cms)	31	13.84	2.66	8.89	18.28
Total Precipitation (in.)	31	11.14	3.90	5.31	20.77
Mean Temperature (F)	31	62.41	2.26	57.77	67.73

Table 2: Franklin County Summary Statistics by Quarter, 1987-2017

Quarter 1

	N	mean	sd	min	max
Pounds (in-shell)	31	3,470,000.00	1,790,000.00	484,000.00	7,739,262.00
Sacks	31	69,481.04	35,824.84	9,685.38	155,000.00
Value (2017 $)	31	1,320,000.00	630,000.00	430,000.00	3,000,000.00
Value per Pound (2017 $)	31	0.44	0.21	0.26	1.01
Trips	31	6,384.84	2,701.15	2,487.00	15503.00
Harvest per Trip (HpT)	31	532.82	179.08	162.40	762.73
Licenses	31	400.29	125.97	248.00	754.00
Harvest per License (HpL)	31	8,778.52	4,132.91	1,869.05	16,561.02
Total Fishing Hours	31	39,411.32	26,039.71	6,288.00	160,111.00
Harvest per Hour (HpH)	31	89.74	25.07	35.39	137.23
Flow (cms)	31	907.35	370.65	374.07	2,052.69
Total Precipitation (in.)	31	13.01	6.08	5.20	32.76
Mean Temperature (F)	31	57.28	2.37	50.53	61.57

Quarter 2

	N	mean	sd	min	max
Pounds (in-shell)	31	3,290,000.00	1,650,000.00	640,000.00	7,872,237.00
Sacks	31	65,751.99	33,048.71	12,809.34	158,000.00
Value (2017 $)	31	1,310,000.00	759,000.00	393,000.00	4,170,000.00
Value per Pound (2017 $)	31	0.44	0.22	0.25	1.08
Trips	31	6,327.39	2,679.86	2,222.00	14,231.00
Harvest per Trip (HpT)	31	523.97	166.01	154.35	750.10
Licenses	31	397.45	146.90	195.00	695.00
Harvest per License (HpL)	31	8,726.28	3,676.02	2,038.93	13,763.42
Total Fishing Hours	31	38,853.58	18,892.40	15,036.00	106,086.00
Harvest per Hour (HpH)	31	84.87	23.74	40.00	129.56
Flow (cms)	31	654.26	277.28	255.70	1,367.04
Total Precipitation (in.)	31	10.04	5.25	1.95	23.31
Mean Temperature (F)	31	74.01	1.53	71.57	78.73

Table 2 cont.: Franklin County Summary Statistics by Quarter, 1987-2017

Quarter 3

	N	mean	sd	min	max
Pounds (in-shell)	31	2,500,000.00	1,470,000.00	372,000.00	5,471,242.00
Sacks	31	49,979.52	29,312.51	7,452.24	109,000.00
Value (2017 $)	31	1,010,000.00	596,000.00	101,000.00	2,250,000.00
Value per Pound (2017 $)	31	0.45	0.23	0.23	1.09
Trips	31	5,410.32	3,121.78	432.00	14399.00
Harvest per Trip (HpT)	31	496.33	185.44	111.05	862.20
Licenses	31	357.58	160.61	107.00	715.00
Harvest per License (HpL)	31	7,111.93	3,271.10	1,494.21	13,300.29
Total Fishing Hours	31	32,393.71	20,601.77	3,116.00	93,850.00
Harvest per Hour (HpH)	31	82.54	27.50	30.75	131.01
Flow (cms)	31	469.52	297.66	181.55	1,532.41
Total Precipitation (in.)	31	19.27	7.24	8.01	36.25
Mean Temperature (F)	31	81.21	0.91	79.57	83.43

Quarter 4

	N	mean	sd	min	max
Pounds (in-shell)	31	3,290,000.00	1,860,000.00	209,000.00	7,281,705.00
Sacks	31	65,768.20	37,207.04	4,175.08	146,000.00
Value (2017 $)	31	1,290,000.00	645,000.00	226,000.00	2,960,000.00
Trips	31	6,288.74	2,764.48	1,760.00	15,020.00
Value per Pound (2017 $)	31	0.47	0.23	0.26	1.08
Harvest per Trip (HpT)	31	518.89	215.85	118.57	811.13
Licenses	31	378.39	132.11	158.00	739.00
Harvest per License (HpL)	31	8,822.63	4,686.37	1,320.72	16,800.20
Total Fishing Hours	31	37,068.64	19,736.41	5213.00	97,006.00
Harvest per Hour (HpH)	31	87.92	27.27	40.03	139.33
Flow (cms)	31	463.34	256.23	184.51	1,227.44
Total Precipitation (in.)	31	9.00	3.91	3.25	18.44
Mean Temperature (F)	31	63.18	2.02	59.63	68.13

Table 3: Levy County Summary Statistics by Quarter, 1987-2017

Quarter 1

	N	mean	sd	min	max
Pounds (in-shell)	31	290,716.20	151,827.40	103,742.50	723,457.90
Sacks	31	5,816.54	3,037.71	2,075.64	14,474.67
Value (2017 $)	31	132,982.60	102,945.00	35,168.85	510,214.00
Value per Pound (2017 $)	31	0.44	0.15	0.28	0.76
Trips	31	646.23	341.76	315.00	1,801.00
Harvest per Trip (HpT)	31	457.92	122.47	254.27	766.54
Licenses	31	44.71	18.55	20.00	94.00
Harvest per License (HpL)	31	6,520.44	2,120.14	3,477.57	11,702.75
Total Fishing Hours	31	3,819.16	1,686.86	1,302	8,562.00
Harvest per Hour (HpH)	31	77.62	24.67	29.27	131.47
Flow (cms)	31	307.08	180.05	83.92	840.35
Total Precipitation (in.)	31	10.32	5.19	4.18	22.99
Mean Temperature (F)	31	58.79	2.34	51.47	63.33

Quarter 2

	N	mean	sd	min	max
Pounds (in-shell)	31	112,018.20	74,097.80	25,013.47	326,951.70
Sacks	31	2,241.22	1,482.52	500.46	6,541.52
Value (2017 $)	31	52,663.44	51,733.71	8,479.45	259,915.30
Value per Pound (2017 $)	31	0.43	0.16	0.28	0.79
Trips	31	235.94	156.59	41.00	754.00
Harvest per Trip (HpT)	31	486.53	136.65	243.09	796.87
Licenses	31	26.35	14.92	10.00	69.00
Harvest per License (HpL)	31	4,231.77	1,537.88	1,800.89	7,078.9
Total Fishing Hours	31	1,371.32	782.45	246.00	3442.00
Harvest per Hour (HpH)	31	81.60	24.21	42.22	152.95
Flow (cms)	31	259.10	149.94	80.50	608.91
Total Precipitation (in.)	31	9.40	2.99	2.30	16.04
Mean Temperature (F)	31	74.29	1.24	72.07	76.90

Table 3 cont.: Levy County Summary Statistics by Quarter, 1987-2017

Quarter 3

	N	mean	sd	min	max
Pounds (in-shell)	31	103,832.30	60,988.57	19,498.57	289,885.60
Sacks	31	2,077.44	1,220.24	390.12	5,799.92
Value (2017 $)	31	47,485.23	41,798.20	7,246.53	172,425.60
Value per Pound (2017 $)	31	0.42	0.16	0.26	0.76
Trips	31	221.19	154.97	67.00	703.00
Harvest per Trip (HpT)	31	488.17	112.69	209.66	654.02
Licenses	31	29.61	15.00	8.00	71.00
Harvest per License (HpL)	31	3,450.22	1,043.14	1,624.88	5,779.55
Total Fishing Hours	31	1,325.87	1,071.10	238.00	5,190.00
Harvest per Hour (HpH)	31	86.68	24.29	42.15	146.26
Flow (cms)	31	201.73	111.31	65.74	506.87
Total Precipitation (in.)	31	21.41	6.43	11.16	35.25
Mean Temperature (F)	31	80.73	0.79	78.93	82.37

Quarter 4

	N	mean	sd	min	max
Pounds (in-shell)	31	338,887.30	200,153.50	46,108.43	865,789.30
Sacks	31	6,780.33	4,004.59	922.52	17,322.38
Value (2017 $)	31	159,162.10	144,324	30,993.27	669,447.20
Value per Pound (2017 $)	31	0.44	0.16	0.28	0.77
Trips	31	704.29	407.53	181.00	1,969.00
Harvest per Trip (HpT)	31	480.76	130.20	214.13	821.08
Licenses	31	45.74	20.80	16.00	106.00
Harvest per License (HpL)	31	7,208.19	2,572.53	2,881.78	13,259.57
Total Fishing Hours	31	4,134.68	2,095.96	1,061.00	10,346.00
Harvest per Hour (HpH)	31	82.19	28.90	31.71	154.52
Flow (cms)	31	184.28	98.25	61.08	506.12
Total Precipitation (in.)	31	6.55	3.90	1.11	19.58
Mean Temperature (F)	31	64.47	2.18	59.90	70.57

Table 4: Wakulla County Summary Statistics by Quarter, 1987-2017

Quarter 1

	N	mean	sd	min	max
Pounds (in-shell)	29	108,173.60	72,148.02	3,402.70	271,153.70
Sacks	29	2,164.30	1,443.51	68.08	5,425.14
Value (2017 $)	29	44,012.52	34,774.78	2,070.75	119,896.80
Value per Pound (2017 $)	29	0.42	0.14	0.26	0.76
Trips	29	151.07	123.48	6.00	397.00
Harvest per Trip (HpT)	29	826.64	420.27	261.75	1,788.39
Licenses	29	18.59	13.29	2.00	51.00
Harvest per License (HpL)	29	6,424.61	4,549.17	567.12	22,354.88
Total Fishing Hours	29	1,228.00	963.68	24.00	3,282.00
Harvest per Hour (HpH)	29	105.58	54.43	31.84	230.43
Flow (cms)	31	98.70	47.01	33.13	237.89
Total Precipitation (in.)	31	14.06	5.54	6.97	31.00
Mean Temperature (F)	31	56.42	2.54	48.73	61.13

Quarter 2

	N	mean	sd	min	max
Pounds (in-shell)	29	74,776.42	67,285.66	1,999.24	304,983.80
Sacks	29	1,496.10	1,346.23	40.00	6,102.00
Value (2017 $)	29	32,172.9	35,738.15	1,553.57	161,580.10
Value per Pound (2017 $)	29	0.42	0.18	0.26	1.02
Trips	29	92.97	95.20	3.00	438.00
Harvest per Trip (HpT)	29	924.62	314.72	422.39	1,772.99
Licenses	29	9.62	8.05	1.00	35.00
Harvest per License (HpL)	29	7,929.52	4,218.93	1,999.24	19,282.05
Total Fishing Hours	29	938.38	1,339.56	9.00	6,779
Harvest per Hour (HpH)	29	121.72	57.51	22.45	243.20
Flow (cms)	31	60.56	35.71	19.11	155.66
Total Precipitation (in.)	31	12.67	6.00	2.85	32.50
Mean Temperature (F)	31	74.08	1.41	71.07	77.17

Table 4 cont.: Wakulla County Summary Statistics by Quarter, 1987-2017

Quarter 3

	N	mean	sd	min	max
Pounds (in-shell)	28	48,089.00	35,173.60	1,911.27	120,569.10
Sacks	28	962.15	703.74	38.24	2,412.30
Value (2017 $)	28	20,125.34	16,197.21	514.17	57,837.56
Value per Pound (2017 $)	28	0.42	0.15	0.26	0.76
Trips	28	65.71	54.73	2.00	208.00
Harvest per Trip (HpT)	28	808.68	344.87	274.07	1,799.54
Licenses	28	8.79	7.21	1.00	27.00
Harvest per License (HpL)	28	6,470.16	4,508.41	1,164.81	17,926.67
Total Fishing Hours	28	548.89	460.25	28.00	1,706.00
Harvest per Hour (HpH)	28	104.95	57.75	34.06	244.56
Flow (cms)	31	53.70	37.78	15.17	179.74
Total Precipitation (in.)	31	20.40	5.46	13.43	32.70
Mean Temperature (F)	31	80.85	0.83	79.20	82.67

Quarter 4

	N	mean	sd	min	max
Pounds (in-shell)	27	128,580.30	90,454.51	3,178.69	373,803.10
Sacks	27	2,572.59	1,809.78	63.60	7,478.91
Value (2017 $)	27	52,821.73	36,121.74	2,716.03	117,777.60
Value per Pound (2017 $)	27	0.49	0.35	0.26	2.12
Trips	27	171.67	142.42	14.00	534.00
Harvest per Trip (HpT)	27	861.48	471.41	211.91	2,281.32
Licenses	27	20.00	18.13	3.00	94.00
Harvest per License (HpL)	27	7,304.53	4,544.53	614.52	18,203.48
Total Fishing Hours	27	1,408.78	1,069.67	58.00	4,154.00
Harvest per Hour (HpH)	27	104.35	58.26	36.72	251.33
Flow (cms)	31	42.13	31.16	14.24	170.29
Total Precipitation (in.)	31	9.38	3.67	3.91	17.05
Mean Temperature (F)	31	62.12	2.27	57.67	67.83

CHAPTER SIX

EMPIRICAL METHODOLOGY

Relationship Between Stock and CPUE

Two empirical specifications are used in this thesis. The purpose of each is to estimate the effect of freshwater inflow on oyster productivity. The first specification, hereafter referred to as Regression 1, utilizes catch per unit effort as a proxy for oyster stock. Catch per unit effort is commonly used in the biological literature as an approximation of fish abundance. There are, however, works that caution against the use of CPUE and indicate that it may not be a good indicator of overall fish abundance (Harley, Myers, & Dunn, 2001; Maunder et al., 2006). Although stock data are not available for all counties, the "Apalachicola Bay Oyster Situation Report" includes a graph in which annual oyster stock in Apalachicola Bay from 1990-2012 is plotted based on stock surveys (Havens et al., 2013). These data are from Florida Department of Agriculture and Consumer Services (FDACS) and are measured as the number of oysters per m^2. I use the WebPlotDigitizer[22] tool to obtain the data from this graph (Rohatgi, 2019). To estimate the relationship between CPUE and stock, I aggregate quarterly CPUE to the annual level then estimate the correlation coefficient between the annual stock estimate and each annual CPUE metric in Franklin County from 1990-2012. A high correlation between the stock and CPUE data suggests CPUE is a good approximation of oyster stock, while a low correlation suggests CPUE is not a good approximation of

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[22] This tool is found at https://automeris.io/WebPlotDigitizer/.

Figure 6: Oyster Stock and HpT in Franklin County, 1990-2012

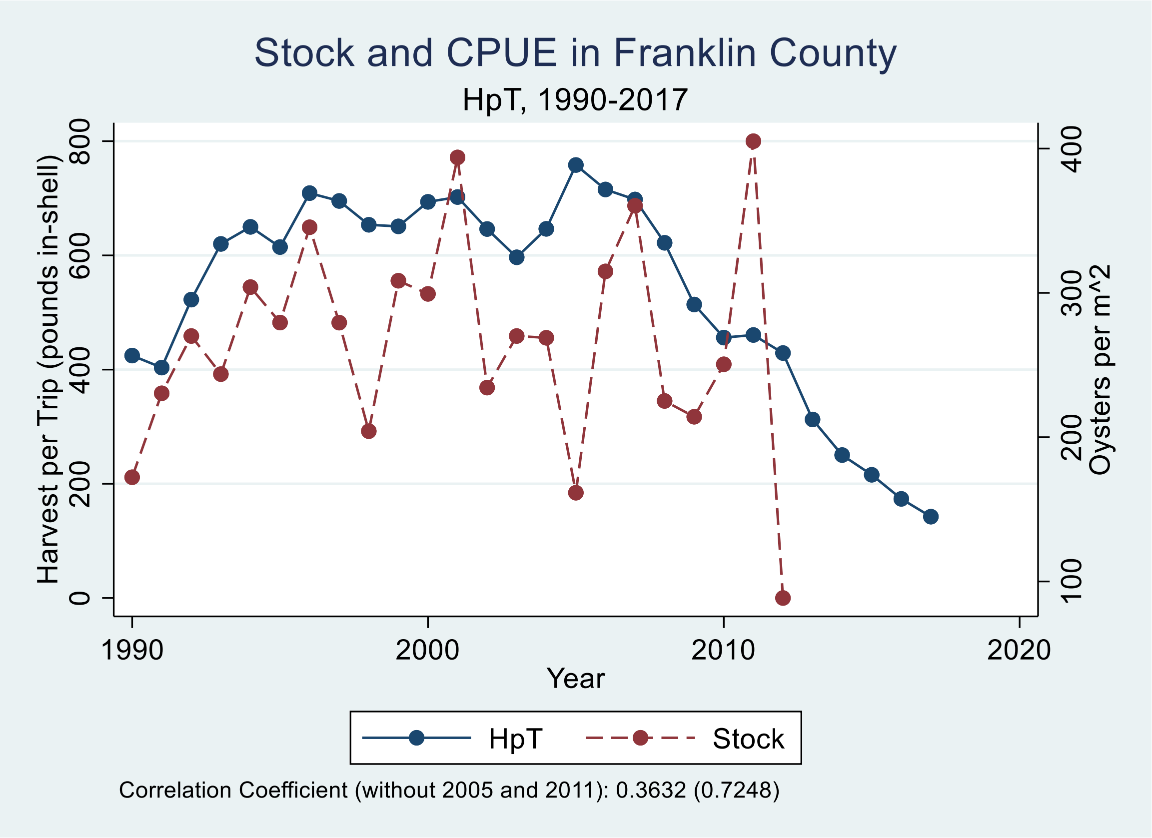
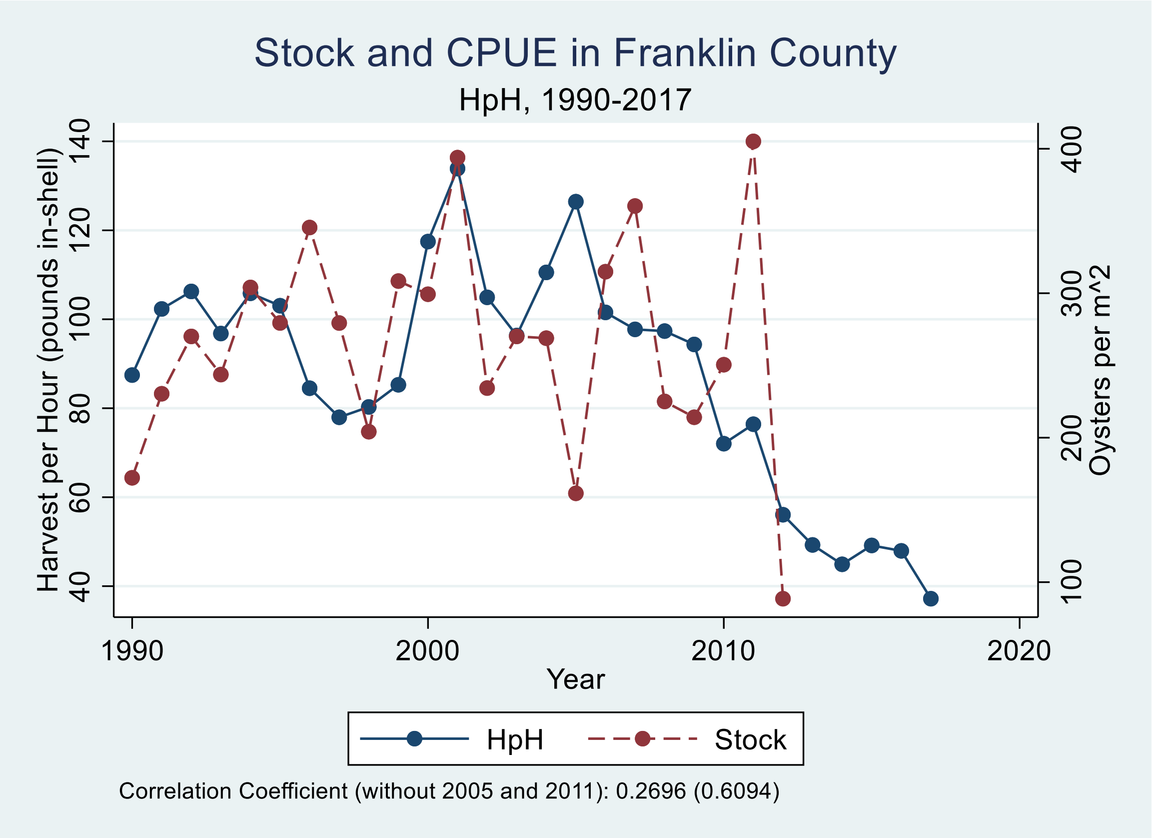


Figure 7: Oyster Stock and HpH in Franklin County, 1990-2012



oyster stock. The correlation between oyster stock and each CPUE metric is depicted with plots and correlation coefficient, where Figures 6 and 7 show the stock and HpT and HpH in Franklin County. Beyond correlation, these plots also show that CPUE diminished greatly after 2010, which implies that the fishery collapse was driven by diminished oyster stock, not simply diminished harvest intensity.

The resulting correlation coefficients do not suggest a particularly strong relationship between stock and CPUE. However, the plots indicate the correlation coefficients may not tell the whole story. In general, stock and CPUE move together, with individual years that belie this pattern. If the correlation coefficients are estimated again with the outlying years – 2005 and 2011 – excluded, the resulting coefficients increase greatly, especially for HpT (0.36 to 0.72) and HpH (0.27 to 0.61).[23] There is reason to believe these specific years are abnormal. In 2004, hurricane activity was extremely high in the Gulf. In April 2010, the Deepwater Horizon oil spill occurred off the coast of Louisiana. It is entirely reasonable to believe these disasters influenced harvest and/or stock levels in the following year. Therefore, I argue that CPUE is a good approximation of stock *in general,* with occasional exceptions. Stock data are not available for the other counties in the final dataset, so it is assumed that the relationship between stock and CPUE in Franklin County holds for the other three counties as well.

It should also be noted that stock surveys, even conducted by biologists from government agencies, are not necessarily exact reflections of true fish abundance themselves. Biologists typically conduct surveys by either counting the number of fish

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[23] The exclusion of licenses as an effort metric is supported by this exercise. The correlation between stock and harvest is just 0.4058 even after excluding 2005 and 2011.

(oysters) in an area then extrapolating that value across the fishing ground or by fishing with “standard equipment” for a certain period of time then estimating total stock based on the fish caught in that period of time. This is noted to make it clear that all measures of stock – whether it be a stock survey or CPUE – are at best an estimate. The true abundance of a fish is impossible to measure, so estimates of stock are the best option for analysis despite their potential shortcomings.

Regression 1

With the relationship between stock and CPUE established, Regression 1 is now presented, based on Equation 1:

Regression 1:

$$
\begin{aligned}
\ln(CPUE)_{yqc} = \beta_0 &+ \beta_1 \ln(BayFlow)_{y,q-z} \cdot Bay_c + \beta_2 \ln(FranklinFlow)_{y,q-z} \cdot Franklin_c \\
&+ \beta_3 \ln(LevyFlow)_{y,q-z} \cdot Levy_c + \beta_4 \ln(WakullaFlow)_{y,q-z} \cdot Wakulla_c \\
&+ \beta_5 \ln(BayFlow)_{y-1,q-z} \cdot Bay_c + \beta_6 \ln(FranklinFlow)_{y-1,q-z} \cdot Franklin_c \\
&+ \beta_7 \ln(LevyFlow)_{y-1,q-z} \cdot Levy_c + \beta_8 \ln(WakullaFlow)_{y-1,q-z} \cdot Wakulla_c \\
&+ \beta_9 TotalPreciptiation_{y,q-z,c} + \beta_{10} TotalPreciptiation_{y-1,q-z,c} \\
&+ \beta_{11} AverageTemperature_{y,q-z,c} + \beta_{12} AverageTemperature_{y-1,q-z,c} \\
&+ \beta_{13} \ln(AvgHpH)_{y-1,q,c} + D_y + D_q + D_c + \mu_{yqc}
\end{aligned}
$$

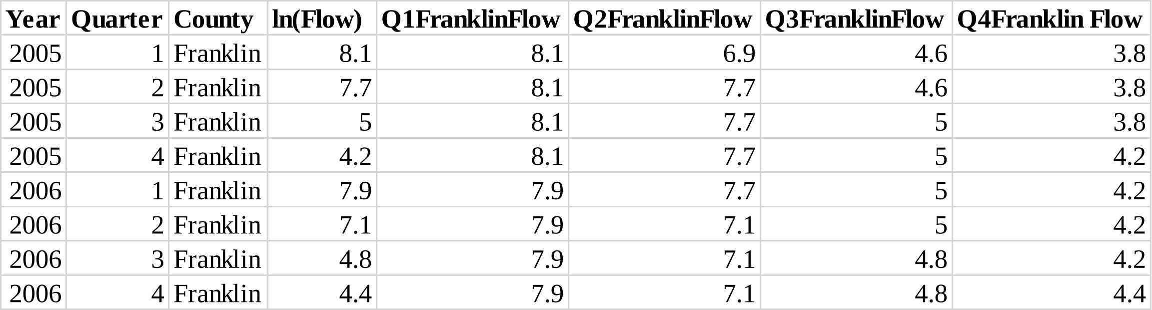
Where $\boldsymbol{\ln(CPUE)_{yqc}}$ is the natural logarithm of CPUE – either HpT or HpH – in harvest year y, quarter q, county c. Harvest year is defined as the non-calendar year beginning in quarter three. Harvest year is used instead of the calendar year to group each quarter in a particular “winter season” in the same year. This regression is run separately for both CPUE variables. $\boldsymbol{\ln(BayFlow)_{y,q-z}}$ is the natural logarithm of freshwater inflow in Bay County, $\mathbf{ln}(\boldsymbol{FranklinFlow})_{\boldsymbol{y,q-z}}$ is the natural logarithm of freshwater inflow in Franklin County, $\mathbf{ln}(\boldsymbol{LevyFlow})_{\boldsymbol{y,q-z}}$ is the natural logarithm of freshwater inflow in Levy County, and $\mathbf{ln}(\boldsymbol{WakullaFlow})_{\boldsymbol{y,q-z}}$ is the natural logarithm of freshwater inflow in Wakulla County, all assigned to year y, quarter $q-z$. The $q-z$ term represents the fact that the flow value in a quarter is assigned based on the flow value in a particular past quarter, ranging from the current quarter to three quarters prior. That is, z can equal zero, one, two, or three. This is discussed further in the next paragraph. $\boldsymbol{Bay_c}$, $\boldsymbol{Franklin_c}$, $\boldsymbol{Levy_c}$, and $\boldsymbol{Wakulla_c}$ are indicator variables that are set equal to one when the observed county is Bay, Franklin, Levy, or Wakulla, respectively, and equal to zero otherwise. The format of the flow variables is somewhat unorthodox and is detailed in the next paragraph. $\boldsymbol{TotalPreciptiation_{yqc}}$ is the total precipitation in inches and $\boldsymbol{AverageTemperature_{yqc}}$ is the average temperature in Fahrenheit, both assigned to harvest year y, quarter q, county c. $\mathbf{ln}(\boldsymbol{AvgHpH})_{\boldsymbol{y-1,q,c}}$ is the natural logarithm of average harvest per hour in the winter season – quarter four to quarter two of the following year – in harvest year $y-1$, quarter q, county c. This variable is included because current stock is expected to be influenced by stock in recent periods. HpH is used for both the HpT and HpH regressions because it is the most granular measure of effort. Finally, $\boldsymbol{D_y}$, $\boldsymbol{D_q}$, and $\boldsymbol{D_c}$ are harvest year, quarter, and county fixed effects, respectively. $\mu_{\boldsymbol{yqc}}$ is an independent and identically distributed error term. These fixed effects are included to account for unobserved differences in year, quarter, and county.

The above regression is estimated a total of eight times: once for each CPUE variable with flow from each quarter, one through four. I do this to isolate the effect of flow in a particular quarter on oyster productivity throughout the following year. I format the data this way because I expect that flow in different quarters does not uniformly affect harvest. To do this, I create a total of 16 “flow” variables, which apply to each observation *regardless of the county for a particular observation*. The variables are “Q1BayFlow,” “Q1FranklinFlow,” “Q1LevyFlow,” “Q1WakullaFlow,” “Q2BayFlow,” and so on. The flow in the quarter of the particular flow variable, for example, quarter one flow in the case of “BayQ1Flow,” is assigned to the quarter that flow was observed in *as well as the subsequent three quarters*. Therefore, flow in quarter q is the flow *assigned* to that quarter, not necessarily the flow that actually occurred in that quarter. The weather variables – precipitation and temperature – are similarly assigned. The purpose of this data structure is to measure the effect of flow in a particular quarter on stock levels in that quarter and also the three following quarters. This data structure is the reason for the $q - z$ notation. The flow value assigned to a quarter is really the freshwater inflow in that county some z quarters ago, where z is either zero, one, two, or three.

As an example, consider the variable “Q3FranklinFlow” for the year 2005-2006. Hypothetically, suppose the natural logarithm of average freshwater inflow in cms to Franklin County in year 2005, quarter three, is equal to five. This value – five – is then assigned to “Q3FranklinFlow” for 2005 quarter three, 2005 quarter four, 2006 quarter one, and 2006 quarter two. This assignment is repeated for all flow variables using the relevant county over the entire dataset. Note that the hypothetical “Q3FranklinFlow” value of five discussed above is assigned to all observations from 2005 quarter three to 2006 quarter two, regardless of the county of the particular observation. This is why I include the county indicator variables. For the harvest observation for Franklin County in 2005, quarter four, the $\boldsymbol{Franklin_c}$ variable is equal to one. In all other counties, the $\boldsymbol{Franklin_c}$ variable is equal to zero. Therefore, only the effect of "Q3FranklinFlow" on CPUE in Franklin County is estimated in the quarter three regression. The reason for this is that freshwater inflow in Franklin County is only expected to affect CPUE in Franklin County. The same is true for the rest of the counties in the dataset. For this reason, this regression atypically does not include the "main effect," or the non-interacted flow variables, by design. Flow in a county is only expected to influence oyster stock in that county. The "main effects" of each county indicator are included as county fixed effects. The above data structure applies to the $y - 1$ flow terms as well; these are simply the flow value assigned to the quarter of interest in the previous year. This allows me to estimate the effect of flow in a particular quarter over the following eight quarters. This is based on the biology of the oyster life cycle and harvest age in the Florida Gulf. Oysters mature quickly and are typically harvested within two years of spawning; therefore "current" stock is expected to be influenced by flow over the past two years – the entirety of the typical oyster's lifespan. The data structure is admittedly somewhat confusing, so Figure 8 is included as an example of the data layout for Franklin County (hypothetical values). Note that 6.9 is the hypothetical value for 2004 quarter two, 4.6 is the value for 2004 quarter three, and 3.8 is the value for 2004 quarter four.

The reason the effects of freshwater inflow are estimated by county as opposed to uniformly across the panel is because freshwater inflow may affect oyster stock differently in different counties. Flow magnitude and the coastal geography of each

Figure 8: Dataset Construction Example



Year	Quarter	County	ln(Flow)	Q1FranklinFlow	Q2FranklinFlow	Q3FranklinFlow	Q4Franklin Flow
2005	1	Franklin	8.1	8.1	6.9	4.6	3.8
2005	2	Franklin	7.7	8.1	7.7	4.6	3.8
2005	3	Franklin	5	8.1	7.7	5	3.8
2005	4	Franklin	4.2	8.1	7.7	5	4.2
2006	1	Franklin	7.9	7.9	7.7	5	4.2
2006	2	Franklin	7.1	7.9	7.1	5	4.2
2006	3	Franklin	4.8	7.9	7.1	4.8	4.2
2006	4	Franklin	4.4	7.9	7.1	4.8	4.4

county are two possible reasons for a differential effect. For example, the summary statistics in Tables 1 and 2 indicate freshwater inflow in Franklin County is substantially greater in magnitude than in Bay County, on average. It is possible that the oysters in counties with low-magnitude flow respond differently to freshwater input than oysters in high-magnitude flow counties, perhaps through biological adaptation. As an example of geographic differences, most harvest in Franklin County occurs in Apalachicola Bay, which is fed by the Apalachicola River and bounded by barrier islands. Most harvest in Levy County occurs at the output of the Suwannee River, which essentially feeds directly to open water. Therefore, fresh water may dissipate more beyond the oyster habitats in Levy County than in Franklin County, causing freshwater input to affect stock differently in each county. As a further example, in Bay County there is a dam below the gage from which those flow data were obtained. Per Crowe, Huang, and Lewis (2008), “freshwater inflows to North Bay are dominated by discharge from the Deer Point Reservoir which in turn is primarily influenced by flow from Econfina Creek,” so the dam is not a concern from an endogeneity perspective. However, no other county has a dam located so near to its river’s output, so the dam represents a structural difference between Bay County and the remaining counties. The possibility that flow affects oysters differently by county is just that – a theory – but is based on knowledge about the counties in this dataset and the mechanisms through which freshwater influences oyster productivity. The remaining variables are not interacted with county indicators because these non-interacted variables are expected to affect stock similarly across counties.

The purpose of this regression is to estimate the effect of freshwater inflow on oyster stock, using CPUE as a proxy for stock. This serves two purposes: one, to establish the biological connection between fresh water and oyster abundance using economic measures, and two, to determine when during the year freshwater inflow is most important for oyster abundance. The results from this regression are used to guide the flow periods considered in the second regression in this thesis.

This regression is run once using each quarter's flow for both CPUE variables: harvest per trip and harvest per hour. This regression assumes that the fishery is not in perfect open access equilibrium. Therefore, if CPUE increases, it can be attributed to an increase in oyster abundance. In open access equilibrium, CPUE is expected to be constant over time. The fact that CPUE is not constant over time suggests that oyster harvest is not in perfect open access equilibrium. This means that harvesters likely do not respond perfectly to changes in oyster abundance, which is assumed in the next regression specification. In reality, no reaction from harvesters is also highly unlikely. Therefore, these two extreme assumptions serve to bound the estimates of the effect of freshwater inflow on oyster abundance because in reality harvester reaction to oyster abundance is likely somewhere between the two.

Regression 2

The second regression estimated in this thesis is based on the regression derived in Equation 16, but is adapted as follows to fit the structure of my data:

Regression 2

$$\begin{aligned}
Harvest_{yqc} = {} & \beta_1 Effort_{yqc} \cdot Bay_c + \beta_2 Effort_{yqc} \cdot Franklin_c + \beta_3 Effort_{yqc} \cdot Levy_c \\
& + \beta_4 Effort_{yqc} \cdot Wakulla_c + \beta_5 Effort_{yqc} \cdot BayFlow_{y,q-z} \cdot Bay_c \\
& + \beta_6 Effort_{y-1,q,c} \cdot BayFlow_{y-1,q-z} \cdot Bay_c + \beta_7 Effort_{yqc} \\
& \cdot FranklinFlow_{y,q-z} \cdot Franklin_c + \beta_8 Effort_{y-1,q,c} \cdot FranklinFlow_{y-1,q-z} \\
& \cdot Franklin_c + \beta_9 Effort_{yqc} \cdot LevyFlow_{y,q-z} \cdot Levy_c + \beta_{10} Effort_{y-1,q,c} \\
& \cdot LevyFlow_{y-1,q-z} \cdot Levy_c + \beta_{11} Effort_{yqc} \cdot WakullaFlow_{y,q-z} \cdot Wakulla_c \\
& + \beta_{12} Effort_{y-1,q,c} \cdot WakullaFlow_{y-1,q-z} \cdot Wakulla_c + \beta_{13} Effort_{yqc} \\
& \cdot Effort_{yqc} \cdot Bay_c + \beta_{14} Effort_{yqc} \cdot Effort_{yqc} \cdot Franklin_c + \beta_{15} Effort_{yqc} \\
& \cdot Effort_{yqc} \cdot Levy_c + \beta_{16} Effort_{yqc} \cdot Effort_{yqc} \cdot Wakulla_c + D_y + D_q + D_c \\
& + \mu_{yqc}
\end{aligned}$$

Where $\boldsymbol{Harvest_{yqc}}$ is pounds harvested (in-shell) in year y, quarter q, county c. $\boldsymbol{Effort_{yqc}}$ is the effort variable of interest – either trips or hours fished – in harvest year y, quarter q, county c. $\boldsymbol{Effort_{yqc} \cdot Effort_{yqc}}$ is the squared effort variable of interest in harvest year y, quarter q, county c. Like Regression 1, Regression 2 is estimated a total of eight times, once for both effort variables for each quarter flow. The “flow” variables and interaction terms are identical to those in Regression 1, except in this case are *not* natural logarithms. That is, $\boldsymbol{BayFlow_{y,q-z}}$ is freshwater inflow in Bay County, $\boldsymbol{FranklinFlow_{y,q-z}}$ is freshwater inflow in Franklin County, $\boldsymbol{LevyFlow_{y,q-z}}$ is freshwater inflow in Levy County, and $\boldsymbol{WakullaFlow_{y,q-z}}$ is freshwater inflow in Wakulla County, all assigned to harvest year y, quarter $q-z$. $\boldsymbol{Bay_c}$, $\boldsymbol{Franklin_c}$, $\boldsymbol{Levy_c}$, and $\boldsymbol{Wakulla_c}$ are indicator variables equal to one when the observed county is

Bay, Franklin, Levy, or Wakulla, respectively, and equal to zero otherwise. Flow values are assigned by the same method detailed for Regression 1, hence the same $q-z$ notation. $\boldsymbol{D_y}$, $\boldsymbol{D_q}$, and $\boldsymbol{D_c}$ are harvest year, quarter, and county fixed effects, respectively. $\mu_{\boldsymbol{yqc}}$ is an independent and identically distributed error term. Note that this regression does not include a constant term as dictated by the derivation in Equation 16.

The purpose of this regression is to estimate the economic value of freshwater inflow as an economic input to oyster fishery production. This regression is an adjusted form of Equation 16. Equation 16 is based on the derivation shown by Barbier and Strand (1998), although I have altered their derivation to model fresh water as a "facultative" habitat instead of an "essential" habitat (Foley et al., 2012). This alteration yields the non-squared "effort" variable. The resulting coefficients from this regression are used in Equation 17 and 17a to solve for the additional oyster harvest and harvest revenue, respectively, yielded by a marginal unit of freshwater inflow by county. The adjustments made to Equation 16 in Regression 2 mean the coefficients in Equation 17 and 17a are not accurate for Regression 2. For Regression 2, the squared effort terms - β_{13} - β_{16} – is used as the β_3 term in Equation 17 and 17a. β_2 is the coefficient on the flow variables in Regression 2: β_5 - β_{12}. Equation 17 and 17a are estimated separately for each flow coefficient in each iteration of Regression 2. Each variable is interacted with the county in question because the terms in Equations 15 and 15a are county-specific. This structure implies that only the errors are assumed to be consistent across counties. This allows me to estimate effect of flow in each quarter in each county on harvest and revenue for both effort metrics. For example, in the interaction using quarter three flow and trips as the effort metric, the value of current and previous year quarter three flow in Franklin County is estimated separately from each other county. The same is true for all counties. Again, the reason for this unorthodox format is to estimate the effect of flow in a particular quarter over the subsequent non-calendar year.

This regression is derived from the Gordon-Schaefer model; therefore this regression is structural in nature. This entails two relevant assumptions for this regression. First, that the zero-profit condition holds in the long run. That is, total revenue equals total cost. This condition is important because it allows me to solve for per unit of harvest effort cost, a necessary variable for Equation 17 and 17a. The second assumption is that – from an economic perspective – harvesters adjust their effort perfectly to changes in stock. That is, harvesters always enter the market when economic rent exists, to the point that the economic rent from fishing is eliminated due to harvest occurring exactly to the point that average cost equals average revenue. This assumption is the opposite of that in Regression 1, where it is assumed that harvesters do not respond "perfectly" to changes in stock. The assumptions about harvester behavior and the zero-profit per unit cost that can be calculated are based on oyster harvest being open access, as detailed in Chapter Two. In reality, it is likely that harvesters respond to stock to an extent, but perhaps not "perfectly." Therefore, the assumptions about harvest effort made in Regression 1 and Regression 2 serve as extreme bounds for actual harvester behavior and the presence of open access equilibrium.

Based on the biology of oysters and the legal harvest seasons, quarter three harvest is not included in either regression. The reason for this is twofold. From a regulatory perspective, not every county allowed summer harvest in the data period. Second, when summer harvest was allowed, harvest levels were lower than in the other quarters. Therefore, quarter three harvest is excluded because it may be fundamentally different than harvest during the “winter season,” which is of primary interest.

An additional consideration is standard errors. The results presented in Chapter Seven include heteroskedasticity-robust standard errors. However, Stock and Watson (2008) show that heteroskedasticity-robust standard errors are inconsistent in a fixed effects model. Ideally, I would cluster the standard errors by county; however, since there are only four counties (clusters), this approach could lead to over rejection of the null hypotheses on the regression coefficients. To account for these issues, I include the p-values generated using the wild cluster bootstrap in Appendix A (Cameron & Miller, 2008; Roodman et al., 2019). I provide more detail on the bootstrapping method in Appendix A. The reason I include both the robust standard errors and the bootstrapped p-values is because while the robust standard errors may be inconsistent, the bootstrapped p-values are highly – perhaps overly – conservative. Therefore, I present both as an upper and lower bound on the true significance of the regression coefficients.

As a final note, consider that the estimated value yielded from the results of Regression 2 assumes infinitely elastic demand for oysters. That is, “price is unaffected by harvest levels” (Barbier and Strand, 2002). Barbier and Strand find that the value of habitat is greater when demand is inelastic than when demand is elastic. Oyster demand elasticity is unknown, but it is likely less than infinitely elastic. Therefore, the estimated value of fresh water from this regression can be thought of as a conservative estimate.

The results of Regression 1 and 2 are presented in Chapter Seven.

CHAPTER SEVEN

EMPIRICAL RESULTS

Regression 1 Results

The results for Regression 1 are now presented. To reiterate, this regression is estimated a total of 8 times. That is, one time using both of the two CPUE metrics for each of the four quarter flow measurements. The following tables are organized by flow quarter. Table 5 shows the relationship between quarter one flow and CPUE. The statistically significant coefficients are generally negative. This suggests that an increase in freshwater inflow is associated with a reduction in oyster stock. However, many of the coefficients are positive (although not significant) and precipitation is positive and significant. This implies that there is not a clear relationship between quarter one flow and stock.

The results for quarter two flow are displayed in Table 6. As in with quarter one flow, there is not a consistent relationship between quarter two flow and CPUE. Although the statistically significant coefficients are generally positive, there is once again contradictory signs. The effect of temperature and weather is similarly minimal, consistent with Table 5.

Table 7 shows the results for quarter three flow. The results in Table 7 indicate a positive, statistically significant relationship between freshwater inflow and stock that is consistent across CPUE measures and county. The results weaken with the HpH regression, but in general there appears to be a strong relationship between stock in a

Table 5: Impact of Quarter One Flow on Oyster Stock, 1988-2017

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q1 Bay Flow) (same year)	0.2056	0.2095
	(0.2743)	(0.3576)
Bay*ln(Q1 Bay Flow) (previous year)	0.3326	-0.1660
	(0.2098)	(0.2838)
Franklin*ln(Q1 Franklin Flow) (same year)	0.0526	0.0624
	(0.0782)	(0.0945)
Franklin*ln(Q1 Franklin Flow) (previous year)	-0.0683	-0.2383**
	(0.0962)	(0.1038)
Levy*ln(Q1 Levy Flow) (same year)	-0.0791	-0.0397
	(0.0591)	(0.0600)
Levy*ln(Q1 Levy Flow) (previous year)	0.1101	0.0138
	(0.0699)	(0.0652)
Wakulla*ln(Q1 Wakulla Flow) (same year)	0.1245	-0.0110
	(0.0825)	(0.0952)
Wakulla*ln(Q1 Wakulla Flow) (previous year)	-0.0344	-0.2032**
	(0.0855)	(0.0995)
Q1 Total Precipitation (inches) (same year)	-0.0041	0.0030
	(0.0043)	(0.0060)
Q1 Total Precipitation (inches) (previous year)	0.0007	0.0112**
	(0.0040)	(0.0049)
Q1 Average Temperature (F) (same year)	0.0010	-0.0076
	(0.0131)	(0.0137)
Q1 Average Temperature (F) (previous year)	-0.0106	-0.0154
	(0.0122)	(0.0134)
ln(Previous Season Avg. HpH)	0.3396***	0.6277***
	(0.0638)	(0.0697)
Obs.	323	323
R-squared	0.7524	0.5890

Robust standard errors in parenthesis

*** p<0.01, ** p<0.05, * p<0.1

Table 6: Impact of Quarter Two Flow on Oyster Stock, 1988-2017

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q2 Bay Flow) (same year)	0.3349*	0.5008**
	(0.1877)	(0.2336)
Bay*ln(Q2 Bay Flow) (previous year)	0.2879**	-0.2974
	(0.1380)	(0.2402)
Franklin*ln(Q2 Franklin Flow) (same year)	0.0248	0.0686
	(0.0654)	(0.0820)
Franklin*ln(Q2 Franklin Flow) (previous year)	-0.0297	-0.0395
	(0.0638)	(0.0797)
Levy*ln(Q2 Levy Flow) (same year)	0.0434	0.0533
	(0.0559)	(0.0570)
Levy*ln(Q2 Levy Flow) (previous year)	0.0950	0.1208**
	(0.0581)	(0.0545)
Wakulla*ln(Q2 Wakulla Flow) (same year)	0.0938	-0.0629
	(0.0794)	(0.0716)
Wakulla*ln(Q2 Wakulla Flow) (previous year)	-0.1180*	-0.0800
	(0.0671)	(0.0737)
Q2 Total Precipitation (inches) (same year)	-0.0095*	-0.0005
	(0.0054)	(0.0052)
Q2 Total Precipitation (inches) (previous year)	-0.0003	0.0070
	(0.0045)	(0.0053)
Q2 Average Temperature (F) (same year)	-0.0037	-0.0206
	(0.0150)	(0.0184)
Q2 Average Temperature (F) (previous year)	-0.0014	-0.0173
	(0.0166)	(0.0203)
ln(Previous Season Avg. HpH)	0.3417***	0.6330***
	(0.0608)	(0.0694)
Obs.	323	323
R-squared	0.7576	0.5951

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Table 7: Impact of Quarter Three Flow on Oyster Stock, 1988-2017

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q3 Bay Flow) (same year)	0.5538***	1.1368***
	(0.2081)	(0.2395)
Bay*ln(Q3 Bay Flow) (previous year)	0.8488***	0.2577
	(0.2234)	(0.2739)
Franklin*ln(Q3 Franklin Flow) (same year)	0.0884	0.1586
	(0.0929)	(0.0983)
Franklin*ln(Q3 Franklin Flow) (previous year)	0.2731***	0.0869
	(0.0939)	(0.0966)
Levy*ln(Q3 Levy Flow) (same year)	0.1057	0.1451
	(0.0877)	(0.0979)
Levy*ln(Q3 Levy Flow) (previous year)	0.3463***	0.1627*
	(0.1009)	(0.0969)
Wakulla*ln(Q3 Wakulla Flow) (same year)	0.0933	0.0373
	(0.0815)	(0.0826)
Wakulla*ln(Q3 Wakulla Flow) (previous year)	0.2746***	-0.0481
	(0.0938)	(0.0782)
Q3 Total Precipitation (inches) (same year)	0.0134***	0.0202***
	(0.0032)	(0.0040)
Q3 Total Precipitation (inches) (previous year)	0.0005	0.0005
	(0.0032)	(0.0039)
Q3 Average Temperature (F) (same year)	0.1309***	0.1361**
	(0.0426)	(0.0527)
Q3 Average Temperature (F) (previous year)	0.0728*	-0.0604
	(0.0422)	(0.0462)
ln(Previous Season Avg. HpH)	0.3063***	0.5823***
	(0.0753)	(0.0859)
Obs.	323	323
R-squared	0.7948	0.6561

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

period and flow in quarter three in the year prior. This relationship is supported by the positive, significant effect of precipitation, another source of freshwater input. The effect of temperature is also positive and significant. This is somewhat surprising because the dermo bacteria is common when temperature is high during the summer. On the other hand, Lorio and Malone (1994) suggest that higher temperatures increase oyster growth, so this result is not entirely unexpected.

Finally, the results for quarter four flow are presented in Table 8. These results are interesting because while the significant coefficients are generally positive, there are also a number of negative (insignificant) coefficients. The results imply that an increase in same year flow has a positive effect on stock while previous year flow decreases stock levels. This is somewhat contradictory to the results for quarter three flow, which indicate previous year freshwater inflow positively affects oyster stock. Despite this, it does appear that quarter four flow has a reasonably strong relationship with oyster stock.

Overall, the results for quarter three and four flow are most consistent across counties and effort variables. Based on the biology of oysters and flow patterns throughout the year, this is not particularly surprising. That is, flow variation in quarters in which the absolute magnitude of flow is low appears to have the greatest effect on stock. The results for quarter one and two flow are less consistent, both in sign and across CPUE metrics. Due to this, it is expected that quarter three and four flow are most relevant in Regression 2.

These results are strengthened by those in Appendix A and B. Tables 5a-8a show that the wild cluster bootstrapped p-values diminish the statistical significance of the

Table 8: Impact of Quarter Four Flow on Oyster Stock, 1988-2017

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q4 Bay Flow) (same year)	0.4226	1.0615***
	(0.2834)	(0.3495)
Bay*ln(Q4 Bay Flow) (previous year)	0.3025	-0.1382
	(0.2288)	(0.2887)
Franklin*ln(Q4 Franklin Flow) (same year)	0.1131	0.2544***
	(0.0760)	(0.0941)
Franklin*ln(Q4 Franklin Flow) (previous year)	-0.0043	-0.1199
	(0.0758)	(0.0886)
Levy*ln(Q4 Levy Flow) (same year)	0.1533*	0.2662***
	(0.0818)	(0.0876)
Levy*ln(Q4 Levy Flow) (previous year)	0.0509	0.0374
	(0.0871)	(0.0962)
Wakulla*ln(Q4 Wakulla Flow) (same year)	0.1103	0.1398*
	(0.0733)	(0.0733)
Wakulla*ln(Q4 Wakulla Flow) (previous year)	-0.0153	-0.1004
	(0.0792)	(0.0846)
Q4 Total Precipitation (inches) (same year)	-0.0044	-0.0045
	(0.0083)	(0.0091)
Q4 Total Precipitation (inches) (previous year)	-0.0179**	-0.0077
	(0.0076)	(0.0074)
Q4 Average Temperature (F) (same year)	-0.0424	-0.0850**
	(0.0392)	(0.0378)
Q4 Average Temperature (F) (previous year)	0.0937***	0.1094**
	(0.0358)	(0.0470)
ln(Previous Season Avg. HpH)	0.3735***	0.6505***
	(0.0770)	(0.0882)
Obs.	323	323
R-squared	0.7605	0.6310

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

coefficients in each regression, as expected. This is especially noticeable for quarter one, two, and four flow, shown in Table 5a, 6a, and 8a, respectively. Almost all statistical significance is eliminated from the county flow variables in these regressions. At the same time, Table 7a shows that the coefficients in the quarter three flow HpT and HpH regressions largely maintain statistical significance, albeit at lower levels than in Table 7. The subsample results in Tables 5b-8b are similar to those in Appendix A in that quarter three flow maintains statistical significance. Interestingly, the sign on the coefficients for quarter one flow flip in subsample results compared to the full data period. This furthers the uncertainty surrounding the effect of flow in quarter one. The fact that quarter three flow remains significant under these robustness-checks strengthens the argument that quarter three flow is the primary driver of oyster productivity. The impact of quarter four flow is weakened by these robustness checks.

Although the derived Equations 17 and 17a using Regression 2 coefficients are the preferred method of estimating the value of freshwater input, I also estimate the value of changes in stock due to freshwater inflow using the results of Regression 1. These results are presented in Appendix C. Because quarter three flow has been shown to have the greatest impact on stock, only the value of quarter three flow is estimated. Briefly, these results indicate that on average a one percent change in quarter three freshwater inflow is worth between -$11.94 and $13,154.65 over a two-year period, depending on the county and effort variable. This large range is likely due to the variation in flow magnitude between counties. In Franklin County, a one percent – about 4.69 cms – change in average quarter three inflow is worth between $8,933.46 and $13,154.65 using hours and trips as the effort metric, respectively. This means that one cms of freshwater inflow is worth between $1,904.78 and $2,804.83 over a two-year period.

Regression 2 Results

The most relevant coefficients in the Regression 2 results are the flow coefficients. That said, the squared effort coefficients are relevant as well because they are included in Equations 17 and 17a, which are used to estimate the value of freshwater inflow. The squared effort terms are also important because of what they suggest about the impact of effort. The derived value equations rely on the assumption that the single effort coefficient will be positive, while the squared effort term is negative. That is, that increased effort increases harvest at a decreasing rate. This is a logical assumption because it is unlikely that additional harvest can be yielded infinitely from additional effort. Therefore, if the squared term is not negative for a particular county, a value is not estimated for freshwater inflow in that county.

Table 9 shows that the results for quarter one flow in Regression 2 imply there is little relationship between quarter one flow and harvest. There is some evidence of a negative relationship between quarter one flow and harvest, which is logical considering the high flow magnitude in quarter one. However, the results are not consistent across effort metrics. Of particular note in Table 9 is the positive coefficients on the squared effort terms for Levy and Wakulla counties. The assumption about the sign of the effort squared coefficient is essential for inference from Equation 17 and 17a. This unexpected signage persists across the Regression 2 results. Therefore, I do not estimate the value of freshwater inflow in Levy and Wakulla Counties because the fisheries do not respond as

Table 9: Impact of Quarter One Flow on Oyster Harvest, 1988-2017

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	684.6900	189.7170*
	(624.7543)	(105.0911)
Bay*Effort*Effort	-0.6418***	-0.0093***
	(0.2375)	(0.0023)
Franklin*Effort	717.3064***	138.4220***
	(126.1963)	(13.1431)
Franklin*Effort*Effort	-0.0125**	-0.0005***
	(0.0056)	(0.0001)
Levy*Effort	409.7586	51.5678
	(399.1645)	(51.6513)
Levy*Effort*Effort	0.0986	0.0066
	(0.1811)	(0.0046)
Wakulla*Effort	-1570.4113	-2.9173
	(1429.6989)	(65.8537)
Wakulla*Effort*Effort	3.7838	0.0100
	(2.8908)	(0.0112)
Bay*Q1 Bay Flow*Effort (same year)	32.1727	0.3907
	(28.2863)	(4.4789)
Bay*Q1 Bay Flow*Effort (previous year)	19.2630	-1.4979
	(23.7777)	(2.0499)
Franklin*Q1 Franklin Flow*Effort (same year)	-0.0322	-0.0101*
	(0.0429)	(0.0055)
Franklin*Q1 Franklin Flow*Effort (previous year)	-0.0039	-0.0075**
	(0.0283)	(0.0038)
Levy*Q1 Levy Flow*Effort (same year)	0.3700	-0.0119
	(0.4977)	(0.0468)
Levy*Q1 Levy Flow*Effort (previous year)	0.3081	-0.0227
	(0.4168)	(0.0453)
Wakulla*Q1 Wakulla Flow*Effort (same year)	8.3571**	-0.2387
	(3.3499)	(0.2558)
Wakulla*Q1 Wakulla Flow*Effort (previous year)	4.6424	0.1787
	(3.7028)	(0.3737)
Obs.	342	342
R-squared	0.9305	0.9535

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Impact of Quarter Two Flow on Oyster Harvest, 1988-2017

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	641.0121	330.2602***
	(772.5635)	(83.1381)
Bay*Effort*Effort	-0.5629**	-0.0087***
	(0.2184)	(0.0018)
Franklin*Effort	728.9651***	127.9944***
	(126.4628)	(10.4612)
Franklin*Effort*Effort	-0.0130**	-0.0004***
	(0.0057)	(0.0000)
Levy*Effort	317.2312	20.4136
	(403.6553)	(60.7474)
Levy*Effort*Effort	0.0956	0.0063
	(0.1817)	(0.0048)
Wakulla*Effort	-1040.4292	-87.6299
	(1437.7374)	(81.3260)
Wakulla*Effort*Effort	3.6895	0.0131
	(2.8136)	(0.0152)
Bay*Q2 Bay Flow*Effort (same year)	26.5142	-7.6491**
	(28.8152)	(3.6130)
Bay*Q2 Bay Flow*Effort (previous year)	24.6427	-2.2495
	(22.8072)	(1.6060)
Franklin*Q2 Franklin Flow*Effort (same year)	-0.0894*	-0.0087
	(0.0473)	(0.0067)
Franklin*Q2 Franklin Flow*Effort (previous year)	0.0118	-0.0074
	(0.0457)	(0.0063)
Levy*Q2 Levy Flow*Effort (same year)	0.7092*	0.0744
	(0.3917)	(0.0592)
Levy*Q2 Levy Flow*Effort (previous year)	0.4308	0.0146
	(0.4349)	(0.0541)
Wakulla*Q2 Wakulla Flow*Effort (same year)	12.0569	-0.0015
	(7.9269)	(0.6914)
Wakulla*Q2 Wakulla Flow*Effort (previous year)	1.0657	1.0870**
	(4.3879)	(0.5369)
Obs.	342	342
R-squared	0.9325	0.9531

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

expected to effort, suggesting the valuation approach is not appropriate for these fisheries. With this in mind, the results for Bay and Franklin counties are most relevant moving forward.

Results for Regression 2 using quarter two flow are presented in Table 10. Once again there is a noteworthy difference in sign between the coefficients in the trips and hours regressions. This implies the relationship between quarter two flow and harvest is not strong because it is expected that trips and hours fished are highly correlated. This is furthered by the fact that the results in Table 10 are generally not statistically significant. These results reinforce those from Regression 1 in that there appears to be little relationship between freshwater inflow in quarter two and oyster harvest. This is supported by the robustness checks.

The results for quarter three flow are shown in Table 11. These results are notably different from Table 9 and 10. The previous year flow coefficients are consistently positive and statistically significant across counties. The coefficients are also more consistently signed across the effort metrics than those for quarter one and two flow. In general, previous year flow has a significant positive effect on harvest, while current year flow has a negative but less significant effect on harvest. The reason for these contradictory signs is unknown, but this phenomenon is consistent with Wilber’s (1992) finding that “sustained high flows [are] detrimental to the same year’s harvestable oyster population.” The effect of previous year quarter three flow appears to be strongest in Franklin County. As a final note, the effort squared variable in the trips regression in Table 11 is not significant. However, it is signed as expected (negative), and a Wald Test indicates that the squared effort and previous year flow terms for Franklin County are

Table 11: Impact of Quarter Three Flow on Oyster Harvest, 1988-2017

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	590.8605	131.6970*
	(727.8337)	(72.3878)
Bay*Effort*Effort	-0.5476***	-0.0098***
	(0.1809)	(0.0022)
Franklin*Effort	529.8896***	110.8683***
	(101.1707)	(9.1238)
Franklin*Effort*Effort	-0.0058	-0.0004***
	(0.0050)	(0.0000)
Levy*Effort	-67.1288	-27.9361
	(366.9861)	(56.7032)
Levy*Effort*Effort	0.0974	0.0071
	(0.1744)	(0.0047)
Wakulla*Effort	-1477.8492	50.6391
	(1637.7433)	(92.1922)
Wakulla*Effort*Effort	3.7176	-0.0031
	(3.0061)	(0.0094)
Bay*Q3 Bay Flow*Effort (same year)	5.0406	-0.2749
	(24.7678)	(2.6262)
Bay*Q3 Bay Flow*Effort (previous year)	49.0885**	3.3486
	(20.3705)	(2.1022)
Franklin*Q3 Franklin Flow*Effort (same year)	-0.0117	-0.0066
	(0.0599)	(0.0085)
Franklin*Q3 Franklin Flow*Effort (previous year)	0.2496***	0.0193***
	(0.0497)	(0.0060)
Levy*Q3 Levy Flow*Effort (same year)	1.3374*	0.1515
	(0.7085)	(0.1017)
Levy*Q3 Levy Flow*Effort (previous year)	1.7090***	0.1660
	(0.6447)	(0.1023)
Wakulla*Q3 Wakulla Flow*Effort (same year)	5.0704	-0.7694
	(8.9855)	(0.7082)
Wakulla*Q3 Wakulla Flow*Effort (previous year)	22.3617***	0.5395
	(7.5409)	(0.5557)
Obs.	342	342
R-squared	0.9391	0.9541

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

jointly significant for both the trips and hours regressions.[24]

Finally, results for Regression 2 with quarter four flow are presented in Table 12. The significant coefficients indicate a negative relationship between flow and harvest. This contradicts the results for quarter four flow from Regression 1 (Table 8). This suggests that there is not a clear relationship between quarter four flow and oyster productivity, especially considering the squared effort and flow coefficients from this regression are generally not statistically significant.

The results from Regression 1 and 2 suggest freshwater inflow is most influential on oyster stock and harvest in quarter three. Not only are the results for quarter three flow consistent across effort variables, but also are consistent between the two regressions. There are certainly significant results on flow in other quarters, but they are less consistent than those in quarter three. Therefore, only the value of freshwater in quarter three is calculated because it appears to have the greatest impact on productivity. Because the effort squared variables for Levy and Wakulla counties are not signed as expected, the value of freshwater is only estimated for Bay and Franklin counties. The effort squared term for trips in Table 11 is not significant, but it is the expected sign (negative) and is jointly significant with previous year flow. Therefore, it is appropriate for use Equations 17 and 17a.

Once again, these results are supported by the wild cluster bootstrap results in Appendix A and the subsample results in Appendix B, particularly for Franklin County.

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[24] The squared effort term and previous year flow term for Franklin County are jointly significant at the 0.01 level for both the trips and hours regression. The Franklin County squared effort term and current year flow are jointly significant in the hours regression, but not the trips regression. Both same and previous year Bay County flow coefficients (in each regression) are jointly significant with the Bay County squared effort term at the 0.01 level.

Table 12: Impact of Quarter Four Flow on Oyster Harvest, 1988-2017

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	3195.5776***	148.3176
	(999.2952)	(91.0041)
Bay*Effort*Effort	-0.6198***	-0.0091***
	(0.2094)	(0.0022)
Franklin*Effort	671.2654***	127.7944***
	(130.6144)	(11.1868)
Franklin*Effort*Effort	-0.0099	-0.0005***
	(0.0062)	(0.0001)
Levy*Effort	787.4071*	36.2604
	(446.5742)	(60.1305)
Levy*Effort*Effort	0.0459	0.0070
	(0.1993)	(0.0048)
Wakulla*Effort	-27.5962	-3.4456
	(1665.7637)	(75.1483)
Wakulla*Effort*Effort	3.2696	0.0042
	(3.1987)	(0.0089)
Bay*Q4 Bay Flow*Effort (same year)	-66.7497*	3.2295
	(35.9764)	(3.9425)
Bay*Q4 Bay Flow*Effort (previous year)	-44.3279	-1.4455
	(30.6604)	(3.8367)
Franklin*Q4 Franklin Flow*Effort (same year)	-0.0060	-0.0011
	(0.0448)	(0.0065)
Franklin*Q4 Franklin Flow*Effort (previous year)	-0.0097	-0.0135**
	(0.0435)	(0.0059)
Levy*Q4 Levy Flow*Effort (same year)	0.1555	0.1313
	(1.0420)	(0.1299)
Levy*Q4 Levy Flow*Effort (previous year)	-0.5655	-0.0831
	(0.6170)	(0.0886)
Wakulla*Q4 Wakulla Flow*Effort (same year)	4.3833	0.9020
	(9.2924)	(0.8395)
Wakulla*Q4 Wakulla Flow*Effort (previous year)	-2.4351	-0.4884
	(7.2114)	(0.5200)
Obs.	342	342
R-squared	0.9297	0.9527

Robust standard errors in parenthesis

*** p<0.01, ** p<0.05, * p<0.1

Table 11a shows that previous year quarter three Franklin County flow remains significant with bootstrapped p-values in the trips regression and is quite close to being significant in the hours regression (p=0.1083). The results in Appendix B indicate that the flow coefficients for quarter three maintain significance using the subsample of data as well. The remaining quarter flow regressions maintain some significant coefficients for both the trips and hours regressions, but sign inconsistencies remain furthering the argument that there is no clear relationship between flow in these quarters and oyster harvest. Combined with the results from Regression 1, quarter three flow appears to have the greatest influence on oyster productivity.

Tables 13-16 show the yearly estimated harvest and revenue yielded by a marginal unit of fresh water by county, calculated by applying the coefficients from the trips and hours regressions in Table 11 to Equation 17 and 17a. Again, values are only estimated for Bay and Franklin counties due to the results for the squared effort terms in Regression 2. The yearly harvest and dockside oyster price included in these tables are based on a “harvest year” beginning in quarter three and ending in quarter two the following calendar year, although quarter three harvest is excluded. Quarter three harvest is excluded because data from those quarters are not included in estimations of Regressions 1 and 2. Therefore, the values estimated in Tables 13-16 are conservative estimates because they do not account for all harvest in a year.

Tables 13-16 yield a number of interesting insights about the oyster fisheries and the value of fresh water. First, the estimated cost per unit of effort is shown in each table. This is calculated by equating total revenue with total cost (effort multiplied by the per

Table 13: Value Estimates, 1988-2017 – Bay County, Q3 Flow, Trips. Additional pounds and revenue from a marginal cms of water.

Year	Pounds Harvested	Trips	Price per Pound	Cost per Trip	Marginal Pounds (same year)	Marginal Pounds (prev. year)#	Marginal Value (same year)	Marginal Value (prev. year)#	Two Year Sum (pounds)	Two Year Sum (value)
1988	452,253	1,478	0.58	23.18	369.82	3,601.54	213.41	2,078.35	3,971.36	2,291.77
1989	333,296	842	0.67	34.76	478.41	4,659.07	319.96	3,115.99	5,137.48	3,435.95
1990	1,630,739	3,334	0.74	47.31	591.16	5,757.05	435.50	4,241.15	6,348.20	4,676.64
1991	2,112,070	4,354	0.46	29.04	586.28	5,709.54	267.27	2,602.87	6,295.81	2,870.14
1992	2,462,021	3,364	0.28	27.04	884.54	8,614.24	248.92	2,424.09	9,498.78	2,673.01
1993	3,486,032	4,343	0.23	24.14	970.12	9,447.63	222.23	2,164.23	10,417.74	2,386.46
1994	1,610,689	2,238	0.24	22.30	869.83	8,470.96	205.30	1,999.32	9,340.79	2,204.62
1995	1,952,419	2,428	0.23	24.68	971.87	9,464.67	227.21	2,212.74	10,436.54	2,439.95
1996	2,206,623	2,876	0.25	25.37	927.31	9,030.68	233.50	2,273.94	9,957.98	2,507.44
1997	504,420	710	0.29	26.62	858.65	8,362.09	245.01	2,386.03	9,220.74	2,631.03
1998	16,994	34	0.45	29.62	604.07	5,882.82	272.60	2,654.78	6,486.89	2,927.38
1999	1,606	9	0.38	8.92	215.68	2,100.39	82.09	799.42	2,316.06	881.50
2000	1,050	5	0.39	10.66	253.71	2,470.79	98.10	955.38	2,724.49	1,053.48
2001	200	1	0.42	10.90	241.63	2,353.13	100.36	977.37	2,594.76	1,077.73
2002	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	1,064,915	1,550	0.32	29.22	830.36	8,086.57	268.95	2,619.16	8,916.93	2,888.10
2004	1,477	3	0.41	26.55	595.01	5,794.58	244.35	2,379.65	6,389.59	2,624.00
2005	48,922	93	0.38	26.45	635.78	6,191.64	243.49	2,371.28	6,827.42	2,614.77
2006	65,830	88	0.37	36.69	904.12	8,804.85	337.73	3,289.03	9,708.96	3,626.76
2007	73,525	137	0.34	24.08	648.63	6,316.78	221.62	2,158.29	6,965.41	2,379.92
2008	31,017	57	0.38	26.81	657.67	6,404.85	246.80	2,403.49	7,062.52	2,650.29
2009	123,504	217	0.39	29.33	687.87	6,698.88	269.99	2,629.32	7,386.75	2,899.31
2010	189,165	261	0.45	42.83	875.96	8,530.63	394.28	3,839.79	9,406.59	4,234.08
2011	538,136	871	0.48	38.64	746.72	7,272.01	355.72	3,464.22	8,018.73	3,819.94
2012	249,481	785	0.61	25.44	384.11	3,740.67	234.16	2,280.38	4,124.77	2,514.53
2013	65,443	284	1.02	30.73	278.50	2,712.23	282.87	2,754.74	2,990.73	3,037.61
2014	569,550	1,509	0.82	40.52	456.17	4,442.47	372.97	3,632.24	4,898.63	4,005.21
2015	747,139	2,206	0.77	34.06	409.34	3,986.36	313.56	3,053.62	4,395.70	3,367.18
2016	150,106	639	0.98	30.34	283.91	2,764.90	279.27	2,719.74	3,048.81	2,999.01
*2017	69,706	227	0.96	38.64	371.13	3,614.32	355.66	3,463.68	3,985.46	3,819.34
Avg.	715,804	1,204	0.49	28.44	606.49	5,906.42	261.82	2,549.80	6,512.91	2,811.62

*Preliminary data included; flow coefficient + $p<0.1$, # $p<0.5$, ^ $p<0.01$

Table 14: Value Estimates, 1988-2017 – Bay County, Q3 Flow, Hours. Additional pounds and revenue from a marginal cms of water.

Year	Pounds Harvested	Hours	Price per Pound	Cost per Hour	Marginal Pounds (same year)#	Marginal Pounds (prev. year)	Marginal Value (same year)#	Marginal Value (prev. year)	Two Year Sum (pounds)	Two Year Sum (value)
1988	452,253	4,501	0.58	7.61	-1,126.99	13,728.06	-650.36	7,922.10	12,601.07	7,271.74
1989	333,296	2,284	0.67	12.81	-1,457.91	17,759.06	-975.05	11,877.28	16,301.15	10,902.23
1990	1,630,739	16,744	0.74	9.42	-1,801.49	21,944.25	-1,327.14	16,166.06	20,142.76	14,838.92
1991	2,112,070	21,660	0.46	5.84	-1,786.62	21,763.15	-814.49	9,921.40	19,976.53	9,106.91
1992	2,462,021	18,753	0.28	4.85	-2,695.56	32,835.05	-758.55	9,239.96	30,139.49	8,481.42
1993	3,486,032	28,208	0.23	3.72	-2,956.34	36,011.69	-677.23	8,249.42	33,055.35	7,572.19
1994	1,610,689	15,457	0.24	3.23	-2,650.73	32,288.93	-625.63	7,620.85	29,638.20	6,995.23
1995	1,952,419	17,006	0.23	3.52	-2,961.68	36,076.66	-692.41	8,434.32	33,114.98	7,741.92
1996	2,206,623	19,980	0.25	3.65	-2,825.87	34,422.39	-711.56	8,667.63	31,596.52	7,956.07
1997	504,420	4,406	0.29	4.29	-2,616.66	31,873.94	-746.63	9,094.87	29,257.28	8,348.23
1998	16,994	272	0.45	3.70	-1,840.85	22,423.66	-830.73	10,119.26	20,582.81	9,288.53
1999	1,606	48	0.38	1.67	-657.25	8,006.08	-250.15	3,047.15	7,348.83	2,797.00
2000	1,050	46	0.39	1.16	-773.16	9,417.94	-298.96	3,641.62	8,644.78	3,342.67
2001	200	5	0.42	2.18	-736.34	8,969.46	-305.84	3,725.44	8,233.12	3,419.61
2002	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	1,064,915	21,307	0.32	2.13	-2,530.44	30,823.72	-819.58	9,983.49	28,293.28	9,163.90
2004	1,477	30	0.41	2.65	-1,813.24	22,087.30	-744.64	9,070.56	20,274.07	8,325.92
2005	48,922	450	0.38	5.47	-1,937.48	23,600.78	-742.02	9,038.66	21,663.30	8,296.64
2006	65,830	540	0.37	5.98	-2,755.21	33,561.59	-1,029.20	12,536.84	30,806.38	11,507.64
2007	73,525	671	0.34	4.92	-1,976.64	24,077.77	-675.37	8,226.81	22,101.13	7,551.44
2008	31,017	287	0.38	5.32	-2,004.20	24,413.46	-752.10	9,161.42	22,409.26	8,409.32
2009	123,504	1,059	0.39	6.01	-2,096.21	25,534.25	-822.77	10,022.23	23,438.04	9,199.47
2010	189,165	1,518	0.45	7.36	-2,669.40	32,516.37	-1,201.55	14,636.20	29,846.97	13,434.66
2011	538,136	4,797	0.48	7.02	-2,275.55	27,718.87	-1,084.02	13,204.63	25,443.32	12,120.61
2012	249,481	4,499	0.61	4.44	-1,170.53	14,258.38	-713.57	8,692.15	13,087.85	7,978.58
2013	65,443	890	1.02	9.81	-848.71	10,338.25	-862.01	10,500.29	9,489.54	9,638.28
2014	569,550	14,389	0.82	4.25	-1,390.13	16,933.43	-1,136.60	13,845.06	15,543.30	12,708.46
2015	747,139	27,914	0.77	2.69	-1,247.41	15,194.89	-955.54	11,639.54	13,947.48	10,684.00
2016	150,106	2,950	0.98	6.57	-865.19	10,539.01	-851.06	10,366.88	9,673.82	9,515.82
*2017	69,706	379	0.96	23.14	-1,130.99	13,776.78	-1,083.85	13,202.57	12,645.79	12,118.72
Avg	715,804	7,967	0.49	5.70	-1,848.23	22,513.63	-797.88	9,719.13	20,665.40	8,921.25

*Preliminary data included; flow coefficient + $p<0.1$, # $p<0.5$, ^ $p<0.01$

Table 15: Value Estimates, 1988-2017 – Franklin County, Q3 Flow, Trips. Additional pounds and revenue from a marginal cms of water.

Year	Pounds Harvested	Trips	Price per Pound	Cost per Trip	Marginal Pounds (same year)	Marginal Pounds (prev. year)^	Marginal Value (same year)	Marginal Value (prev. year)^	Two Year Sum (pounds)	Two Year Sum (value)
1988	4,235,445	15,457	0.58	20.86	-72.58	1,548.30	-42.08	897.61	1,475.72	855.54
1989	7,289,733	17,823	0.67	35.73	-108.33	2,311.07	-72.07	1,537.43	2,202.73	1,465.37
1990	8,488,585	20,639	0.71	38.15	-108.94	2,323.96	-76.95	1,641.68	2,215.02	1,564.73
1991	8,625,149	19,675	0.45	25.70	-116.11	2,477.04	-51.84	1,105.95	2,360.93	1,054.11
1992	12,400,000	20,403	0.30	23.81	-161.47	3,444.78	-48.02	1,024.50	3,283.30	976.48
1993	14,600,000	21,984	0.27	23.59	-175.91	3,752.77	-47.58	1,015.04	3,576.86	967.46
1994	6,767,891	11,472	0.26	20.26	-156.26	3,333.46	-40.88	872.07	3,177.21	831.19
1995	6,270,560	9,168	0.26	23.40	-181.16	3,864.68	-47.20	1,006.85	3,683.52	959.65
1996	7,699,521	10,547	0.30	28.38	-193.36	4,124.93	-57.26	1,221.45	3,931.57	1,164.19
1997	8,039,687	12,147	0.31	26.91	-175.30	3,739.83	-54.28	1,157.94	3,564.52	1,103.66
1998	12,200,000	17,741	0.31	27.83	-181.52	3,872.34	-56.14	1,197.66	3,690.82	1,141.52
1999	11,700,000	18,484	0.30	24.70	-167.80	3,579.80	-49.82	1,062.87	3,412.00	1,013.04
2000	18,300,000	24,641	0.28	26.99	-196.83	4,199.00	-54.44	1,161.31	4,002.17	1,106.87
2001	9,918,938	15,412	0.27	23.23	-170.46	3,636.53	-46.86	999.64	3,466.07	952.78
2002	11,100,000	17,351	0.29	24.53	-170.19	3,630.75	-49.47	1,055.45	3,460.56	1,005.98
2003	8,133,500	13,668	0.29	22.84	-157.61	3,362.43	-46.07	982.84	3,204.82	936.77
2004	11,000,000	14,842	0.31	30.68	-196.89	4,200.42	-61.89	1,320.39	4,003.52	1,258.49
2005	8,079,770	11,816	0.37	33.11	-181.11	3,863.76	-66.80	1,425.01	3,682.64	1,358.21
2006	16,200,000	21,764	0.35	34.23	-197.58	4,215.05	-69.04	1,472.91	4,017.47	1,403.87
2007	14,500,000	21,454	0.33	29.14	-179.04	3,819.60	-58.78	1,253.97	3,640.56	1,195.19
2008	16,800,000	29,692	0.35	26.32	-149.99	3,199.80	-53.09	1,132.68	3,049.81	1,079.58
2009	11,800,000	25,316	0.41	24.74	-123.00	2,623.90	-49.90	1,064.53	2,500.90	1,014.63
2010	12,300,000	26,140	0.41	25.41	-124.89	2,664.38	-51.27	1,093.66	2,539.49	1,042.39
2011	22,100,000	44,754	0.39	25.44	-130.99	2,794.45	-51.32	1,094.73	2,663.46	1,043.42
2012	7,688,312	23,393	0.58	25.09	-87.05	1,857.06	-50.62	1,079.87	1,770.01	1,029.25
2013	3,330,389	13,863	0.76	23.96	-63.63	1,357.44	-48.33	1,031.04	1,293.81	982.71
2014	2,840,054	11,777	0.79	25.16	-63.87	1,362.62	-50.76	1,082.82	1,298.74	1,032.06
2015	2,240,937	11,947	0.86	21.30	-49.68	1,059.87	-42.96	916.43	1,010.19	873.47
2016	2,376,495	14,418	1.01	21.76	-43.66	931.35	-43.89	936.31	887.69	892.42
*2017	595,797	4,166	1.05	19.77	-37.88	808.09	-39.87	850.59	770.21	810.72
Avg.	9,587,359	18,065	0.46	26.10	-137.44	2,931.98	-52.65	1,123.17	2,794.54	1,070.52

*Preliminary data included; flow coefficient + p<0.1, # p<0.5, ^ p<0.01

Table 16: Value Estimates, 1988-2017 – Franklin County, Q3 Flow, Hours. Additional pounds and revenue from a marginal cms of water

Year	Pounds Harvested	Hours	Price per Pound	Cost per Hour	Marginal Pounds (same year)	Marginal Pounds (prev. year)^	Marginal Value (same year)	Marginal Value (prev. year)^	Two Year Sum (pounds)	Two Year Sum (value)
1988	4,235,445	78,834	0.58	4.09	-593.64	1,735.95	-344.16	1006.40	1,142.31	662.24
1989	7,289,733	85,661	0.67	7.43	-886.09	2,591.15	-589.47	1,723.76	1,705.06	1,134.29
1990	8,488,585	90,752	0.71	8.68	-891.04	2,605.61	-629.44	1,840.64	1,714.57	1,211.20
1991	8,625,149	77,318	0.45	6.54	-949.73	2,777.24	-424.04	1,239.98	1,827.51	815.95
1992	12,400,000	130,113	0.30	3.73	-1,320.77	3,862.26	-392.81	1,148.66	2,541.49	755.86
1993	14,600,000	137,220	0.27	3.78	-1,438.86	4,207.59	-389.18	1,138.05	2,768.72	748.87
1994	6,767,891	69,092	0.26	3.36	-1,278.09	3,737.46	-334.36	977.76	2,459.36	643.39
1995	6,270,560	60,647	0.26	3.54	-1,481.77	4,333.05	-386.04	1,128.87	2,851.28	742.83
1996	7,699,521	104,807	0.30	2.86	-1,581.55	4,624.84	-468.32	1,369.48	3,043.29	901.16
1997	8,039,687	107,302	0.31	3.05	-1,433.90	4,193.07	-443.97	1,298.27	2,759.17	854.30
1998	12,200,000	134,898	0.31	3.66	-1,484.71	4,341.64	-459.20	1,342.81	2,856.94	883.61
1999	11,700,000	127,878	0.30	3.57	-1,372.54	4,013.65	-407.52	1,191.68	2,641.11	784.16
2000	18,300,000	137,253	0.28	4.84	-1,609.95	4,707.89	-445.26	1,302.05	3,097.94	856.79
2001	9,918,938	79,348	0.27	4.51	-1,394.30	4,077.26	-383.28	1,120.79	2,682.96	737.52
2002	11,100,000	121,261	0.29	3.51	-1,392.08	4,070.78	-404.68	1,183.37	2,678.70	778.69
2003	8,133,500	77,036	0.29	4.05	-1,289.20	3,769.94	-376.83	1,101.96	2,480.74	725.12
2004	11,000,000	87,357	0.31	5.21	-1,610.50	4,709.48	-506.25	1,480.41	3,098.99	974.15
2005	8,079,770	81,692	0.37	4.79	-1,481.42	4,332.02	-546.37	1,597.71	2,850.60	1,051.34
2006	16,200,000	156,133	0.35	4.77	-1,616.11	4,725.89	-564.73	1,651.42	3,109.78	1,086.69
2007	14,500,000	145,654	0.33	4.29	-1,464.49	4,282.52	-480.79	1,405.94	2,818.03	925.15
2008	16,800,000	169,356	0.35	4.61	-1,226.85	3,587.59	-434.28	1,269.95	2,360.75	835.67
2009	11,800,000	143,967	0.41	4.35	-1,006.04	2,941.90	-408.15	1,193.54	1,935.86	785.39
2010	12,300,000	168,009	0.41	3.95	-1,021.56	2,987.29	-419.32	1,226.20	1,965.73	806.88
2011	22,100,000	363,203	0.39	3.13	-1,071.43	3,133.12	-419.74	1,227.41	2,061.69	807.67
2012	7,688,312	126,577	0.58	4.64	-712.02	2,082.13	-414.04	1,210.74	1,370.10	796.70
2013	3,330,389	68,915	0.76	4.82	-520.46	1,521.95	-395.32	1,156.00	1,001.49	760.68
2014	2,840,054	58,522	0.79	5.06	-522.44	1,527.76	-415.17	1,214.05	1,005.31	798.88
2015	2,240,937	35,902	0.86	7.09	-406.37	1,188.32	-351.37	1,027.49	781.95	676.12
2016	2,376,495	60,218	1.01	5.21	-357.09	1,044.23	-358.99	1,049.78	687.13	690.79
*2017	595,797	5,213	1.05	15.80	-309.83	906.03	-326.13	953.68	596.19	627.55
Avg.	9,587,359	109,671	0.46	4.96	-1,124.16	3,287.32	-430.64	1,259.30	2,163.16	828.66

*Preliminary data included; flow coefficient + p<0.1, # p<0.5, ^ p<0.01

unit cost of effort) and solving for per unit cost, shown by Equation 17. The per unit cost of effort is remarkably similar in each county for both effort metrics. The average per unit cost per trip over the data period is \$28.44 and \$26.10 in Bay and Franklin counties, respectively. The average cost per hour is \$5.70 and \$4.96, respectively. Because the zero-profit per unit cost should include the cost of labor, these estimates are quite small when considering “normal” hourly wages. This suggests that oyster harvesters have an extremely low opportunity cost of not harvesting because they are willing to work for such a low “wage.” In the context of the harvest region, this is not entirely surprising because the regions are largely rural with scarce employment opportunities. Also, it is possible that harvesters derive non-monetary utility from harvesting. For example, harvesters may enjoy the act of harvesting itself.

Table 15 and 16 show that in the county of primary interest, Franklin County, a marginal average cms of freshwater input in quarter three yields on average between 2,931.98 and 3,287.32 pounds of oysters harvested worth between \$1,123.17 and \$1,259.30 in the *following* year, depending on whether trips or hours is used as the effort variable. The previous year flow coefficients used to estimate these values are highly statistically significant. Netting out the apparently negative effect of fresh water in the current year and the yield from an additional average quarter three cms in Franklin County is between \$1,070.52 and \$828.66, although the negative same year effect is not statistically significant. These values are calculated simply by summing the average same and previous year values, found in the bottom row of Tables 13-16. Similar results are seen in Bay County (Table 13 and 14), although the previous year flow coefficient is only statistically significant in when trips is used as the effort variable, not when hours is used. Also, the trips regression yields a positive effect of same year flow in Bay County, while the hours regression yields a negative effect of same year flow, although neither are statistically significant. Despite the sometimes-negative effect of same year flow, the average marginal harvest and revenue resulting from previous year quarter three flow outweighs the diminished harvest and revenue from flow in the current year.

Average harvest is higher in Franklin County than Bay County, so it is somewhat counterintuitive that a cms of fresh water is estimated to be worth more in Bay County than Franklin County. The explanation for this is likely the fact that average quarter three flow is substantially higher in Franklin County than in Bay County – 469.52 versus 15.27 cms. Therefore, a one unit change in Bay County flow proportionally larger than a one unit change in Franklin County flow. A more effective method of presenting the value of flow is by calculating the value of an average standard deviation of quarter three freshwater inflow. These calculations (for Regression 2 values) using trips and hours, respectively, are shown in Tables 19 and 20. It is clear that a standard deviation of freshwater inflow in Franklin County ($318,650.98 trips; $246,560.64 hours) is worth more than a standard deviation of freshwater inflow in Bay County ($8,213.85; $32,027.29).[25] This is logical given the magnitude of Franklin County harvest compared to Bay County harvest. These values are generally consistent with those in Tables 17 and 18, which are derived from the Regression 1 coefficients. For the two counties for which

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[25] The values in Tables 19 and 20 are calculated simply by multiplying the average pounds and value yielded from a marginal cms of freshwater input annually (found in Tables 13-16) by a standard deviation of each county's quarter three flow. For example, Franklin County previous year value using trips as the effort variable ($1,123.17; 297.66 cms): $1{,}123.17 \cdot 297.66 = 334322.78$.

values are estimated from both regressions (Bay and Franklin), the Regression 1 value estimates are consistently larger than the Regression 2 value estimates (Bay two-year value: $90,636.69 trips, $90,112.65 hours; Franklin two-year value: $834,004.81 trips, $566,381.36 hours). That said, the values derived from each method are reasonably similar. The values from Regression 2 in Tables 19 and 20 are considered more reliable, but both are valid. Interestingly, fresh water appears to be worth the most in Bay and Franklin counties. Also, the Regression 1 values using hours for Wakulla County are negative, which furthers the uncertainty about the role of freshwater input in the county.

Table 17: Reg. 1 Annual Average Value of a Standard Deviation Change in Quarter Three Flow, 1988-2017; Trips[26]

County	Std. Dev. %, Q3 Flow (cms)	Pounds (same year)	Pounds (next year)	Value (same year; 2017 $)	Value (next year; 2017 $)	Two Year Sum (pounds)	Two Year Sum (value; 2017 $)
Bay	23.51	93,196.46	142,842.06	35,786.69	54,850.24	236,038.52	90,636.69
Franklin	63.40	537,682.09	1,660,962.71	203,958.43	630,046.38	2,198,644.80	834,004.81
Levy	55.18	45,050.61	147,592.71	21,349.69	69,943.96	192,643.31	91,293.65
Wakulla	70.35	17,909.70	52,707.63	7,253.79	21,347.00	70,618.03	28,600.09

Table 18: Reg. 1 Annual Average Value of a Standard Deviation Change in Quarter Three Flow, 1988-2017; Hours

County	Std. Dev. %, Q3 Flow (cms)	Pounds (same year)	Pounds (next year)	Value (same year; 2017 $)	Value (next year; 2017 $)	Two Year Sum (pounds)	Two Year Sum (value; 2017 $)
Bay	23.51	191,307.69	43,366.08	73,460.52	16,652.13	234,673.76	90,112.65
Franklin	63.40	964,584.72	528,539.81	365,892.81	200,488.55	1,493,124.52	566,381.36
Levy	55.18	61,841.88	69,340.29	29,306.65	32,860.24	61,841.88	69,340.29
Wakulla	70.35	7,159.52	-9,232.73	2,899.83	-3,739.10	-2,073.21	-839.98

Table 19: Reg. 2 Annual Average Value of a Standard Deviation Change in Quarter Three Flow, 1988-2017; Trips

County	Std. Dev., Q3 Flow (cms)	Pounds (same year)	Pounds (next year)	Value (same year; 2017 $)	Value (next year; 2017 $)	Two Year Sum (pounds)	Two Year Sum (value; 2017 $)
Bay	3.59	2,177.30	21,204.05	939.93	9,153.78	19,026.75	8,213.85
Franklin	297.66	-40,910.39	872,733.17	-15,671.80	334,322.78	831,822.61	318,650.98
Levy	111.31	N/A	N/A	N/A	N/A	N/A	N/A
Wakulla	37.78	N/A	N/A	N/A	N/A	N/A	N/A

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[26] The results in Tables 17 and 18 are calculated slightly differently than those in Tables 19 and 20. The values in Tables 17 and 18 are calculated by the same method used in Appendix C, but the “percent change” is the percent change that equals a standard deviation of freshwater inflow in each county.

Table 20: Reg. 2 Annual Average Value of a Standard Deviation Change in Quarter Three Flow, 1988-2017; Hours[27]

County	Std. Dev., Q3 Flow (cms)	Pounds (same year)	Pounds (next year)	Value (same year; 2017 $)	Value (next year; 2017 $)	Two Year Sum (pounds)	Two Year Sum (value; 2017 $)
Bay	3.59	-6,635.15	80,823.93	-2,864.39	34,891.68	74,188.78	32,027.29
Franklin	297.66	-334,617.47	978,503.67	-128,273.60	374,843.24	643,886.20	246,560.64
Levy	111.31	N/A	N/A	N/A	N/A	N/A	N/A
Wakulla	37.78	N/A	N/A	N/A	N/A	N/A	N/A

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[27] Values are not calculated for Levy and Wakulla counties in Tables 19 and 20 due to the negative effort squared coefficients discussed in Chapter Seven.

CHAPTER EIGHT

IMPLICATIONS AND CONCLUSION

Based on the results shown in Chapter Seven, the primary finding of this thesis is that freshwater inflow in quarter three of the previous year is most relevant to Florida oyster fishery production in the current year. As expected, the relationship between quarter three flow and oyster production is positive. These results are strengthened by the results in Appendix A, where wild cluster bootstrapped p-values are presented, and Appendix B, where regression results excluding the years following the Apalachicola Bay fishery collapse are presented, both as a robustness check of the significance of the coefficients from each iteration of Regression 1 and 2.

Interestingly, quarter three flow does not appear to have a significant effect on oyster production in the same year. The effect of previous year quarter three flow is consistent across counties, albeit with varying significance. This suggests that the effect of fresh water on oyster productivity is not exclusive to Franklin County, which was the motivation for including multiple counties in the analysis. That said, the effect does appear to be strongest and most consistent in Franklin County, especially considering Appendix A. The results for quarter one, two, and four flow are less consistent. There is some indication that flow in these quarters is negatively related to oyster productivity. In quarters one and two, this may be related to the fact that flow magnitude is highest in these quarters. However, these results are inconsistent across counties and effort variables and are therefore less convincing than the findings for quarter three flow. In terms of value, I find that over a two-year period, a standard deviation of freshwater inflow is worth between -$839.98 and $834,004.81 using the Regression 1 valuation method and $8,213.85 and $318,650.98 using the Regression 2 valuation method, depending on the county and harvest effort metric used in the calculation.[28] This wide range may be due to variation in flow magnitude by county. The values estimated using Regression 2, the preferred estimation method, are supported by the values estimated using Regression 1, found in Appendix C. The estimates from Regression 1 are larger than those from Regression 2, but are in the same order of magnitude, which strengthens the evidence that the estimates from Regression 2 are accurate.

The fact that freshwater inflow is most relevant in quarter three is not surprising based on the biology of oysters and the seasonality of river flow in the region. As shown in Tables 1-4, average flow is highest in quarters one and two and diminishes throughout the year, consistent across counties. Flow is important because of its effect on bay salinity, so low overall magnitude may be more relevant than relatively low flows. For example, in Franklin County average flow in quarter one is 907.35 cms, while in quarter three it is 469.52 cms. This means that average quarter one flow could decrease by 33 percent and still be roughly 25 percent higher than average quarter three flow. The point of this example is to illustrate that a year of extraordinarily low quarter one flow may affect bay salinity level less than moderately low quarter three flow. High salinity supports predation, and combined with high temperature, which supports disease, it is not surprising that quarter three is an especially fragile time for oyster populations

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[28] The range for Regression 1 becomes $90,112.65 to $834,004.81 if only Bay and Franklin counties are considered as in Regression 2.

biologically. Conversely, because flow in quarter one is relatively high to begin with – and therefore salinity is low – it is logical that an increase in quarter one flow may actually be bad for oyster productivity due to the range of salinity oysters can tolerate. The impact of flow being strongest the following year suggests the mechanism that drives these results is reproduction. Oysters mature in one to two years, so it follows that high salinity in the previous quarter three – when reproduction occurs– affects mature, harvestable oyster stock in the current period by altering reproduction. The minimal impact of same year quarter three flow supports the biology that suggests higher salinity yields higher individual oyster growth – ignoring the effects of predation – and therefore may provide some benefit for oyster productivity.

Flow in quarter three is low compared to quarters one and two, but average flow is actually lowest in quarter four. Interestingly, the results indicate that quarter four flow does not have a clear effect on oyster productivity in either direction, at least not consistently. This suggests that freshwater inflow is not the sole determinant of oyster productivity. It also strengthens the argument that flow influences reproduction, which largely occurs in quarter three. Lastly, the lack of relationship between freshwater inflow and oyster productivity in quarter four suggests that low flow is not very harmful when temperature is low. This logical because dermo thrives when both temperature and salinity are high.

This thesis was motivated by the Tri-State Water War, which primarily affects Franklin County. Florida’s legal argument is that reduced freshwater inflow from the Apalachicola River leads to a reduction in oyster productivity. This argument is supported by the results in this thesis, although the relationship is not quite so absolute in that quarter three flow is of most relevance. That is, based on my results, increasing freshwater input to Apalachicola Bay is not necessarily beneficial at all times of the year. Returning to quarter three flow, the value of flow can be further applied to the situation in Apalachicola Bay. As detailed in *Florida v. Georgia* (2018), the Corps' guidelines call for a (nonbinding) minimum of 5,000 cfs to pass through Jim Woodruff Dam to the Apalachicola River at all times, which is equal to roughly 141.58 cms. The average quarter three flow of the Apalachicola River over the data period is 469.52 cms. Considering the extreme case in which the Corps reduces Apalachicola River to the minimum level allowed by the guidelines, quarter three flow would fall by 327.94 cms. Based on the average per unit cost of effort and oyster price shown in Tables 15 and 16, such a reduction would lead to an average loss of 916,513.52 pounds of harvest worth $351,066.33 over a two-year period using trips as the effort variable in Regression 2 or 709,386.69 pounds of harvest worth $271,750.76 using hours fished.[29] Assuming the flow reduction persisted, this lost harvest and revenue would apply annually, ignoring potential increases in the scale of productivity reduction over time due to a diminishing overall stock. Again, this is an extreme scenario because it is unlikely that flow would be reduced to the minimum for an entire quarter, but it represents a worst-case scenario.

The revenue estimates in the previous are certainly substantial, but it must be considered that the water of the ACF Basin provides economic value beyond oyster production. Notably, the City of Atlanta derives substantial value from the ACF through

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[29] These values are calculated in the same manner as those in Tables 19 and 20. Using the Regression 1 results (Tables 17 and 18) would yield higher value estimates.

domestic water use, manufacturing, or energy production. However, the value estimated in this thesis considers just one of many uses derived from freshwater input to the Gulf. A number of other aquatic species, many commercially valuable, are likely affected by variation in salinity. Also, the estimated values in this thesis are based on dockside price, the price harvesters sell at to dealers. Dealers then sell the harvest to the public at a higher price, meaning there is further revenue generated from oyster harvest that could not be considered in this thesis due to a lack of data.

This thesis was also motivated by the collapse of the Apalachicola Bay fishery in 2013. A number of causes have been suggested, ranging from overfishing following the 2010 BP oil spill to inadequate freshwater inflow. Although the relationship between freshwater inflow and the collapse is not specifically tested in this thesis, the preceding analyses do provide some insight to the relationship. First, the robustness check presented in Appendix B indicates that a positive relationship between freshwater inflow and productivity exists even if the post-collapse years are excluded. The collapse exacerbates this relationship, but it is somewhat unclear whether freshwater inflow specifically is driving the drop in harvest. Figure 4 shows that Apalachicola River flow in 2011 and 2012 – the years immediately preceding the official collapse – was relatively low, but not abnormally so. At the same time, Figures 6 and 7 show that CPUE *has* been abnormally low in recent years, which suggests that the drop in harvest is not being driven simply by diminished harvest effort and instead is driven by a change in oyster abundance.

It is clear that oyster stock in Apalachicola Bay has been diminished. It is less clear what is driving this collapse, however, even in light of the results of this thesis.

Ceteris paribus, the flow levels in 2011 and 2012 do not appear to be low enough to have caused the collapse alone considering similar flow levels were observed in the early 2000s without a subsequent collapse. However, Figure 4 shows that extreme low flow years are concentrated after 2000. It is possible that *frequent* low flow events contributed to the collapse by weakening the oyster population over the years. If this is the case, the low flow years of 2011 and 2012 are relevant as part of a larger phenomenon. Further research is necessary to speak to the validity of this theory.

Broadly speaking, this thesis contributes to the literature regarding the economics of natural resources and fisheries. The results provide evidence of a relationship between fresh water and oyster productivity as well as an estimate of the monetary value of fresh water. This thesis, along with the related literature, serves to quantify the importance of natural resources in economic processes. Such work is important as natural environments are increasingly diminished to make way for development.

REFERENCES CITED

Armstrong, C. W., Foley, N. S., & Kahui, V. (2016). A Production Function Analysis of Fisheries and Habitat: Open Access versus Optimal Management. *Land Economics*, *92*(4), 760–771. https://doi.org/10.3368/le.92.4.760

Arthington, A. H., Bunn, S. E., Poff, N. L., & Naiman, R. J. (2006). The Challenge of Providing Environmental Flow Rules to Sustain River Ecosystems. *Ecological Applications*, *16*(4), 1311–1318. https://doi.org/10.1890/1051-0761(2006)016[1311:TCOPEF]2.0.CO;2

Atlanta Regional Comission. (2019a). Tri-State Water Wars — Background and History. Retrieved March 19, 2019, from ARC website: https://atlantaregional.org/natural-resources/water-wars/tri-state-water-wars-background-and-history/

Atlanta Regional Comission. (2018b). U.S. Supreme Court: Equitable Apportionment. Retrieved April 4, 2019, from ARC website: https://atlantaregional.org/natural-resources/water-wars/u-s-supreme-court-equitable-apportionment/

Barbier, E. B. (1994). Valuing Environmental Functions: Tropical Wetlands. *Land Economics*, *70*(2), 155–173. https://doi.org/10.2307/3146319

Barbier, E. B. (2000). Valuing the environment as input: review of applications to mangrove-fishery linkages. *Ecological Economics*, *35*(1), 47–61. https://doi.org/10.1016/S0921-8009(00)00167-1

Barbier, E. B. (2007). Valuing Ecosystem Services as Productive Inputs. *Economic Policy*, *22*(49), 177–229. Retrieved from JSTOR.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, *81*(2), 169–193. https://doi.org/10.1890/10-1510.1

Barbier, E. B., & Strand, I. (1998). Valuing Mangrove-Fishery Linkages – A Case Study of Campeche, Mexico. *Environmental and Resource Economics*, *12*(2), 151–166. https://doi.org/10.1023/A:1008248003520

Barbier, E. B., Strand, I., & Sathirathai, S. (2002). Do Open Access Conditions Affect the Valuation of an Externality? Estimating the Welfare Effects of Mangrove-Fishery Linkages in Thailand. *Environmental and Resource Economics*, *21*(4), 343–365. https://doi.org/10.1023/A:1015129502284

Barnes, R. (n.d.). On Florida’s ‘Forgotten Coast,’ a Supreme Court fight over fresh water. Retrieved March 22, 2019, from Washington Post website: https://www.washingtonpost.com/politics/courts_law/on-floridas-forgotten-coast-a-supreme-court-fight-over-fresh-water/2018/01/07/8348adb6-f0c8-11e7-b3bf-ab90a706e175_story.html

Becnel, T. (2008, December 28). Apalachicola Bay oystermen still harvest by hand. Retrieved March 22, 2019, from Sarasota Herald-Tribune website: https://www.heraldtribune.com/article/20081227/news/605239806

Bell, F. W. (1997). The economic valuation of saltwater marsh supporting marine recreational fishing in the southeastern United States. *Ecological Economics*, *21*(3), 243–254. https://doi.org/10.1016/S0921-8009(96)00105-X

Bragg, R. (2002, June 15). An Oyster and a Way of Life, Both at Risk. *The New York Times*. Retrieved from https://www.nytimes.com/2002/06/15/us/an-oyster-and-a-way-of-life-both-at-risk.html

Cambridge University Press. (2019). MEMORANDUM OF UNDERSTANDING | definition in the Cambridge English Dictionary. Retrieved April 4, 2019, from https://dictionary.cambridge.org/us/dictionary/english/memorandum-of-understanding

Cameron, A. C., Gelbach, J. B., & Miller, D. L. (2008). Bootstrap-Based Improvements for Inference with Clustered Errors. *The Review of Economics and Statistics*, *90*(3), 414–427. https://doi.org/10.1162/rest.90.3.414

Carter, N. T. (2018). *Army Corps of Engineers: Water Resource Authorization and Project Delivery Processes [June 1, 2018]*. Retrieved from https://www.hsdl.org/?abstract&did=

Chanton, J., & Lewis, F. G. (2002). Examination of coupling between primary and secondary production in a river-dominated estuary: Apalachicola Bay, Florida, U.S.A. *Limnology and Oceanography*, *47*(3), 683–697. https://doi.org/10.4319/lo.2002.47.3.0683

Chesapeake Bay Foundation. (2019). Oyster Fact Sheet. Retrieved March 14, 2019, from http://www.cbf.org/about-the-bay/more-than-just-the-bay/chesapeake-wildlife/eastern-oysters/oyster-fact-sheet.html

Chesapeake Bay Program. (2019). Atlantic Oyster Drill | Chesapeake Bay Program. Retrieved April 2, 2019, from https://www.chesapeakebay.net/S=0/fieldguide/critter/atlantic_oyster_drill

Colorado v. New Mexico, 467 U.S. 310 (1984). (1984, June 4). Retrieved February 13, 2019, from Justia Law website: https://supreme.justia.com/cases/federal/us/467/310/

Copeland, B. J. (1966). Effects of Decreased River Flow on Estuarine Ecology. *Journal (Water Pollution Control Federation)*, *38*(11), 1831–1839.

Couch, C. A., Hopkins, E. H., & Hardy, P. S. (1996). *Influences of environmental settings on aquatic ecosystems in the Apalachicola-Chattahoochee-Flint River basin* (USGS Numbered Series No. 95–4278). Retrieved from U.S. Geological Survey ; Earth Science Information Center, Open-File Reports Section [distributor], website: http://pubs.er.usgs.gov/publication/wri954278

Crowe, J. B., Huang, W., & Lewis, F. G. (2008). *Assessment of Freshwater Inflows to North Bay from the Deer Point Watershed of the St. Andrew Bay System* (No. Water Resources Assessment 08-01).

Daily, G. C., Alexander, S., Ehrlich, P. R., Goulder, L., Lubchenco, J., Matson, P. A., … Woodwell, G. M. (1997). Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems. Retrieved April 8, 2019, from esa.org website: https://www.esa.org/esa/wp-content/uploads/2013/03/issue2.pdf

Dias, P. C. (1996). Sources and sinks in population biology. *Trends in Ecology & Evolution*, *11*(8), 326–330. https://doi.org/10.1016/0169-5347(96)10037-9

Downs, R. (2018, November 29). Water woes killing Gulf Coast oyster industry. Retrieved February 12, 2019, from UPI website: https://www.upi.com/Water-woes-killing-Gulf-Coast-oyster-industry/1631543507355/

Ellis, G. M., & Fisher, A. C. (1986). *Working Paper No. 427: Valuing the Environment as Input*.

Ensley, G. (2015, August 5). Nothing’s better than an Apalachicola oyster. *Tallahassee Democrat*. Retrieved from https://www.tallahassee.com/story/news/local/2015/08/05/nothings-better-apalachicola-oyster/31159367/

Evans, A. C. (2015, January). The Oysterman. Retrieved April 3, 2019, from THE BITTER SOUTHERNER website: https://bittersoutherner.com/the-oysterman

Ewart, J. W., & Ford, S. E. (1993). History and Impact of MSX and Dermo Diseases on Oyster Stocks In the Northeast Region. *NRAC Fact Sheet*, *200*, 8.

Feldman, D. L. (2009). Preventing the repetition: Or, what Los Angeles’ experience in water management can teach Atlanta about urban water disputes. *Water Resources Research*, *45*(4). https://doi.org/10.1029/2008WR007605

Field, B. C. (2008). *Natural Resource Economics: An Introduction, Second Edition*. Waveland Press.

Fish and Wildlife Research Institute. (2018). Eastern Oyster, Crassostrea virginica (Gmelin, 1791). Retrieved May 6, 2019, from https://myfwc.com/media/19253/eastern-oyster-18.pdf

Florida Department of Agriculture and Consumer Services. (2019a). Apalachicola Bay Oyster Harvesting License / Aquaculture / Business Services / Home - Florida Department of Agriculture & Consumer Services. Retrieved March 22, 2019, from https://www.freshfromflorida.com/Business-Services/Aquaculture/Apalachicola-Bay-Oyster-Harvesting-License

Florida Department of Agriculture and Consumer Services. (2019d). Aquaculture Certificate of Registration / Aquaculture Submerged Land Leasing / Aquaculture / Business Services / Home - Florida Department of Agriculture & Consumer Services. Retrieved March 23, 2019, from https://www.freshfromflorida.com/Business-Services/Aquaculture/Aquaculture-Submerged-Land-Leasing/Aquaculture-Certificate-of-Registration

Florida Department of Agriculture and Consumer Services. (2019c). Aquaculture Submerged Land Leasing / Aquaculture / Business Services / Home - Florida Department of Agriculture & Consumer Services. Retrieved March 23, 2019, from https://www.freshfromflorida.com/Business-Services/Aquaculture/Aquaculture-Submerged-Land-Leasing

Florida Department of Agriculture and Consumer Services. (2019b). Shellfish / Aquaculture / Business Services / Home - Florida Department of Agriculture & Consumer Services. Retrieved March 23, 2019, from https://www.freshfromflorida.com/Business-Services/Aquaculture/Shellfish

Florida Department of Environmental Protection. (2019, February 27). Apalachicola Bay Aquatic Preserve. Retrieved May 6, 2019, from https://floridadep.gov/rcp/aquatic-preserve/locations/apalachicola-bay-aquatic-preserve

Florida Fish and Wildlife Conservation Comission. (2018b). Fees. Retrieved March 22, 2019, from Florida Fish And Wildlife Conservation Commission website: http://myfwc.com/license/commercial/saltwater/fees/

Florida Fish and Wildlife Conservation Comission. (2019e). O-R. Retrieved March 22, 2019, from Florida Fish And Wildlife Conservation Commission website: http://myfwc.com/fishing/saltwater/rulemaking/history/o-r/

Florida Fish and Wildlife Conservation Comission. (2019d). Oysters. Retrieved March 22, 2019, from Florida Fish And Wildlife Conservation Commission website: http://myfwc.com/fishing/saltwater/commercial/oysters/

Florida Fish and Wildlife Conservation Comission. (2019c). Saltwater. Retrieved March 22, 2019, from Florida Fish And Wildlife Conservation Commission website: http://myfwc.com/license/commercial/saltwater/

Florida Fish and Wildlife Conservation Comission. (2019a). Shellfish. Retrieved March 22, 2019, from Florida Fish And Wildlife Conservation Commission website: http://myfwc.com/fishing/saltwater/commercial/shellfish/

Florida Fish and Wildlife Conservation Comission. (2019f). Shellfish. Retrieved March 23, 2019, from Florida Fish And Wildlife Conservation Commission website: http://myfwc.com/fishing/saltwater/recreational/shellfish/

Florida Fish and Wildlife Conservation Comission. (2019g). Wholesale Retail Dealers. Retrieved April 6, 2019, from Florida Fish And Wildlife Conservation Commission website: http://myfwc.com/research/saltwater/fishstats/commercial-fisheries/wholesale-retail-dealers/

Florida Fish and Wildlife Conservation Comission. (2002, July 23). Fishery Dependent Monitoring. Retrieved April 6, 2019, from Florida Fish And Wildlife Conservation Commission website: http://sedarweb.org/docs/wpapers/SEDAR7_DW39.pdf

Florida Fish and Wildlife Conservation Comission. (2013, May). 2012 – 2013 Florida Gulf Coast Oyster Disaster Report. Retrieved January 26, 2019, from http://www.floridajobs.org/docs/default-source/2015-community-development/2015-cmty-plan-acsc/20122013floridagulfcoastoysterdisasterreport.pdf?sfvrsn=2

Florida Governor. (n.d.). Gov. Rick Scott and Florida Cabinet Approve Land Lease for Innovative Oyster Harvesting Technique. Retrieved March 23, 2019, from https://www.flgov.com/gov-rick-scott-and-florida-cabinet-approve-land-lease-for-innovative-oyster-harvesting-technique-2/

Florida v. Georgia, 585 U.S. ___ (2018). (n.d.). Retrieved April 4, 2019, from Justia Law website: https://supreme.justia.com/cases/federal/us/585/142-orig/

Foley, N., Kahui, V., Armstrong, C. W., & van Rensburg, T. (2009). *Estimating Linkages between Redfish and Cold Water Coral on the Norwegian Coast* [Working Paper]. Retrieved from National University of Ireland, Galway website: https://aran.library.nuigalway.ie/handle/10379/1125

Foley, N. S., Armstrong, C. W., Kahui, V., Mikkelsen, E., & Reithe, S. (2012). A Review of Bioeconomic Modelling of Habitat-Fisheries Interactions [Research article]. https://doi.org/10.1155/2012/861635

Freeman, A. M. (1991). Valuing environmental resources under alternative management regimes. *Ecological Economics*, *3*(3), 247–256. https://doi.org/10.1016/0921-8009(91)90035-D

Gordon, H. S. (1954). The Economic Theory of a Common-Property Resource: The Fishery. *Journal of Political Economy*, *62*(2), 124–142.

Harley, S. J., Myers, R. A., & Dunn, A. (2001). Is catch-per-unit-effort proportional to abundance? *Canadian Journal of Fisheries and Aquatic Sciences*, *58*(9), 1760–1772. https://doi.org/10.1139/f01-112

Havens, K., Allen, M., Camp, E., Irani, T., Lindsey, A., Morris, J. G., … Walters, C. (2013, April 25). Apalachicola Bay Oyster Situation Report. Retrieved January 26, 2019, from Florida Sea Grant website: https://www.flseagrant.org/news/2013/04/apalachicola-oyster-report/

Hull, J. W. (2000, October). *The War Over Water*. 12.

Institute of Food and Agricultural Sciences. (2017, June 23). Oyster Culture. Retrieved March 23, 2019, from Florida Shellfish Aquaculture Online Resource Guide website: http://shellfish.ifas.ufl.edu/oyster-culture/

Kennedy, C. J., & Barbier, E. B. (2016). The economic value of freshwater inputs to an estuarine fishery. *Water Resources and Economics*, *13*, 46–59. https://doi.org/10.1016/j.wre.2015.11.003

Lawrence, S. J. (2016). *Water use in the Apalachicola-Chattahoochee-Flint River Basin, Alabama, Florida, and Georgia, 2010, and water-use trends, 1985-2010* (USGS Numbered Series No. 2016–5007; p. 84). Retrieved from U.S. Geological Survey website: http://pubs.er.usgs.gov/publication/sir20165007

Legal Information Institute. (2007, August 6). Original jurisdiction. Retrieved March 21, 2019, from LII / Legal Information Institute website: https://www.law.cornell.edu/wex/original_jurisdiction

Livingston, R. J., Lewis, F. G., Woodsum, G. C., Niu, X.-F., Galperin, B., Huang, W., … Ray, G. L. (2000). Modelling Oyster Population Response to Variation in Freshwater Input. *Estuarine, Coastal and Shelf Science*, *50*(5), 655–672. https://doi.org/10.1006/ecss.1999.0597

Livingston, Robert J., Niu, X., Lewis, F. G., & Woodsum, G. C. (1997). Freshwater Input to a Gulf Estuary: Long-Term Control of Trophic Organization. *Ecological Applications*, *7*(1), 277–299. https://doi.org/10.2307/2269424

Loneragan, N. R., & Bunn, S. E. (1999). River flows and estuarine ecosystems: Implications for coastal fisheries from a review and a case study of the Logan River, southeast Queensland. *Australian Journal of Ecology*, *24*(4), 431–440. https://doi.org/10.1046/j.1442-9993.1999.00975.x

Lorio, W. J., & Malone, S. (1994). The Cultivation of American Oysters. *SRAC*, *432*, 8.

Lynne, G. D., Conroy, P., & Prochaska, F. J. (1981). Economic valuation of marsh areas for marine production processes. *Journal of Environmental Economics and Management*, *8*(2), 175–186. https://doi.org/10.1016/0095-0696(81)90006-1

Maryland Sea Grant. (n.d.). Biology of the Oyster. Retrieved April 1, 2019, from mdsg.umd.edu website: https://ww2.mdsg.umd.edu/store/books/mdoysters/mdoyst2.pdf

Maunder, M. N., Sibert, J. R., Fonteneau, A., Hampton, J., Kleiber, P., & Harley, S. J. (2006). Interpreting catch per unit effort data to assess the status of individual stocks and communities. *ICES Journal of Marine Science*, *63*(8), 1373–1385. https://doi.org/10.1016/j.icesjms.2006.05.008

Meeter, D. A., Livingston, R. J., & Woodsum, G. C. (1979). Long-Term Climatological Cycles and Population Changes in a River-Dominated Estuarine System. In Robert J. Livingston (Ed.), *Ecological Processes in Coastal and Marine Systems* (pp. 315–338). https://doi.org/10.1007/978-1-4615-9146-7_15

Mississippi-Alabama Sea Grant Legal Program. (2014, December). Inventory of Shellfish Restoration Permitting & Programs in the Coastal States. Retrieved March 22, 2019, from Mississippi-Alabama Sea Grant Legal Program website: http://masglp.olemiss.edu/projects/files/tnc-report.pdf

MyFlorida. (2003, December 4). Florida Counties. Retrieved April 14, 2019, from Official State of Florida Geographic Data Portal website: http://geodata.myflorida.com/datasets/swfwmd::florida-counties

National Oceanic and Atmospheric Administration. (July 6, 2017a). NOAA’s National Ocean Service Education: Estuaries. Retrieved March 14, 2019, from https://oceanservice.noaa.gov/education/kits/estuaries/estuaries03_ecosystem.html

National Oceanic and Atmospheric Administration. (July 6, 2017b). NOAA's National Ocean Service Education: Estuaries. Retrieved March 14, 2019, from https://oceanservice.noaa.gov/education/kits/estuaries/estuaries02_economy.html

National Oceanic and Atmospheric Administration. (July 6, 2017c). NOAA's National Ocean Service Education: Estuaries. Retrieved April 1, 2019, from https://oceanservice.noaa.gov/education/kits/estuaries/estuaries01_whatis.html

National Oceanic and Atmospheric Administration. (2018). Estuary Habitat | NOAA Fisheries. Retrieved February 13, 2019, from /estuary-habitat

National Oceanic and Atmospheric Administration. (n.d.). Oysters - Fish Facts. Retrieved April 1, 2019, from https://chesapeakebay.noaa.gov/fish-facts/oysters

Northwest Florida Water Management District. (2017). Apalachicola River and Bay | Northwest Florida Water Management District. Retrieved March 15, 2019, from https://www.nwfwater.com/Water-Resources/Surface-Water-Improvement-and-Management/Apalachicola-River-and-Bay

Organisation for Economic Co-operation and Development. (2001, November 4). OECD Glossary of Statistical Terms - Common property resources (environmental) Definition. Retrieved April 3, 2019, from OECD website: https://stats.oecd.org/glossary/detail.asp?ID=391

Oyez. (n.d.). Florida v. Georgia. Retrieved March 15, 2019, from Oyez website: https://www.oyez.org/cases/2017/142-orig

Pillion, D. (2014, September 12). Florida oysters in crisis: "Our industry needs to be shut down," Apalachicola seafood rep says. Retrieved March 14, 2019, from al.com website: https://www.al.com/news/beaches/2014/09/florida_oysters_in_crisis_our.html

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., … Stromberg, J. C. (1997). The Natural Flow Regime. *BioScience*, *47*(11), 769–784. https://doi.org/10.2307/1313099

Reiley, L. (2018). Saving Florida's oysters could mean killing a way of life. Retrieved March 23, 2019, from http://www.tampabay.com/projects/2018/special-report/shell-game/panhandle-apalachicola-wild-oysters-aquaculture

Richter, B. D., Mathews, R., Harrison, D. L., & Wigington, R. (2003). Ecologically Sustainable Water Management: Managing River Flows for Ecological Integrity. *Ecological Applications*, *13*(1), 206–224. Retrieved from JSTOR.

Rohatgi, A. (2019, April). WebPlotDigitizer. Retrieved April 7, 2019, from WebPlotDigitizer website: https://automeris.io/WebPlotDigitizer/

Roodman, D., Nielsen, M. Ø., MacKinnon, J. G., & Webb, M. D. (2019). Fast and wild: Bootstrap inference in Stata using boottest. *The Stata Journal*, *19*(1), 4–60. https://doi.org/10.1177/1536867X19830877

Ruhl, J. B. (2003). Equitable Apportionment of Ecosystem Services: New Water Law for a New Water Age. *Journal of Land Use & Environmental Law*, *19*(1), 47–57.

Ruhl, J. B. (2005). Water Wars, Eastern Style: Divvying Up the Apalachicola-Chattahoochee-Flint River Basin. *Journal of Contemporary Water Research & Education*, *131*(1), 47–54. https://doi.org/10.1111/j.1936-704X.2005.mp131001008.x

Ryan, M. (2009, October 13). Riparian doctrine. Retrieved March 18, 2019, from LII / Legal Information Institute website: https://www.law.cornell.edu/wex/riparian_doctrine

Schaefer, M. B. (1954). Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Inter-American Tropical Tuna Commission Bulletin*, *1*, 23–56.

Schaefer, M. B. (1957). Some Considerations of Population Dynamics and Economics in Relation to the Management of the Commercial Marine Fisheries. *Journal of the Fisheries Research Board of Canada*, *14*(5), 669–681. https://doi.org/10.1139/f57-025

Stock, J. H., & Watson, M. W. (2008). Heteroskedasticity-Robust Standard Errors for Fixed Effects Panel Data Regression. *Econometrica*, *76*(1), 155–174. https://doi.org/10.1111/j.0012-9682.2008.00821.x

Thompson, J. N., & Post, E. (n.d.). Population ecology - Calculating population growth. Retrieved May 4, 2019, from Encyclopedia Britannica website: https://www.britannica.com/science/population-ecology

United States Bureau of Reclamation. (n.d.). Bureau of Reclamation: Lower Colorado Region - Law of the River. Retrieved March 18, 2019, from https://www.usbr.gov/lc/region/g1000/lawofrvr.html

United States Department of Agriculture. (2013, June). USDA Aquaculture. Retrieved March 23, 2019, from freshfromflorida.com website: http://shellfish.ifas.ufl.edu/wp-content/uploads/2012-Florida-Aquaculture-Survey.pdf

United States Department of Agriculture. (2019, March 16). USDA/NASS 2018 State Agriculture Overview for Georgia. Retrieved March 16, 2019, from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=GEORGIA

United States Environmental Protection Agency. (2018). Ecosystem Services [Overviews and Factsheets]. Retrieved March 21, 2019, from US EPA website: https://www.epa.gov/eco-research/ecosystem-services

United States Fish and Wildlife Service. (n.d.). Florida's Big Bend. Retrieved March 15, 2019, from Southeast Region of the U.S. Fish and Wildlife Service website: https://www.fws.gov/southeast/gulf-restoration/next-steps/focal-area/floridas-big-bend/

United States Geological Survey. (2017). Water Resources of the United States—National Water Information System (NWIS) Mapper. Retrieved April 6, 2019, from https://maps.waterdata.usgs.gov/mapper/index.html

United States Geological Survey. (n.d.). USGS NWC Apalachicola-Chattahoochee-Flint River Basin Focus Area Study. Retrieved April 7, 2019, from https://water.usgs.gov/watercensus/ACF-FAS/index.html

USF Water Institute. (n.d.). Oyster Mapping & Monitoring. Retrieved April 1, 2019, from http://www.sarasota.wateratlas.usf.edu/oysters/?section=Oyster%20Life%20Cycle

Wang, H., Huang, W., Harwell, M. A., Edmiston, L., Johnson, E., Hsieh, P., … Liu, X. (2008). Modeling oyster growth rate by coupling oyster population and hydrodynamic models for Apalachicola Bay, Florida, USA. *Ecological Modelling*, *211*(1), 77–89. https://doi.org/10.1016/j.ecolmodel.2007.08.018

Wilber, D. H. (1992). Associations between freshwater inflows and oyster productivity in Apalachicola Bay, Florida. *Estuarine, Coastal and Shelf Science*, *35*(2), 179–190. https://doi.org/10.1016/S0272-7714(05)80112-X

Zachary, A., & Haven, D. S. (1973). Survival and activity of the oyster drill Urosalpinx cinerea under conditions of fluctuating salinity. *Marine Biology*, *22*(1), 45–52. https://doi.org/10.1007/BF00388909

APPENDICES

APPENDIX A

WILD CLUSTER ROBUSTNESS CHECK

Tables 5a-12a are equivalent to Tables 5-12 except for the standard errors. Tables 5a-12a do not contain standard errors but rather p-values calculated using the wild cluster bootstrap. These values were calculated out of concern that the robust standard errors included in Tables 5-12 may be inconsistent (Watson & Stock, 2008). Wild cluster bootstrapping was chosen based on the work of Cameron and Miller (2008) who show that the wild cluster method is effective with as few as five clusters. Since the cluster level in this analysis is county, the number of clusters is four. Although this is lower than Cameron and Miller test, the wild cluster bootstrap is the best available option. The p-values were obtained using the Stata command "boottest"[30] following the methods shown by Roodman et al. (2019). Bootstrapping consists of a random sample, so each iteration yields a slightly different p-value. To account for this, I ran the bootstrap three consecutive times for each coefficient in each regression and selected the median p-value of the three. The following results should be viewed as highly conservative estimates of significance.

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[30] This package is the work of David Roodman.

Table 5a: Impact of Quarter One Flow on Oyster Stock, 1988-2017; Bootstrapped Standard Errors

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q1 Bay Flow) (same year)	0.2056	0.2095
	[0.4283]	[0.6790]
Bay*ln(Q1 Bay Flow) (previous year)	0.3326	-0.1660
	[0.4123]	[0.3481]
Franklin*ln(Q1 Franklin Flow) (same year)	0.0526	0.0624
	[0.6241]	[0.6882]
Franklin*ln(Q1 Franklin Flow) (previous year)	-0.0683	-0.2383
	[0.4290]	[0.4110]
Levy*ln(Q1 Levy Flow) (same year)	-0.0791*	-0.0397
	[0.0798]	[0.7567]
Levy*ln(Q1 Levy Flow) (previous year)	0.1101*	0.0138
	[0.0608]	[0.8935]
Wakulla*ln(Q1 Wakulla Flow) (same year)	0.1245	-0.0110
	[0.1969]	[0.9038]
Wakulla*ln(Q1 Wakulla Flow) (previous year)	-0.0344*	-0.2032
	[0.0823]	[0.1778]
Q1 Total Precipitation (inches) (same year)	-0.0041	0.0030
	[0.6179]	[0.8958]
Q1 Total Precipitation (inches) (previous year)	0.0007	0.0112*
	[0.6443]	[0.0641]
Q1 Average Temperature (F) (same year)	0.0010	-0.0076
	[0.9530]	[0.7334]
Q1 Average Temperature (F) (previous year)	-0.0106	-0.0154*
	[0.3890]	[0.0558]
ln(Previous Season Avg. HpH)	0.3396*	0.6277**
	[0.0576]	[0.0322]
Obs.	323	323
R-squared	0.7524	0.5890

Wild cluster (by county) bootstrapped p-values in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 6a: Impact of Quarter Two Flow on Oyster Stock, 1988-2017; Bootstrapped Standard Errors

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q2 Bay Flow) (same year)	0.3349	0.5008
	[0.1977]	[0.1568]
Bay*ln(Q2 Bay Flow) (previous year)	0.2879**	-0.2974
	[0.1029]	[0.1916]
Franklin*ln(Q2 Franklin Flow) (same year)	0.0248	0.0686
	[0.7520]	[0.2323]
Franklin*ln(Q2 Franklin Flow) (previous year)	-0.0297	-0.0395
	[0.3413]	[0.6697]
Levy*ln(Q2 Levy Flow) (same year)	0.0434	0.0533
	[0.6605]	[0.2066]
Levy*ln(Q2 Levy Flow) (previous year)	0.0950*	0.1208
	[0.0576]	[0.2633]
Wakulla*ln(Q2 Wakulla Flow) (same year)	0.0938	-0.0629
	[0.3875]	[0.1167]
Wakulla*ln(Q2 Wakulla Flow) (previous year)	-0.1180	-0.0800
	[0.2825]	[0.2447]
Q2 Total Precipitation (inches) (same year)	-0.0095	-0.0005
	[0.2394]	[0.9567]
Q2 Total Precipitation (inches) (previous year)	-0.0003	0.0070
	[0.9266]	[0.4080]
Q2 Average Temperature (F) (same year)	-0.0037	-0.0206
	[0.6865]	[0.3429]
Q2 Average Temperature (F) (previous year)	-0.0014	-0.0173**
	[0.7093]	[0.0197]
ln(Previous Season Avg. HpH)	0.3417*	0.6330**
	[0.0605]	[0.0358]
Obs.	323	323
R-squared	0.7576	0.5951

Wild cluster (by county) bootstrapped p-values in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 7a: Impact of Quarter Three Flow on Oyster Stock, 1988-2017; Bootstrapped Standard Errors

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q3 Bay Flow) (same year)	0.5538	1.1368*
	[0.1856]	[0.0535]
Bay*ln(Q3 Bay Flow) (previous year)	0.8488**	0.2577
	[0.0424]	[0.3938]
Franklin*ln(Q3 Franklin Flow) (same year)	0.0884	0.1586*
	[0.7062]	[0.0541]
Franklin*ln(Q3 Franklin Flow) (previous year)	0.2731**	0.0869
	[0.0468]	[0.2934]
Levy*ln(Q3 Levy Flow) (same year)	0.1057	0.1451
	[0.5810]	[0.3172]
Levy*ln(Q3 Levy Flow) (previous year)	0.3463**	0.1627**
	[0.0490]	[0.0487]
Wakulla*ln(Q3 Wakulla Flow) (same year)	0.0933	0.0373
	[0.5160]	[0.8411]
Wakulla*ln(Q3 Wakulla Flow) (previous year)	0.2746	-0.0481
	[0.2377]	[0.1729]
Q3 Total Precipitation (inches) (same year)	0.0134**	0.0202**
	[0.0486]	[0.0469]
Q3 Total Precipitation (inches) (previous year)	0.0005	0.0005
	[0.9199]	[0.9286]
Q3 Average Temperature (F) (same year)	0.1309	0.1361*
	[0.2939]	[0.0536]
Q3 Average Temperature (F) (previous year)	0.0728	-0.0604
	[0.3717]	[0.6374]
ln(Previous Season Avg. HpH)	0.3063	0.5823**
	[0.1943]	[0.0343]
Obs.	323	323
R-squared	0.7948	0.6561

Wild cluster (by county) bootstrapped p-values in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 8a: Impact of Quarter Four Flow on Oyster Stock, 1988-2017; Bootstrapped Standard Errors

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q4 Bay Flow) (same year)	0.4226	1.0615**
	[0.2049]	[0.0475]
Bay*ln(Q4 Bay Flow) (previous year)	0.3025	-0.1382
	[0.2817]	[0.6286]
Franklin*ln(Q4 Franklin Flow) (same year)	0.1131	0.2544
	[0.3708]	[0.2829]
Franklin*ln(Q4 Franklin Flow) (previous year)	-0.0043	-0.1199
	[0.9317]	[0.5591]
Levy*ln(Q4 Levy Flow) (same year)	0.1533	0.2662
	[0.2737]	[0.3517]
Levy*ln(Q4 Levy Flow) (previous year)	0.0509	0.0374
	[0.6862]	[0.4798]
Wakulla*ln(Q4 Wakulla Flow) (same year)	0.1103	0.1398
	[0.3135]	[0.4446]
Wakulla*ln(Q4 Wakulla Flow) (previous year)	-0.0153	-0.1004
	[0.7995]	[0.1245]
Q4 Total Precipitation (inches) (same year)	-0.0044	-0.0045
	[0.6337]	[0.8763]
Q4 Total Precipitation (inches) (previous year)	-0.0179	-0.0077
	[0.4376]	[0.9294]
Q4 Average Temperature (F) (same year)	-0.0424	-0.0850**
	[0.5681]	[0.0451]
Q4 Average Temperature (F) (previous year)	0.0937*	0.1094**
	[0.0574]	[0.0430]
ln(Previous Season Avg. HpH)	0.3735*	0.6505**
	[0.0539]	[0.0460]
Obs.	323	323
R-squared	0.7605	0.6310

Wild cluster (by county) bootstrapped p-values in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 9a: Impact of Quarter One Flow on Oyster Harvest, 1988-2017; Bootstrapped Standard Errors

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	684.6900	189.7170
	[0.4255]	[0.5214]
Bay*Effort*Effort	-0.6418	-0.0093
	[0.5494]	[0.2081]
Franklin*Effort	717.3064	138.4220**
	[0.1078]	[0.0266]
Franklin*Effort*Effort	-0.0125**	-0.0005*
	[0.0405]	[0.0986]
Levy*Effort	409.7586	51.5678
	[0.4492]	[0.4523]
Levy*Effort*Effort	0.0986	0.0066
	[0.6853]	[0.4533]
Wakulla*Effort	-1570.4113	-2.9173
	[0.5943]	[0.9716]
Wakulla*Effort*Effort	3.7838	0.0100
	[0.5597]	[0.6581]
Bay*Q1 Bay Flow*Effort (same year)	32.1727	0.3907
	[0.5374]	[0.9567]
Bay*Q1 Bay Flow*Effort (previous year)	19.2630	-1.4979
	[0.6103]	[0.6472]
Franklin*Q1 Franklin Flow*Effort (same year)	-0.0322*	-0.0101
	[0.0800]	[0.1359]
Franklin*Q1 Franklin Flow*Effort (previous year)	-0.0039	-0.0075*
	[0.5322]	[0.0862]
Levy*Q1 Franklin Flow*Effort (same year)	0.3700	-0.0119
	[0.6664]	[0.4877]
Levy*Q1 Franklin Flow*Effort (previous year)	0.3081	-0.0227
	[0.3072]	[0.5504]
Wakulla*Q1 Wakulla Flow*Effort (same year)	8.3571	-0.2387
	[0.4338]	[0.5778]
Wakulla*Q1 Wakulla Flow*Effort (previous year)	4.6424	0.1787
	[0.5848]	[0.7233]
Obs.	342	342
R-squared	0.9305	0.9535

Wild cluster (by county) bootstrapped p-values in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 10a: Impact of Quarter Two Flow on Oyster Harvest, 1988-2017; Bootstrapped Standard Errors

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	641.0121	330.2602
	[0.6305]	[0.1356]
Bay*Effort*Effort	-0.5629	-0.0087
	[0.5400]	[0.2164]
Franklin*Effort	728.9651	127.9944**
	[0.1093]	[0.0338]
Franklin*Effort*Effort	-0.0130*	-0.0004*
	[0.0592]	[0.0906]
Levy*Effort	317.2312	20.4136
	[0.5645]	[0.8086]
Levy*Effort*Effort	0.0956	0.0063
	[0.6962]	[0.4895]
Wakulla*Effort	-1040.4292	-87.6299
	[0.7540]	[0.6947]
Wakulla*Effort*Effort	3.6895	0.0131
	[0.5692]	[0.4713]
Bay*Q2 Bay Flow*Effort (same year)	26.5142	-7.6491
	[0.7612]	[0.5375]
Bay*Q2 Bay Flow*Effort (previous year)	24.6427	-2.2495
	[0.6964]	[0.5923]
Franklin*Q2 Franklin Flow*Effort (same year)	-0.0894	-0.0087
	[0.1156]	[0.2494]
Franklin*Q2 Franklin Flow*Effort (previous year)	0.0118	-0.0074
	[0.9042]	[0.2922]
Levy*Q2 Franklin Flow*Effort (same year)	0.7092	0.0744
	[0.4881]	[0.5818]
Levy*Q2 Franklin Flow*Effort (previous year)	0.4308	0.0146
	[0.4954]	[0.4079]
Wakulla*Q2 Wakulla Flow*Effort (same year)	12.0569	-0.0015
	[0.5084]	[0.9957]
Wakulla*Q2 Wakulla Flow*Effort (previous year)	1.0657	1.0870
	[0.7727]	[0.5371]
Obs.	342	342
R-squared	0.9325	0.9531

Wild cluster (by county) bootstrapped p-values in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 11a: Impact of Quarter Three Flow on Oyster Harvest, 1988-2017; Bootstrapped Standard Errors

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	590.8605	131.6970
	[0.5120]	[0.4245]
Bay*Effort*Effort	-0.5476	-0.0098
	[0.5366]	[0.2532]
Franklin*Effort	529.8896	110.8683**
	[0.1009]	[0.0240]
Franklin*Effort*Effort	-0.0058	-0.0004**
	[0.1094]	[0.0397]
Levy*Effort	-67.1288	-27.9361
	[0.9070]	[0.8076]
Levy*Effort*Effort	0.0974	0.0071
	[0.6298]	[0.4638]
Wakulla*Effort	-1477.8492	50.6391
	[0.5963]	[0.5581]
Wakulla*Effort*Effort	3.7176	-0.0031
	[0.5990]	[0.3663]
Bay*Q3 Bay Flow*Effort (same year)	5.0406	-0.2749
	[0.9302]	[0.9029]
Bay*Q3 Bay Flow*Effort (previous year)	49.0885	3.3486
	[0.3978]	[0.1821]
Franklin*Q3 Franklin Flow*Effort (same year)	-0.0117	-0.0066
	[0.7589]	[0.5566]
Franklin*Q3 Franklin Flow*Effort (previous year)	0.2496**	0.0193
	[0.0317]	[0.1083]
Levy*Q3 Franklin Flow*Effort (same year)	1.3374	0.1515
	[0.5070]	[0.4718]
Levy*Q3 Franklin Flow*Effort (previous year)	1.7090	0.1660
	[0.5189]	[0.5796]
Wakulla*Q3 Wakulla Flow*Effort (same year)	5.0704	-0.7694
	[0.7269]	[0.6622]
Wakulla*Q3 Wakulla Flow*Effort (previous year)	22.3617	0.5395
	[0.5106]	[0.6232]
Obs.	342	342
R-squared	0.9391	0.9541

Wild cluster (by county) bootstrapped p-values in brackets

*** p<0.01, ** p<0.05, * p<0.1

Table 12a: Impact of Quarter Four Flow on Oyster Harvest, 1988-2017; Bootstrapped Standard Errors

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	3195.5776	148.3176
	[0.5671]	[0.3954]
Bay*Effort*Effort	-0.6198	-0.0091
	[0.5617]	[0.1559]
Franklin*Effort	671.2654**	127.7944**
	[0.0490]	[0.0157]
Franklin*Effort*Effort	-0.0099*	-0.0005*
	[0.0568]	[0.0843]
Levy*Effort	787.4071	36.2604
	[0.5424]	[0.5583]
Levy*Effort*Effort	0.0459	0.0070
	[0.6951]	[0.4475]
Wakulla*Effort	-27.5962	-3.4456
	[0.9680]	[0.9417]
Wakulla*Effort*Effort	3.2696	0.0042
	[0.5644]	[0.6955]
Bay*Q4 Bay Flow*Effort (same year)	-66.7497	3.2295
	[0.6091]	[0.0541]
Bay*Q4 Bay Flow*Effort (previous year)	-44.3279	-1.4455
	[0.6613]	[0.7362]
Franklin*Q4 Franklin Flow*Effort (same year)	-0.0060	-0.0011
	[0.8030]	[0.2015]
Franklin*Q4 Franklin Flow*Effort (previous year)	-0.0097	-0.0135**
	[0.5607]	[0.0310]
Levy*Q4 Franklin Flow*Effort (same year)	0.1555	0.1313
	[0.7871]	[0.3842]
Levy*Q4 Franklin Flow*Effort (previous year)	-0.5655	-0.0831
	[0.6771]	[0.5249]
Wakulla*Q4 Wakulla Flow*Effort (same year)	4.3833	0.9020
	[0.5967]	[0.4600]
Wakulla*Q4 Wakulla Flow*Effort (previous year)	-2.4351*	-0.4884
	[0.0636]	[0.3986]
Obs.	342	342
R-squared	0.9297	0.9527

Wild cluster (by county) bootstrapped p-values in brackets
*** p<0.01, ** p<0.05, * p<0.1

APPENDIX B

Subsample Robustness Check (1987-2012)

The following tables show Regressions 1 and 2 estimated using the data period 1987 to 2012. This is a robustness check to determine whether the effect of freshwater inflow on oyster stock and harvest persists when the years following the fishery collapse are excluded. These tables reinforce the finding that quarter three flow has the greatest effect on oyster stock and harvest, particularly in Franklin County. The magnitude and significance of the coefficients dissipates, but the overall findings are generally supported. It should be noted that due to the diminished magnitude of the coefficients, values estimated on these regressions would generally be lower than those estimated from the coefficients yielded using the full data period (1987-2017). There are also some unexpected results from the subsample regressions, including the negative, statistically significant effect of current year quarter three flow on harvest (Table 11b).

Table 5b: Impact of Quarter One Flow on Oyster Stock; 1987-2012

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q1 Bay Flow) (same year)	0.5647*	0.2331
	(0.2954)	(0.3926)
Bay*ln(Q1 Bay Flow) (previous year)	0.3765	0.0539
	(0.2694)	(0.2976)
Franklin*ln(Q1 Franklin Flow) (same year)	0.1664**	0.0760
	(0.0691)	(0.0921)
Franklin*ln(Q1 Franklin Flow) (previous year)	0.0286	-0.1603
	(0.0731)	(0.1047)
Levy*ln(Q1 Levy Flow) (same year)	-0.0618	-0.0255
	(0.0581)	(0.0635)
Levy*ln(Q1 Levy Flow) (previous year)	0.1645**	0.0437
	(0.0679)	(0.0666)
Wakulla*ln(Q1 Wakulla Flow) (same year)	0.1644**	0.0121
	(0.0771)	(0.1006)
Wakulla*ln(Q1 Wakulla Flow) (previous year)	-0.0713	-0.1726*
	(0.0861)	(0.0970)
Q1 Total Precipitation (inches) (same year)	-0.0006	0.0077
	(0.0041)	(0.0057)
Q1 Total Precipitation (inches) (previous year)	0.0066	0.0096**
	(0.0042)	(0.0048)
Q1 Average Temperature (F) (same year)	0.0177	0.0025
	(0.0139)	(0.0144)
Q1 Average Temperature (F) (previous year)	0.0000	-0.0220
	(0.0128)	(0.0141)
ln(Previous Season Avg. HpH)	0.2399***	0.6423***
	(0.0701)	(0.0835)
Obs.	276	276
R-squared	0.7262	0.6131

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Table 6b: Impact of Quarter Two Flow on Oyster Stock; 1987-2012

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q2 Bay Flow) (same year)	0.3984*	0.4635*
	(0.2405)	(0.2680)
Bay*ln(Q2 Bay Flow) (previous year)	0.3478	0.4224*
	(0.2115)	(0.2507)
Franklin*ln(Q2 Franklin Flow) (same year)	0.0414	0.0970
	(0.0701)	(0.0882)
Franklin*ln(Q2 Franklin Flow) (previous year)	-0.0227	-0.0226
	(0.0631)	(0.0853)
Levy*ln(Q2 Levy Flow) (same year)	0.0343	0.0866
	(0.0611)	(0.0665)
Levy*ln(Q2 Levy Flow) (previous year)	0.1067*	0.1313**
	(0.0630)	(0.0538)
Wakulla*ln(Q2 Wakulla Flow) (same year)	0.0505	-0.0788
	(0.0797)	(0.0733)
Wakulla*ln(Q2 Wakulla Flow) (previous year)	-0.1773***	-0.0682
	(0.0660)	(0.0752)
Q2 Total Precipitation (inches) (same year)	0.0005	0.0076
	(0.0061)	(0.0060)
Q2 Total Precipitation (inches) (previous year)	0.0090*	0.0110*
	(0.0048)	(0.0059)
Q2 Average Temperature (F) (same year)	-0.0169	-0.0242
	(0.0157)	(0.0188)
Q2 Average Temperature (F) (previous year)	-0.0054	-0.0174
	(0.0159)	(0.0184)
ln(Previous Season Avg. HpH)	0.2330***	0.6143***
	(0.0676)	(0.0809)
Obs.	276	276
R-squared	0.7239	0.6268

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Table 7b: Impact of Quarter Three Flow on Oyster Stock; 1987-2012

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q3 Bay Flow) (same year)	0.5695*	0.9595***
	(0.2951)	(0.3427)
Bay*ln(Q3 Bay Flow) (previous year)	0.5331	0.1722
	(0.3304)	(0.3326)
Franklin*ln(Q3 Franklin Flow) (same year)	0.0319	0.1243
	(0.1012)	(0.1133)
Franklin*ln(Q3 Franklin Flow) (previous year)	0.2052*	0.0939
	(0.1160)	(0.1194)
Levy*ln(Q3 Levy Flow) (same year)	0.0356	0.0744
	(0.0983)	(0.1130)
Levy*ln(Q3 Levy Flow) (previous year)	0.2697**	0.1443
	(0.1271)	(0.1226)
Wakulla*ln(Q3 Wakulla Flow) (same year)	0.0432	-0.0091
	(0.0873)	(0.0899)
Wakulla*ln(Q3 Wakulla Flow) (previous year)	0.1656	-0.0839
	(0.1095)	(0.0919)
Q3 Total Precipitation (inches) (same year)	0.0124***	0.0218***
	(0.0037)	(0.0047)
Q3 Total Precipitation (inches) (previous year)	-0.0019	-0.0027
	(0.0035)	(0.0038)
Q3 Average Temperature (F) (same year)	0.1117***	0.1670***
	(0.0425)	(0.0537)
Q3 Average Temperature (F) (previous year)	0.0432	-0.0741
	(0.0392)	(0.0456)
ln(Previous Season Avg. HpH)	0.2765***	0.6431***
	(0.0799)	(0.0992)
Obs.	276	276
R-squared	0.7310	0.6647

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Table 8b: Impact of Quarter Four Flow on Oyster Stock; 1987-2012

	(1) ln(HpT)	(2) ln(HpH)
Bay*ln(Q4 Bay Flow) (same year)	0.2570	0.4952
	(0.3379)	(0.4230)
Bay*ln(Q4 Bay Flow) (previous year)	-0.0575	0.0793
	(0.2807)	(0.3342)
Franklin*ln(Q4 Franklin Flow) (same year)	0.1490*	0.1399
	(0.0819)	(0.1040)
Franklin*ln(Q4 Franklin Flow) (previous year)	-0.0990	-0.1137
	(0.0731)	(0.0978)
Levy*ln(Q4 Levy Flow) (same year)	0.0642	0.1304
	(0.0847)	(0.1026)
Levy*ln(Q4 Levy Flow) (previous year)	-0.0161	0.0149
	(0.0867)	(0.1018)
Wakulla*ln(Q4 Wakulla Flow) (same year)	0.1013	0.0450
	(0.0739)	(0.0824)
Wakulla*ln(Q4 Wakulla Flow) (previous year)	-0.1164	-0.1204
	(0.0768)	(0.0892)
Q4 Total Precipitation (inches) (same year)	0.0111	0.0121
	(0.0087)	(0.0085)
Q4 Total Precipitation (inches) (previous year)	0.0013	-0.0004
	(0.0081)	(0.0090)
Q4 Average Temperature (F) (same year)	-0.1323***	-0.1142**
	(0.0414)	(0.0443)
Q4 Average Temperature (F) (previous year)	0.0992**	0.1357**
	(0.0393)	(0.0566)
ln(Previous Season Avg. HpH)	0.2515***	0.7018***
	(0.0817)	(0.1022)
Obs.	276	276
R-squared	0.7239	0.6353

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Table 9b: Impact of Quarter One Flow on Oyster Harvest; 1987-2012

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	1104.7660	209.1898*
	(678.1654)	(117.1622)
Bay*Effort*Effort	-0.4997**	-0.0098***
	(0.2105)	(0.0025)
Franklin*Effort	642.0958***	133.4910***
	(119.9334)	(13.1146)
Franklin*Effort*Effort	-0.0100*	-0.0005***
	(0.0055)	(0.0001)
Levy*Effort	-280.9728	25.5155
	(576.2415)	(72.1800)
Levy*Effort*Effort	0.5213	0.0063
	(0.3977)	(0.0072)
Wakulla*Effort	852.0061	77.2124
	(1197.3841)	(63.3551)
Wakulla*Effort*Effort	-1.4646	-0.0047
	(2.4037)	(0.0103)
Bay*Q1 Bay Flow*Effort (same year)	6.5439	0.0280
	(28.4734)	(4.4753)
Bay*Q1 Bay Flow*Effort (previous year)	16.6772	-1.0665
	(23.3226)	(2.3484)
Franklin*Q1 Franklin Flow*Effort (same year)	-0.0343	-0.0113**
	(0.0408)	(0.0053)
Franklin*Q1 Franklin Flow*Effort (previous year)	-0.0167	-0.0086**
	(0.0252)	(0.0037)
Levy*Q1 Franklin Flow*Effort (same year)	0.0454	-0.0368
	(0.4769)	(0.0551)
Levy*Q1 Franklin Flow*Effort (previous year)	0.4664	0.0134
	(0.4979)	(0.0541)
Wakulla*Q1 Wakulla Flow*Effort (same year)	7.1154**	-0.1249
	(3.2957)	(0.2435)
Wakulla*Q1 Wakulla Flow*Effort (previous year)	6.4474*	0.2250
	(3.6490)	(0.3606)
Obs.	289	289
R-squared	0.9550	0.9643

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Table 10b: Impact of Quarter Two Flow on Oyster Harvest; 1987-2012

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	1582.8812	398.4643**
	(1166.1692)	(198.3055)
Bay*Effort*Effort	-0.4624***	-0.0106***
	(0.1737)	(0.0031)
Franklin*Effort	682.8258***	118.9713***
	(117.0874)	(10.4639)
Franklin*Effort*Effort	-0.0115**	-0.0004***
	(0.0054)	(0.0000)
Levy*Effort	-249.9331	-10.4448
	(538.2991)	(77.8888)
Levy*Effort*Effort	0.5009	0.0066
	(0.3874)	(0.0078)
Wakulla*Effort	1347.4722	-4.2800
	(1198.7185)	(82.8478)
Wakulla*Effort*Effort	-1.1840	-0.0040
	(2.3034)	(0.0149)
Bay*Q2 Bay Flow*Effort (same year)	-10.5854	-9.2507
	(39.3619)	(6.5944)
Bay*Q2 Bay Flow*Effort (previous year)	1.9448	-2.9914
	(34.0790)	(4.9380)
Franklin*Q2 Franklin Flow*Effort (same year)	-0.1063**	-0.0082
	(0.0418)	(0.0056)
Franklin*Q2 Franklin Flow*Effort (previous year)	-0.0178	-0.0091
	(0.0410)	(0.0062)
Levy*Q2 Franklin Flow*Effort (same year)	0.6085	0.0857
	(0.5729)	(0.0811)
Levy*Q2 Franklin Flow*Effort (previous year)	0.2253	0.0385
	(0.5889)	(0.0869)
Wakulla*Q2 Wakulla Flow*Effort (same year)	13.5023*	0.4418
	(7.6434)	(0.6804)
Wakulla*Q2 Wakulla Flow*Effort (previous year)	-0.1026	1.0056*
	(4.0884)	(0.5628)
Obs.	289	289
R-squared	0.9570	0.9633

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Table 11b: Impact of Quarter Three Flow on Oyster Harvest; 1987-2012

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	1261.3658	295.9215**
	(904.6358)	(121.5764)
Bay*Effort*Effort	-0.4709***	-0.0087***
	(0.1741)	(0.0023)
Franklin*Effort	522.0552***	107.0243***
	(96.2585)	(9.7027)
Franklin*Effort*Effort	-0.0057	-0.0004***
	(0.0048)	(0.0000)
Levy*Effort	-163.4074	28.1825
	(456.6680)	(70.7348)
Levy*Effort*Effort	0.3021	0.0030
	(0.3468)	(0.0078)
Wakulla*Effort	1180.3094	190.4200**
	(1435.2315)	(94.4473)
Wakulla*Effort*Effort	-1.0153	-0.0175*
	(2.6051)	(0.0096)
Bay*Q3 Bay Flow*Effort (same year)	-14.1471	-6.8887*
	(28.6962)	(3.8214)
Bay*Q3 Bay Flow*Effort (previous year)	26.4530	0.5692
	(24.3406)	(3.5907)
Franklin*Q3 Franklin Flow*Effort (same year)	-0.1160**	-0.0163*
	(0.0589)	(0.0088)
Franklin*Q3 Franklin Flow*Effort (previous year)	0.1422***	0.0123**
	(0.0468)	(0.0057)
Levy*Q3 Franklin Flow*Effort (same year)	1.3211	0.0655
	(0.9800)	(0.1366)
Levy*Q3 Franklin Flow*Effort (previous year)	0.4773	0.0457
	(0.6311)	(0.1054)
Wakulla*Q3 Wakulla Flow*Effort (same year)	4.6837	-1.2029
	(8.8633)	(0.7331)
Wakulla*Q3 Wakulla Flow*Effort (previous year)	16.7738**	0.2875
	(7.0732)	(0.5870)
Obs.	289	289
R-squared	0.9597	0.9636

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

Table 12b: Impact of Quarter Four Flow on Oyster Harvest; 1987-2012

	(1) Pounds Effort: Trips	(2) Pounds Effort: Hours
Bay*Effort	3351.8984**	305.5036**
	(1410.0128)	(144.2938)
Bay*Effort*Effort	-0.5786***	-0.0090***
	(0.2182)	(0.0024)
Franklin*Effort	663.5913***	125.8493***
	(125.2915)	(11.3930)
Franklin*Effort*Effort	-0.0109*	-0.0005***
	(0.0060)	(0.0001)
Levy*Effort	113.6604	30.8434
	(528.0445)	(66.3578)
Levy*Effort*Effort	0.4877	0.0064
	(0.3855)	(0.0075)
Wakulla*Effort	2361.9376	97.6093
	(1543.0506)	(73.9445)
Wakulla*Effort*Effort	-1.7098	-0.0091
	(2.9094)	(0.0085)
Bay*Q4 Bay Flow*Effort (same year)	-64.9165	-2.3376
	(47.1575)	(5.7364)
Bay*Q4 Bay Flow*Effort (previous year)	-52.7043	-5.2700
	(41.0741)	(5.2443)
Franklin*Q4 Franklin Flow*Effort (same year)	-0.0598	-0.0087
	(0.0389)	(0.0058)
Franklin*Q4 Franklin Flow*Effort (previous year)	-0.0518	-0.0181***
	(0.0383)	(0.0054)
Levy*Q4 Franklin Flow*Effort (same year)	0.2059	0.0809
	(0.9943)	(0.1305)
Levy*Q4 Franklin Flow*Effort (previous year)	-0.7317	-0.0559
	(0.6682)	(0.1212)
Wakulla*Q4 Wakulla Flow*Effort (same year)	9.0205	1.0754
	(10.2839)	(0.8608)
Wakulla*Q4 Wakulla Flow*Effort (previous year)	-2.6049	-0.4570
	(6.5296)	(0.4713)
Obs.	289	289
R-squared	0.9551	0.9646

Robust standard errors in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

APPENDIX C

ESTIMATED VALUES, REGRESSION 1

I use the results from Regression 1, quarter three flow (Table 7), to calculate the values in Appendix C. The flow coefficients show the percent increase in stock from a one percent increase in freshwater inflow. To estimate the value of fresh water, I use these coefficients to calculate the expected change in CPUE from an additional unit of freshwater input over a harvest year, holding effort constant. Then, I determine the harvest level that would yield the new CPUE value and subtract the actual harvest from this estimated harvest. The resulting difference is the expected change in harvest (measured in pounds of oysters) from a marginal percent of freshwater inflow. I then multiply the change in harvest by the average price per pound in the period to yield the estimates of revenue from a marginal percent of freshwater inflow. These tables show the estimated pounds and revenue yielded from a marginal one percent of freshwater inflow.

Table 21: R1 Value Estimates, 1988-2017 – Bay County, Q3 Flow, Trips.

Year	Pounds Harvested	Trips	Price per Pound	Cost per Trip	Marginal Pounds (same year)^	Marginal Pounds (prev. year)^	Marginal Value (same year)^	Marginal Value (prev. year)^	Two Year Sum (pounds)	Two Year Sum (value)
1988	452,253	1,478	0.58	23.18	2,504.59	3,838.78	1,445.33	2,215.26	6,343.38	3,660.59
1989	333,296	842	0.67	34.76	1,845.78	2,829.03	1,234.46	1,892.06	4,674.81	3,126.52
1990	1,630,739	3,334	0.74	47.31	9,031.00	13,841.75	6,653.03	10,197.05	22,872.75	16,850.08
1991	2,112,070	4,354	0.46	29.04	11,696.50	17,927.50	5,332.21	8,172.80	29,624.00	13,505.01
1992	2,462,021	3,364	0.28	27.04	13,634.50	20,897.75	3,836.82	5,880.74	34,532.25	9,717.56
1993	3,486,032	4,343	0.23	24.14	19,305.75	29,589.75	4,422.49	6,778.31	48,895.50	11,200.80
1994	1,610,689	2,238	0.24	22.30	8,920.00	13,671.63	2,105.30	3,226.79	22,591.63	5,332.09
1995	1,952,419	2,428	0.23	24.68	10,812.50	16,572.25	2,527.84	3,874.41	27,384.75	6,402.25
1996	2,206,623	2,876	0.25	25.37	12,220.25	18,730.00	3,077.08	4,716.25	30,950.25	7,793.33
1997	504,420	710	0.29	26.62	2,793.47	4,281.56	797.08	1,221.70	7,075.03	2,018.78
1998	16,994	34	0.45	29.62	94.11	144.24	42.47	65.09	238.35	107.56
1999	1,606	9	0.38	8.92	8.89	13.63	3.39	5.19	22.53	8.57
2000	1,050	5	0.39	10.66	5.81	8.91	2.25	3.44	14.72	5.69
2001	200	1	0.42	10.90	1.11	1.70	0.46	0.70	2.80	1.16
2002	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	1,064,915	1,550	0.32	29.22	5,897.50	9,039.13	1,910.14	2,927.68	14,936.63	4,837.82
2004	1,477	3	0.41	26.55	8.18	12.54	3.36	5.15	20.72	8.51
2005	48,922	93	0.38	26.45	270.94	415.25	103.76	159.03	686.19	262.80
2006	65,830	88	0.37	36.69	364.56	558.77	136.18	208.73	923.33	344.91
2007	73,525	137	0.34	24.08	407.18	624.09	139.12	213.24	1,031.27	352.36
2008	31,017	57	0.38	26.81	171.77	263.28	64.46	98.80	435.05	163.26
2009	123,504	217	0.39	29.33	683.97	1,048.31	268.46	411.46	1,732.28	679.92
2010	189,165	261	0.45	42.83	1,047.61	1,605.66	471.55	722.73	2,653.27	1,194.28
2011	538,136	871	0.48	38.64	2,980.19	4,567.75	1,419.69	2,175.97	7,547.94	3,595.67
2012	249,481	785	0.61	25.44	1,381.64	2,117.63	842.27	1,290.94	3,499.27	2,133.21
2013	65,443	284	1.02	30.73	362.42	555.48	368.10	564.19	917.91	932.29
2014	569,550	1,509	0.82	40.52	3,154.19	4,834.38	2,578.92	3,952.67	7,988.56	6,531.58
2015	747,139	2,206	0.77	34.06	4,137.69	6,341.81	3,169.54	4,857.93	10,479.50	8,027.47
2016	150,106	639	0.98	30.34	831.28	1,274.11	817.70	1,253.30	2,105.39	2,071.00
*2017	69,706	227	0.96	38.64	386.03	591.67	369.94	567.01	977.70	936.95
Avg.	715,804	1,204	0.49	28.44	3,964.12	6,075.80	1,522.19	2,333.06	10,039.92	3,855.24

*Preliminary data included; flow coefficient + $p<0.1$, # $p<0.5$, ^ $p<0.01$

Table 22: R1 Value Estimates, 1988-2017 – Bay County, Q3 Flow, Hours.

Year	Pounds Harvested	Hours	Price per Pound	Cost per Hour	Marginal Pounds (same year)^	Marginal Pounds (prev. year)	Marginal Value (same year)^	Marginal Value (prev. year)	Two Year Sum (pounds)	Two Year Sum (value)
1988	452,253	4,501	0.58	7.61	5,141.22	1,165.41	2,966.86	672.52	6,306.63	3,639.38
1989	333,296	2,284	0.67	12.81	3,788.91	858.84	2,534.03	574.40	4,647.75	3,108.42
1990	1,630,739	16,744	0.74	9.42	18,538.38	4,202.38	13,657.00	3,095.84	22,740.76	16,752.84
1991	2,112,070	21,660	0.46	5.84	24,010.00	5,442.75	10,945.70	2,481.25	29,452.75	13,426.95
1992	2,462,021	18,753	0.28	4.85	27,988.25	6,344.25	7,876.05	1,785.31	34,332.50	9,661.35
1993	3,486,032	28,208	0.23	3.72	39,629.50	8,983.25	9,078.18	2,057.85	48,612.75	11,136.03
1994	1,610,689	15,457	0.24	3.23	18,310.38	4,150.75	4,321.63	979.66	22,461.13	5,301.29
1995	1,952,419	17,006	0.23	3.52	22,195.13	5,031.25	5,188.98	1,176.25	27,226.38	6,365.23
1996	2,206,623	19,980	0.25	3.65	25,085.00	5,686.25	6,316.45	1,431.81	30,771.25	7,748.26
1997	504,420	4,406	0.29	4.29	5,734.25	1,299.84	1,636.20	370.90	7,034.09	2,007.10
1998	16,994	272	0.45	3.70	193.18	43.79	87.18	19.76	236.97	106.94
1999	1,606	48	0.38	1.67	18.26	4.14	6.95	1.58	22.40	8.52
2000	1,050	46	0.39	1.16	11.93	2.70	4.61	1.05	14.64	5.66
2001	200	5	0.42	2.18	2.27	0.52	0.94	0.21	2.79	1.16
2002	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2003	1,064,915	21,307	0.32	2.13	12,106.00	2,744.25	3,921.01	888.83	14,850.25	4,809.84
2004	1,477	30	0.41	2.65	16.79	3.81	6.90	1.56	20.60	8.46
2005	48,922	450	0.38	5.47	556.15	126.07	213.00	48.28	682.22	261.28
2006	65,830	540	0.37	5.98	748.36	169.64	279.55	63.37	918.00	342.92
2007	73,525	671	0.34	4.92	835.84	189.47	285.59	64.74	1,025.30	350.32
2008	31,017	287	0.38	5.32	352.60	79.93	132.32	29.99	432.53	162.31
2009	123,504	1,059	0.39	6.01	1,403.99	318.26	551.07	124.92	1,722.25	675.99
2010	189,165	1,518	0.45	7.36	2,150.44	487.48	967.95	219.43	2,637.92	1,187.38
2011	538,136	4,797	0.48	7.02	6,117.50	1,386.75	2,914.24	660.62	7,504.25	3,574.85
2012	249,481	4,499	0.61	4.44	2,836.11	642.91	1,728.94	391.93	3,479.02	2,120.87
2013	65,443	890	1.02	9.81	743.96	168.64	755.62	171.28	912.60	926.90
2014	569,550	14,389	0.82	4.25	6,474.69	1,467.69	5,293.81	1,200.01	7,942.38	6,493.82
2015	747,139	27,914	0.77	2.69	8,493.50	1,925.31	6,506.16	1,474.82	10,418.81	7,980.98
2016	150,106	2,950	0.98	6.57	1,706.42	386.81	1,678.55	380.50	2,093.23	2,059.05
*2017	69,706	379	0.96	23.14	792.42	179.63	759.39	172.14	972.05	931.53
Avg.	715,804	7,967	0.49	5.70	8,137.29	1,844.58	3,124.65	708.30	9,981.87	3,832.95

*Preliminary data included; flow coefficient + p<0.1, # p<0.5, ^ p<0.01

Table 23: R1 Value Estimates, 1988-2017 – Franklin County, Q3 Flow, Trips.

Year	Pounds Harvested	Trips	Price per Pound	Cost per Trip	Marginal Pounds (same year)^	Marginal Pounds (prev. year)^	Marginal Value (same year)^	Marginal Value (prev. year)^	Two Year Sum (pounds)	Two Year Sum (value)
1988	4,235,445	15,457	0.58	20.86	3,744.50	11,566.50	2,170.83	6,705.56	15,311.00	8,876.39
1989	7,289,733	17,823	0.67	35.73	6,444.50	19,908.00	4,287.20	13,243.78	26,352.50	17,530.98
1990	8,488,585	20,639	0.71	38.15	7,505.00	23,182.00	5,301.65	16,376.13	30,687.00	21,677.78
1991	8,625,149	19,675	0.45	25.70	7,625.00	23,555.00	3,404.41	10,516.83	31,180.00	13,921.24
1992	12,400,000	20,403	0.30	23.81	10,996.00	33,969.00	3,270.29	10,102.62	44,965.00	13,372.91
1993	14,600,000	21,984	0.27	23.59	12,909.00	39,875.00	3,491.58	10,785.25	52,784.00	14,276.83
1994	6,767,891	11,472	0.26	20.26	5,983.50	18,483.00	1,565.34	4,835.34	24,466.50	6,400.68
1995	6,270,560	9,168	0.26	23.40	5,543.50	17,124.50	1,444.22	4,461.36	22,668.00	5,905.58
1996	7,699,521	10,547	0.30	28.38	6,807.00	21,027.00	2,015.64	6,226.38	27,834.00	8,242.02
1997	8,039,687	12,147	0.31	26.91	7,107.50	21,956.00	2,200.65	6,798.09	29,063.50	8,998.74
1998	12,200,000	17,741	0.31	27.83	10,749.00	33,204.00	3,324.52	10,269.56	43,953.00	13,594.08
1999	11,700,000	18,484	0.30	24.70	10,352.00	31,980.00	3,073.58	9,495.07	42,332.00	12,568.65
2000	18,300,000	24,641	0.28	26.99	16,188.00	50,008.00	4,477.09	13,830.63	66,196.00	18,307.72
2001	9,918,938	15,412	0.27	23.23	8,769.00	27,089.00	2,410.50	7,446.45	35,858.00	9,856.95
2002	11,100,000	17,351	0.29	24.53	9,856.00	30,448.00	2,865.12	8,851.18	40,304.00	11,716.31
2003	8,133,500	13,668	0.29	22.84	7,190.00	22,212.00	2,101.64	6,492.58	29,402.00	8,594.22
2004	11,000,000	14,842	0.31	30.68	9,753.00	30,131.00	3,065.82	9,471.56	39,884.00	12,537.38
2005	8,079,770	11,816	0.37	33.11	7,143.00	22,066.00	2,634.43	8,138.23	29,209.00	10,772.67
2006	16,200,000	21,764	0.35	34.23	14,354.00	44,339.00	5,015.88	15,493.87	58,693.00	20,509.75
2007	14,500,000	21,454	0.33	29.14	12,821.00	39,605.00	4,209.12	13,002.27	52,426.00	17,211.39
2008	16,800,000	29,692	0.35	26.32	14,864.00	45,920.00	5,261.62	16,254.94	60,784.00	21,516.56
2009	11,800,000	25,316	0.41	24.74	10,393.00	32,105.00	4,216.49	13,025.17	42,498.00	17,241.66
2010	12,300,000	26,140	0.41	25.41	10,897.00	33,661.00	4,472.92	13,816.91	44,558.00	18,289.83
2011	22,100,000	44,754	0.39	25.44	19,568.00	60,446.00	7,665.81	23,679.87	80,014.00	31,345.68
2012	7,688,312	23,393	0.58	25.09	6,797.00	20,996.50	3,952.40	12,209.30	27,793.50	16,161.70
2013	3,330,389	13,863	0.76	23.96	2,944.50	9,095.25	2,236.50	6,908.32	12,039.75	9,144.82
2014	2,840,054	11,777	0.79	25.16	2,510.75	7,756.00	1,995.20	6,163.40	10,266.75	8,158.60
2015	2,240,937	11,947	0.86	21.30	1,981.25	6,119.75	1,713.11	5,291.51	8,101.00	7,004.62
2016	2,376,495	14,418	1.01	21.76	2,101.00	6,490.00	2,112.18	6,524.54	8,591.00	8,636.72
*2017	595,797	4,166	1.05	19.77	526.75	1,627.06	554.45	1,712.64	2,153.81	2,267.09
Avg.	9,587,359	18,065	0.46	26.10	8,480.79	26,198.15	3,217.01	9,937.64	34,678.94	13,154.65

*Preliminary data included; flow coefficient + p<0.1, # p<0.5, ^ p<0.01

Table 24: R1 Value Estimates, 1988-2017 – Franklin County, Q3 Flow, Hours.

Year	Pounds Harvested	Hours	Price per Pound	Cost per Hour	Marginal Pounds (same year)	Marginal Pounds (prev. year)	Marginal Value (same year)	Marginal Value (prev. year)	Two Year Sum (pounds)	Two Year Sum (value)
1988	4,235,445	78,834	0.58	4.09	6,717.50	3,680.50	3,894.40	2,133.73	10,398.00	6,028.13
1989	7,289,733	85,661	0.67	7.43	11,561.50	6,335.00	7,691.28	4,214.35	17,896.50	11,905.63
1990	8,488,585	90,752	0.71	8.68	13,463.00	7,377.00	9,510.48	5,211.23	20,840.00	14,721.71
1991	8,625,149	77,318	0.45	6.54	13,679.00	7,495.00	6,107.40	3,346.37	21,174.00	9,453.76
1992	12,400,000	130,113	0.30	3.73	19,727.00	10,809.00	5,866.95	3,214.67	30,536.00	9,081.62
1993	14,600,000	137,220	0.27	3.78	23,157.00	12,689.00	6,263.43	3,432.08	35,846.00	9,695.50
1994	6,767,891	69,092	0.26	3.36	10,733.50	5,882.00	2,807.99	1,538.79	16,615.50	4,346.78
1995	6,270,560	60,647	0.26	3.54	9,944.50	5,449.00	2,590.79	1,419.60	15,393.50	4,010.39
1996	7,699,521	104,807	0.30	2.86	12,211.00	6,691.50	3,615.84	1,981.44	18,902.50	5,597.28
1997	8,039,687	107,302	0.31	3.05	12,750.50	6,987.00	3,947.85	2,163.34	19,737.50	6,111.19
1998	12,200,000	134,898	0.31	3.66	19,283.00	10,565.00	5,963.98	3,267.61	29,848.00	9,231.59
1999	11,700,000	127,878	0.30	3.57	18,572.00	10,177.00	5,514.15	3,021.62	28,749.00	8,535.76
2000	18,300,000	137,253	0.28	4.84	29,042.00	15,914.00	8,032.10	4,401.31	44,956.00	12,433.41
2001	9,918,938	79,348	0.27	4.51	15,732.00	8,620.00	4,324.55	2,369.54	24,352.00	6,694.08
2002	11,100,000	121,261	0.29	3.51	17,683.00	9,690.00	5,140.42	2,816.87	27,373.00	7,957.29
2003	8,133,500	77,036	0.29	4.05	12,899.50	7,068.00	3,770.53	2,065.98	19,967.50	5,836.51
2004	11,000,000	87,357	0.31	5.21	17,498.00	9,588.00	5,500.43	3,013.95	27,086.00	8,514.38
2005	8,079,770	81,692	0.37	4.79	12,814.50	7,022.00	4,726.16	2,589.81	19,836.50	7,315.96
2006	16,200,000	156,133	0.35	4.77	25,749.00	14,108.00	8,997.76	4,929.92	39,857.00	13,927.68
2007	14,500,000	145,654	0.33	4.29	23,001.00	12,603.00	7,551.20	4,137.55	35,604.00	11,688.75
2008	16,800,000	169,356	0.35	4.61	26,666.00	14,612.00	9,439.33	5,172.41	41,278.00	14,611.75
2009	11,800,000	143,967	0.41	4.35	18,645.00	10,216.00	7,564.37	4,144.68	28,861.00	11,709.06
2010	12,300,000	168,009	0.41	3.95	19,549.00	10,712.00	8,024.32	4,396.98	30,261.00	12,421.30
2011	22,100,000	363,203	0.39	3.13	35,102.00	19,234.00	13,751.29	7,534.97	54,336.00	21,286.26
2012	7,688,312	126,577	0.58	4.64	12,193.50	6,681.00	7,090.42	3,884.95	18,874.50	10,975.37
2013	3,330,389	68,915	0.76	4.82	5,282.00	2,894.00	4,011.95	2,198.14	8,176.00	6,210.10
2014	2,840,054	58,522	0.79	5.06	4,504.25	2,468.25	3,579.36	1,961.43	6,972.50	5,540.78
2015	2,240,937	35,902	0.86	7.09	3,554.00	1,947.50	3,073.01	1,683.93	5,501.50	4,756.93
2016	2,376,495	60,218	1.01	5.21	3,769.00	2,065.25	3,789.06	2,076.24	5,834.25	5,865.30
*2017	595,797	5,213	1.05	15.80	944.94	517.75	994.64	544.98	1,462.69	1,539.62
Avg.	9,587,359	109,671	0.46	4.96	15,214.27	8,336.59	5,771.18	3,162.28	23,550.86	8,933.46

*Preliminary data included; flow coefficient + p<0.1, # p<0.5, ^ p<0.01

Table 25: R1 Value Estimates, 1988-2017 – Levy County, Q3 Flow, Trips.

Year	Pounds Harvested	Trips	Price per Pound	Cost per Trip	Marginal Pounds (same year)	Marginal Pounds (prev. year)^	Marginal Value (same year)	Marginal Value (prev. year)^	Two Year Sum (pounds)	Two Year Sum (value)
1988	608,908	1,281	0.57	35.73	643.63	2,108.69	368.51	1,207.34	2,752.31	1,575.85
1989	948,962	2,742	0.63	28.78	1,003.13	3,286.31	635.38	2,081.57	4,289.44	2,716.95
1990	375,415	1,542	0.72	23.16	396.81	1,300.06	287.48	941.86	1,696.88	1,229.34
1991	174,864	688	0.45	15.00	184.84	605.56	83.07	272.14	790.41	355.21
1992	482,357	1,073	0.32	18.85	509.88	1,670.41	162.80	533.34	2,180.28	696.13
1993	491,367	1,187	0.29	15.61	519.38	1,701.59	149.16	488.67	2,220.97	637.82
1994	432,339	965	0.33	19.65	457.00	1,497.22	152.64	500.06	1,954.22	652.70
1995	288,794	680	0.36	20.35	305.28	1,000.09	111.40	364.94	1,305.38	476.34
1996	618,886	1,206	0.33	22.29	654.13	2,143.25	216.40	709.05	2,797.38	925.45
1997	321,988	774	0.37	20.11	340.34	1,115.06	125.30	410.51	1,455.41	535.80
1998	914,208	1,567	0.29	22.51	966.38	3,165.94	283.95	930.24	4,132.31	1,214.19
1999	987,797	1,811	0.32	22.74	1,044.13	3,420.75	331.52	1,086.14	4,464.88	1,417.66
2000	556,390	1,236	0.35	20.68	588.13	1,926.81	205.77	674.14	2,514.94	879.91
2001	548,007	1,133	0.35	22.30	579.25	1,897.75	203.42	666.44	2,477.00	869.86
2002	605,542	1,241	0.33	21.17	640.13	2,097.06	211.54	693.00	2,737.19	904.54
2003	355,354	833	0.34	19.01	375.63	1,230.63	127.46	417.58	1,606.25	545.04
2004	427,158	772	0.31	22.39	451.50	1,479.25	139.16	455.94	1,930.75	595.10
2005	1,366,093	1,890	0.38	36.39	1,444.13	4,730.75	553.72	1,813.90	6,174.88	2,367.62
2006	1,333,834	2,009	0.37	32.46	1,409.88	4,619.13	525.01	1,720.07	6,029.00	2,245.07
2007	1,032,057	1,878	0.32	23.15	1,090.88	3,574.13	349.95	1,146.57	4,665.00	1,496.52
2008	661,370	1,527	0.33	18.81	699.13	2,290.38	231.31	757.77	2,989.50	989.08
2009	278,690	742	0.35	17.22	294.56	965.09	102.86	337.01	1,259.66	439.88
2010	664,600	998	0.38	32.86	702.56	2,301.56	264.00	864.86	3,004.13	1,128.86
2011	1,120,123	1,511	0.33	31.94	1,184.00	3,879.13	388.53	1,272.93	5,063.13	1,661.46
2012	1,079,381	1,982	0.45	32.10	1,141.00	3,738.00	512.21	1,678.03	4,879.00	2,190.24
2013	653,731	1,815	0.67	31.69	691.06	2,263.88	463.07	1,517.00	2,954.94	1,980.07
2014	927,790	2,840	0.71	30.47	980.69	3,212.94	696.66	2,282.39	4,193.63	2,979.05
2015	1,211,140	3,206	0.67	33.36	1,280.25	4,194.25	860.95	2,820.56	5,474.50	3,681.51
2016	1,859,464	4,264	0.71	40.75	1,965.63	6,439.38	1,398.98	4,583.04	8,405.00	5,982.02
*2017	1,844,469	4,481	0.75	40.61	1,949.63	6,387.50	1,465.04	4,799.88	8,337.13	6,264.93
Avg.	772,369	1,662	0.44	25.74	816.43	2,674.75	386.91	1,267.56	3,491.18	1,654.47

*Preliminary data included; flow coefficient + p<0.1, # p<0.5, ^ p<0.01

Table 26: R1 Value Estimates, 1988-2017 – Levy County, Q3 Flow, Hours.

Year	Pounds Harvested	Hours	Price per Pound	Cost per Hour	Marginal Pounds (same year)	Marginal Pounds (prev. year)+	Marginal Value (same year)	Marginal Value (prev. year)+	Two Year Sum (pounds)	Two Year Sum (value)
1988	608,908	8,159	0.57	5.61	883.56	990.69	505.89	567.22	883.56	990.69
1989	948,962	17,039	0.63	4.63	1,376.94	1,543.88	872.16	977.90	1,376.94	1,543.88
1990	375,415	9,765	0.72	3.66	544.69	610.78	394.61	442.49	544.69	610.78
1991	174,864	5,362	0.45	1.92	253.75	284.50	114.04	127.85	253.75	284.50
1992	482,357	8,454	0.32	2.39	699.91	784.78	223.47	250.57	699.91	784.78
1993	491,367	8,139	0.29	2.28	713.00	799.47	204.76	229.59	713.00	799.47
1994	432,339	6,160	0.33	3.08	627.31	703.41	209.52	234.93	627.31	703.41
1995	288,794	4,406	0.36	3.14	419.06	469.88	152.92	171.46	419.06	469.88
1996	618,886	8,271	0.33	3.25	898.00	1,006.94	297.08	333.12	898.00	1,006.94
1997	321,988	5,136	0.37	3.03	467.22	523.88	172.00	192.86	467.22	523.88
1998	914,208	10,082	0.29	3.50	1,326.56	1,487.44	389.78	437.05	1,326.56	1,487.44
1999	987,797	13,604	0.32	3.03	1,433.31	1,607.06	455.10	510.26	1,433.31	1,607.06
2000	556,390	8,434	0.35	3.03	807.38	905.25	282.48	316.72	807.38	905.25
2001	548,007	7,865	0.35	3.21	795.19	891.56	279.25	313.09	795.19	891.56
2002	605,542	7,927	0.33	3.31	878.63	985.19	290.35	325.57	878.63	985.19
2003	355,354	4,499	0.34	3.52	515.63	578.16	174.96	196.18	515.63	578.16
2004	427,158	4,297	0.31	4.02	619.81	694.97	191.04	214.20	619.81	694.97
2005	1,366,093	10,845	0.38	6.34	1,982.25	2,222.63	760.05	852.22	1,982.25	2,222.63
2006	1,333,834	11,348	0.37	5.75	1,935.38	2,170.13	720.69	808.11	1,935.38	2,170.13
2007	1,032,057	8,657	0.32	5.02	1,497.50	1,679.13	480.39	538.66	1,497.50	1,679.13
2008	661,370	6,933	0.33	4.14	959.63	1,076.00	317.49	356.00	959.63	1,076.00
2009	278,690	2,948	0.35	4.33	404.38	453.44	141.21	158.34	404.38	453.44
2010	664,600	4,617	0.38	7.10	964.31	1,081.25	362.36	406.30	964.31	1,081.25
2011	1,120,123	9,641	0.33	5.01	1,625.38	1,822.38	533.36	598.01	1,625.38	1,822.38
2012	1,079,381	12,630	0.45	5.04	1,566.25	1,756.13	703.11	788.34	1,566.25	1,756.13
2013	653,731	9,748	0.67	5.90	948.56	1,063.56	635.62	712.68	948.56	1,063.56
2014	927,790	14,373	0.71	6.02	1,346.31	1,509.44	956.39	1,072.27	1,346.31	1,509.44
2015	1,211,140	16,356	0.67	6.54	1,757.38	1,970.50	1,181.81	1,325.13	1,757.38	1,970.50
2016	1,859,464	22,350	0.71	7.77	2,698.13	3,025.38	1,920.31	2,153.22	2,698.13	3,025.38
*2017	1,844,469	8,408	0.75	21.64	2,676.38	3,000.75	2,011.16	2,254.91	2,676.38	3,000.75
Avg.	772,369	9,215	0.44	4.91	1,120.73	1,256.62	531.11	595.51	1,120.73	1,256.62

*Preliminary data included; flow coefficient + p<0.1, # p<0.5, ^ p<0.01

Table 27: R1 Value Estimates, 1988-2017 – Wakulla County, Q3 Flow, Trips.

Year	Pounds Harvested	Trips	Price per Pound	Cost per Trip	Marginal Pounds (same year)	Marginal Pounds (prev. year)^	Marginal Value (same year)	Marginal Value (prev. year)^	Two Year Sum (pounds)	Two Year Sum (value)
1988	416,973	999	0.57	31.45	389.03	1,145.00	223.24	657.03	1,534.03	880.27
1989	243,405	547	0.65	37.69	227.13	668.41	146.52	431.18	895.53	577.69
1990	412,904	697	0.74	57.41	385.28	1,133.84	284.37	836.87	1,519.13	1,121.24
1991	275,853	520	0.50	34.97	257.41	757.50	129.24	380.32	1,014.91	509.56
1992	254,571	284	0.28	33.50	237.53	699.05	67.60	198.96	936.58	266.56
1993	475,413	546	0.27	30.38	443.59	1,305.47	117.87	346.87	1,749.06	464.74
1994	181,104	234	0.30	30.18	168.97	497.31	50.18	147.68	666.28	197.86
1995	262,684	316	0.29	32.04	245.09	721.31	71.95	211.74	966.41	283.69
1996	315,190	362	0.33	37.60	294.09	865.50	96.72	284.64	1,159.59	381.36
1997	94,779	127	0.35	34.04	88.44	260.27	30.72	90.42	348.70	121.15
1998	69,310	87	0.38	39.83	64.67	190.33	24.62	72.47	255.00	97.09
1999	134,049	188	0.33	30.95	125.06	368.09	41.34	121.68	493.16	163.02
2000	201,740	214	0.33	40.62	188.23	553.98	61.77	181.78	742.22	243.55
2001	605,382	674	0.31	36.58	564.88	1,662.38	175.22	515.66	2,227.25	690.89
2002	299,174	228	0.32	54.84	279.16	821.50	88.85	261.47	1,100.66	350.32
2003	192,271	121	0.33	67.85	179.41	527.98	58.34	171.70	707.39	230.05
2004	81,224	100	0.32	34.60	75.79	223.04	24.59	72.36	298.83	96.95
2005	247,171	217	0.40	59.51	230.61	678.73	91.77	270.09	909.34	361.86
2006	496,670	348	0.38	71.70	463.44	1,363.84	177.32	521.84	1,827.28	699.16
2007	586,906	355	0.36	77.76	547.63	1,611.63	196.18	577.33	2,159.25	773.51
2008	393,739	389	0.38	50.40	367.38	1,081.22	139.31	410.01	1,448.59	549.32
2009	392,769	352	0.41	59.53	366.50	1,078.56	148.91	438.24	1,445.06	587.15
2010	542,503	844	0.42	35.05	506.19	1,489.69	210.22	618.67	1,995.88	828.88
2011	639,788	995	0.42	35.25	597.00	1,756.88	249.24	733.48	2,353.88	982.73
2012	51,527	121	0.62	34.85	48.08	141.49	29.97	88.20	189.57	118.17
2013	7,090	27	0.73	25.21	6.62	19.47	4.84	14.23	26.08	19.07
2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2015	1,999	3	1.02	89.39	1.87	5.49	1.91	5.61	7.36	7.51
2016	17,302	19	0.52	62.35	16.14	47.51	8.42	24.78	63.66	33.19
*2017	18,956	68	2.20	80.41	17.69	52.05	38.86	114.36	69.74	153.21
Avg.	272,843	344	0.50	46.41	254.58	749.22	103.11	303.44	1,003.81	406.54

*Preliminary data included; flow coefficient + p<0.1, # p<0.5, ^ p<0.01

Table 28: R1 Value Estimates, 1988-2017 – Wakulla County, Q3 Flow, Hours.

Year	Pounds Harvested	Hours	Price per Pound	Cost per Hour	Marginal Pounds (same year)	Marginal Pounds (prev. year)	Marginal Value (same year)	Marginal Value (prev. year)	Two Year Sum (pounds)	Two Year Sum (value)
1988	416,973	6,535	0.57	4.81	155.53	-200.59	89.25	-115.11	-45.06	-25.86
1989	243,405	6,655	0.65	3.10	90.77	-117.09	58.55	-75.54	-26.33	-16.98
1990	412,904	12,796	0.74	3.13	154.00	-198.63	113.66	-146.60	-44.63	-32.94
1991	275,853	6,136	0.50	2.96	102.91	-132.69	51.67	-66.62	-29.78	-14.95
1992	254,571	3,763	0.28	2.53	94.95	-122.45	27.02	-34.85	-27.50	-7.83
1993	475,413	7,215	0.27	2.30	177.34	-228.69	47.12	-60.76	-51.34	-13.64
1994	181,104	2,338	0.30	3.02	67.55	-87.13	20.06	-25.87	-19.58	-5.81
1995	262,684	3,457	0.29	2.93	98.00	-126.34	28.77	-37.09	-28.34	-8.32
1996	315,190	3,397	0.33	4.01	117.56	-151.63	38.66	-49.87	-34.06	-11.20
1997	94,779	997	0.35	4.34	35.35	-45.59	12.28	-15.84	-10.23	-3.56
1998	69,310	682	0.38	5.08	25.85	-33.34	9.84	-12.69	-7.48	-2.85
1999	134,049	1,626	0.33	3.58	50.00	-64.48	16.53	-21.32	-14.48	-4.79
2000	201,740	1,999	0.33	4.35	75.25	-97.05	24.69	-31.84	-21.80	-7.15
2001	605,382	6,471	0.31	3.81	225.81	-291.19	70.05	-90.33	-65.38	-20.28
2002	299,174	2,066	0.32	6.05	111.59	-143.94	35.52	-45.81	-32.34	-10.29
2003	192,271	1,094	0.33	7.50	71.72	-92.47	23.32	-30.07	-20.75	-6.75
2004	81,224	1,044	0.32	3.31	30.30	-39.07	9.83	-12.68	-8.77	-2.85
2005	247,171	1,918	0.40	6.73	92.17	-118.89	36.68	-47.31	-26.72	-10.63
2006	496,670	3,015	0.38	8.28	185.25	-238.91	70.88	-91.41	-53.66	-20.53
2007	586,906	2,819	0.36	9.79	218.88	-282.31	78.41	-101.13	-63.44	-22.73
2008	393,739	1,864	0.38	10.52	146.88	-189.41	55.70	-71.82	-42.53	-16.13
2009	392,769	2,307	0.41	9.08	146.53	-188.91	59.54	-76.76	-42.38	-17.22
2010	542,503	4,729	0.42	6.26	202.38	-260.94	84.05	-108.37	-58.56	-24.32
2011	639,788	3,875	0.42	9.05	238.63	-307.75	99.62	-128.48	-69.13	-28.86
2012	51,527	581	0.62	7.26	19.22	-24.79	11.98	-15.45	-5.57	-3.47
2013	7,090	116	0.73	5.87	2.64	-3.41	1.93	-2.49	-0.77	-0.56
2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2015	1,999	9	1.02	29.80	0.75	-0.96	0.76	-0.98	-0.22	-0.22
2016	17,302	80	0.52	14.81	6.46	-8.32	3.37	-4.34	-1.87	-0.97
*2017	18,956	58	2.20	94.28	7.07	-9.12	15.54	-20.03	-2.04	-4.49
Avg.	272,843	3,091	0.50	9.60	101.77	-131.24	41.22	-53.15	-29.47	-11.94

*Preliminary data included; flow coefficient + p<0.1, # p<0.5, ^ p<0.01