The Effect of Algae Blooms on Property Values located on Florida's Indian River Lagoon

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Honors Thesis submitted in partial fulfillment of the requirements for Graduation with Distinction in Economics in Trinity College of Duke University.

Duke
University
Durham, North Carolina
2023

Acknowledgements

I am grateful for the consistent guidance from my faculty advisor Professor Christopher D. Timmins. His experience and insights into environmental economics and studying property values with water quality inspired my paper and enabled its research methods and analysis to be as educated as possible. I also want to thank Professor Kent P. Kimbrough for providing weekly feedback on my paper through the Honors Thesis Workshop; his recommendations improved my paper significantly. I also want to thank all of my peers in the Honors Thesis Workshop for providing their feedback throughout the two semesters. Lastly, I want to thank Duke's Social Science Research Institute (SSRI) and the Marine Resources Council for providing my paper with data into water quality and property sale prices that served as the basis for my paper's regression analysis.

Abstract

Florida's Indian River Lagoon has algae blooms that devastate ecosystems, water quality, and markets for seafood, recreation, and housing. This study estimates part of their economic impact by examining water quality's relationship with prices of properties sold near the estuary from 2007 to 2016. Using water quality scores from 0 to 100, my regression analysis estimates that one-unit increases in water quality are associated with one-percent increases in sale price. Upon summing this relationship over all properties in the sample, my paper estimates that these algae blooms have cost the housing market between $756 million to $3.6 billion.

JEL Classification: Q5, Q51, R21

Keywords: Algae blooms (brown tide), hedonic regression, fixed effects

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1. Introduction

Pollution of waterways is a severe issue along Florida's coastlines because it jeopardizes the sustainability of the ecosystems and harms the economic prosperity of the towns relying on the water for revenues from tourism, recreation, seafood, and housing markets. My research paper seeks to quantify the economic effects of algae blooms by exploring their impact on prices of properties located on or near the Indian River Lagoon, which is a set of three brackish, shallow-water lagoons known as the Mosquito Lagoon, Indian River, and Banana River. This Lagoon system is located on the Atlantic coast of Florida, and many of the homes and properties in these counties are located on the river system. Because the Indian River Lagoon provides enormous recreational benefits along with beautiful natural sceneries, the waterway adds significant value to these properties.

The ecosystem's health is important through the economic value that it adds to local properties and economies. Hazen and Sawyer's 2008 Economic Assessment and Analysis Update of the Indian River Lagoon studied willingness to pay and estimated that the Indian River Lagoon added $934 million in annualized real estate value to properties located within 0.3 miles of the waterway (Hazen and Sawyer, 2008). A similar investigation in 2016 found that the Indian River Lagoon generates annual revenues of $7.4 billion for the local economies (St. Johns River Water Management District, 2022). The Indian River Lagoon is unique because it supports biodiversity with over 2,200 animal species such as game fish (i.e. red drum, snook, speckled sea trout) and crustaceans (St. Johns River Water Management District, 2022).

In the last decade, algae blooms, known as brown tide, have hit the Indian River Lagoon, suffocating its water, killing its seagrass and fish populations, and leaving the waterway with a murkiness and stench that severely hurt the ecosystem's value to humans and marine life. These algae blooms have been most significant on the portions of the Indian River Lagoon located alongside Volusia, Brevard, and Indian River Counties, so the study's sample will be properties located within these three counties. Scientific findings reveal that these algae blooms are triggered by an excess of nutrients in the water, which are the products of runoff from sewage and fertilizers (Lapointe et al., 2015).

There is a great deal of economic literature exploring the effects of red tide (another type of algae bloom that is prevalent in the Gulf of Mexico) on the economies near estuaries on Florida's west coast, with property values, restaurant and lodging revenues as economic proxies. However, research into the Indian River Lagoon's brown tide algae blooms is more limited. Literature studying the Indian River Lagoon establishes a clear connection between sewage runoff and algae blooms, and demonstrates their adverse effects on seagrass and marine life (Lapointe et al., 2020). However, there are few, if any, published papers exploring the economic effects of the Indian River Lagoon's algae blooms, and I have found none that explore the economic proxy of property values here. I suspect that this disparity in literature can be explained by the fact that red tide is a more widespread issue than brown tide.

My paper aims to fill this gap by studying the effect of algae blooms on property values located directly on or near the Indian River Lagoon (defined by my paper as location within 3 U.S. Survey Miles of the waterway). Property values are the ideal proxy for measuring the economic effects of the algae blooms because their values strongly reflect the soundness of the ecosystem that they reside on. It's easy to restrict the sample to homes close enough to the water that property value will heavily depend on the recreational benefits of the waterway, which are in turn reliant on water quality. Because property values are more reliant on water health when they are located closer to the lagoon, there are spatial trends.

Algae blooms also harm commercial fishing revenues, but these are harder to isolate to the Indian River Lagoon because seafood is extracted from both inshore and offshore sites. For example, Brevard County is located beside the lagoon but its commercial fishing and seafood revenues can come from seafood caught well off the coast of Florida, and it is impossible to know what percentage of these revenues were from the lagoon and which were from offshore sites that are not affected by algae blooms. Property values are preferable because they are the unit of measurement, allowing for increased granularity, making trend identification stronger than county revenues for a variable such as commercial fishing revenues. I intend for my research to educate policy towards solutions to algae blooms, which will likely include sustainable economic development, improved waste practices, and ecosystem repair. My paper builds upon research into the economic effects of algae blooms and estimates water quality's effect on property prices near the Indian River Lagoon.

My paper explores existing literature studying the relationship between water quality and economic metrics, primarily property prices. My paper then transitions into a discussion of the water quality and property data, and incorporates this data into regression analysis to estimate the effect of water quality on property prices.

2. Literature Review

There is a great deal of literature studying related issues such as red tide on Florida's west coast and the effect of algae blooms on housing values on the Great Lakes. Bechard (2021) explores the effect of red tide on property values in Southwest Florida between the years of 2002 and 2018. He uses the Zillow Transaction and Assessment Dataset and defines treatment homes as those located within any of the 6 counties that experienced over 10 days of *K. Brevis* (red tide, a water quality issue prominent in southwest Florida) in the same month, and the control homes are those located within 6 counties that are similar in nearly all characteristics except for exposure to red tide. Bechard employs a difference in differences model to calculate the difference in property values between treatment and control groups and months and runs the model on distance bands of 1 mile increments, ranging from 0-5 miles, to find the effect of red tide on property values for each mile from the water's bank. He finds that among homes located within 1 mile of the water, those in the treatment condition sold for up to 30% less than control homes in the same month, essentially showing that in order to live amongst red tide, homeowners had to be compensated by having 30% of the original cost taken off. Bechard's paper has three major takeaways for my research. First, it demonstrates the benefits of using property values as the dependent variable to represent economic effects. Property values are good proxies for the economic effect of algae blooms because they are strongly linked with waterway health and the extent of this connection depends on the proximity of the home to the water, allowing for the regression estimates to include spatial considerations. Second, it employs a difference in differences model, which is appealing because it allows one to compare the difference between the changes over time in property values for treatment and control houses. Third, it provides an effective framework for selecting treatment and control groups. This metric serves as a threshold for assigning towns into the treatment group. My unit of assignment between water quality and property is at the property level, which is a luxury in terms of granularity and precision, and means that my regressions explore identification of observables as opposed to assignment to treatment and control.

Although they study different waterways, Wolf et al. (2022) explore a dependent variable that is more related to my paper: property prices (synonymous in this context with property values). Wolf et al. (2022) study the effect of algae blooms on Lake Erie on property prices within 1.2 km of the lake (because the results were not statistically significant beyond this distance). The authors use data from county auditors and tax offices to determine transaction prices. They employ a two-stage least squares (2SLS) regression to estimate the effect of algae blooms on property prices, controlling for housing attributes such as distance to the lake. The second stage regression employs property prices as the dependent variable. The first stage regression employs algae levels (a measure of harmful algae blooms) as the dependent variable with controls of property attributes, total phosphorus (a metric of algae blooms) and an interaction term between total phosphorus and distance to the Maumee River. Total phosphorus is a good instrument because it's correlated with harmful algae blooms but uncorrelated with property values. The Maumee River has a large agricultural purpose, so algae blooms can be sparked from its runoff fertilizer such as phosphorus and nitrogen. Thus, total phosphorus serves as a solid instrument because the only way it impacts decisions of home buyers is through its impact on algae growth. This paper finds that a 1 ug/L increase in algae concentrations lead to a decrease in property values by 1.7%, which is $2,205 on average. This paper has three takeaways for my research. First, this paper identifies a spatial component to the algae bloom effects (1.2 km) and I expect to see a similar trend in Florida housing data. Second, it adds controls for house attributes that I will implement in my regression. Third, it concludes by discussing economic benefits of water clean-up. I aim to add a similar conservation proposal to my paper.

Zhang et al. (2022) continue to provide insight into research involving property prices as they explore the economic costs of cyanobacterial algae blooms by looking at their impact on residential property values. Zhang et al. (2022) study this using transaction data for properties in 30 states that are close to 633 inland bodies of water. The Indian River Lagoon's algae is different (*Aureoumbra lagunensis*) but both cause negative environmental effects on waterways. This paper quantifies the effect of algae blooms by examining the marginal willingness to pay in order to reduce the algae frequency. The authors use water quality data from NASA satellite images and property price data from Zillow's ZTRAX database (which contains millions of spatially explicit transactions in the U.S.) and employ a scale hedonic property model with a regression equation with fixed-effects for census block, sale year-by-state, and sale month. The census block fixed effects control for household attributes such as the quality of local schools or urban centers. The sale year-by-state fixed effects control for time trends such as inflation that may vary by state. The monthly fixed effects control for seasonal trends in the housing market. This paper finds that a 10% increase in the annual occurrence in algae blooms leads to a reduction of 3.3% to 4.3% in housing prices, depending on the region. This paper has strong takeaways for my research because it shows the benefits of temporal and location-based fixed effects in regression analysis to compare different homes sold in the same year and same census block. It uses marginal willingness to pay as a metric for economic impact. These authors assigned properties to treatment and control based on how close they are to the water (with properties closest to the water assigned to the treatment group). My research instead aims for all homes in the study to differ only in the extent they were hit by algae blooms (and their varying water qualities as a result). This is critical in attributing differing trends in property prices to algae blooms.

The Indian River Lagoon's algae blooms are largely caused by sewage and runoff, so literature establishing this connection in other settings was examined. Wolf and Klaiber (2017) conduct a literature review to establish a connection between sewage runoff and eutrophication-induced algae blooms. They study metrics of water quality such as secchi depth (a measure of water transparency), and then examine water quality's impact on homes near a lake in six counties of Ohio. They use property price data from county auditor websites and employ a hedonic regression allowing for spatial heterogeneity to find that adjacent properties lose 22% of their value when their lake suffers from algae blooms. They state that their goal is to provide policymakers with preference data regarding home valuation amidst algae blooms. This allows policy to evaluate tradeoffs in measuring cleanup projects given budget constraints. This paper is insightful for my research because I use a hedonic regression model that controls for factors that impact house demand and include a policy discussion that helps resolve the Indian River Lagoon's algae blooms.

Bechard (2020) sheds insight into my research because this paper designs an econometric regression methodology to estimate the effect of one additional day of red tide on sales in a local region, which is applicable to my study of the economic effects of the algae blooms. The paper finds that during months with 17 or more days of red tide, each additional day with red tide results in a decline in lodging sales by 1 to 2% and a decline in restaurant sales by 0.5 to 1% (Bechard, 2020). Red and brown tide share many symptoms (i.e. reduced water visibility, dying seagrass, dying fish). Thus, this paper's methods for estimating the causal effect of red tide on the economics of Florida communities applies to my paper's setting as well. Bechard (2020) uses a spline approach to focus the regression on the most severe months in terms of water quality issues. In months with little to no red tide, businesses can make up for lost sales by compensating on days not affected by red tide. Therefore, to truly understand the effect of red tide on restaurant and lodging sales, it is necessary to estimate this effect during a month that businesses did not have enough “normal days” to compensate. Thus, there is a spline (or knot) introduced at day 17 (meaning 17 days exposed to red tide). The paper estimates two separate linear effects for the effect of red tide on sector sales, one for months in which there were fewer than 17 days of red tide and another for months with greater than 17 days of red tide. This paper studies lodging and restaurants because they are correlated with tourism, which is reliant on water quality (Bechard 2020). My paper uses property values as the economic proxy, but the trends are similar because algae blooms also hurt the appeal of water-based properties. This paper obtains publicly available data from the Florida Department of Revenue and gathers environmental health data from NOAA, exploring both sides of the issue: the economies and the ecosystems.

Larkin and Adams (2007) also provide a solid foundation for estimating the relationship between algae blooms and revenues, which generally relates to algae’s effects on property values because both topics attempt to quantify different types of ecosystem services. This economics paper employs a time-series model to estimate the effect of algal blooms on coastal businesses in Northwest Florida, revealing that algal blooms reduced lodging and restaurant revenues by $2.8 million and $3.7 million per month, which is significantly greater than the same effect estimated for the occurrence of tropical storms and rainfall (Larkin & Adams, 2017). My regression controls for time in its county by year fixed effects because property values on Florida’s coast are seasonal and subject to external trends such as recessions.

Zhang (2012) provides insight into water quality's impact on health. This is important because algae blooms also reduce property values because poor water quality introduces health risks such as illness incidence and unhealthy body weight. Zhang identifies a causal relationship between improved drinking water quality and the health of residents in rural China (Zhang, 2012). The paper's main application to my research is its econometric approach to quantifying a relationship between water quality and human health. In order to explain the effect of algae blooms on property values, it is important to prove that deteriorating water quality has adverse human health outcomes. In the Indian River Lagoon, toxic algae increases the health risks of recreational activities such as boating and swimming because it's harmful to breathe or swallow when it infiltrates the water. Toxic algae increases the risk associated with seafood consumption through bioaccumulation, where proportions of toxins increase as they move up the food chain. So, gamefish contain levels of toxins from algae that are dangerously high for human consumption. Thus, decreased water quality has negative human health consequences, and this is reflected in property values.

Walsh et al. (2010) estimate the effect of algae blooms on property values in Central Florida lakes. They use property data from the Orange County Property Appraiser and analyze water quality data from the Orange County Economic Development Partnership to estimate the effect of water quality on house prices in Central Florida. The authors use a hedonic property price model that reveals that a one unit increase in secchi depth leads to a $5,500 (1.24%) increase in the price of a mean lakefront property, and a $700 (0.36%) increase for non-lakefront properties (Walsh et al., 2010). The paper reveals the presence of edge effects (the impact of water quality on property values varies depending on whether a home is located on the water or not), proximity effects (the influence of the water quality decreases as distance between the property and water increases), and area effects (the impact of water quality on property value is an increasing function of the water body's surface area) (Walsh et al., 2010).

Since my research builds upon knowledge that algae blooms are causing ecosystem deterioration, it is important that I provide literature establishing this link. Lapointe et al. (2020) provide quantitative and qualitative evidence from historical records of policy decisions and water quality testing to show that algae blooms in the Indian River Lagoon consist of excessive levels of chlorophyll a, phytoplankton, and *Aureoumbra lagunensis* (brown tide) (Lapointe et al., 2020). These are the chemicals that contribute to the water quality scores that my paper uses. The authors discuss water sampling results from wet and dry seasons from 2013 to 2015 to demonstrate that eutrophication and nutrition surplus are driving seagrass loss through light limitation (Lapointe et al., 2020). Between 2011 and 2017, the Indian River Lagoon lost 95% of its seagrass (Lapointe et al., 2020). The authors assert that human wastewater is the primary driver of eutrophication.

These papers provide a solid foundation for my paper because they demonstrate that algae blooms, and deteriorating water quality more generally, have a negative impact on house prices. Although their settings are different, the effect of water quality on house prices is likely similar on the Indian River Lagoon, making this literature particularly relevant to my paper. Many of these papers estimate the amount that algae blooms devalue a home by calculating a compensating price differential, a tool of hedonic regression models that quantifies the precise amount that someone needs to pay or be paid for a good or bad characteristic, respectively. Hedonic regression is also useful in these papers because it estimates the influence that a demand-affecting factor such as water quality has on the price.

The remainder of this paper will employ data on water quality and property prices from the Indian River Lagoon to estimate the compensating price differential of water quality on property prices in this area.

3. Data

3.1. Overview

My paper aims to estimate the effect of algae blooms on property values. Thus, there are two components to the data that I will use. First, I have compiled water quality data from fifteen portions of the Indian River, corresponding to the locations that have water testing stations. Second, I have compiled property transactions of single-family homes located within 3 miles of the Indian River. The 3 mile parameter aims to restrict the study's focus to solely properties that derive significant value from the Indian River Lagoon, and this distance aligns with much of the literature discussed above. However, because the 3 mile distance is to some extent arbitrary, my paper includes robustness checks, running the same regression models with 1 and 5 mile distance parameters. These modifications in the distance parameter had negligible impacts on the results in terms of damage per property, but expanding the amount of homes implicated increases the overall damage, as discussed later. Combining water quality and property price data allows my paper to estimate the effect of water quality on property values. All of my data is confined to the three counties of Volusia, Brevard, and Indian River County (shown in Figure 1). Because these are all located on the Indian River Lagoon, and have had varying severities of algae blooms, they create the perfect scenario for the assignment of unique water quality values to every property.

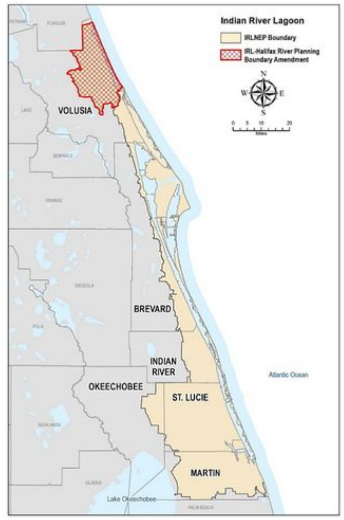

Fig 1: Map of Indian River Lagoon, with annotations for Volusia, Brevard, and Indian River County

My combined dataset includes 154,658 sales transactions of single-family homes from 2007 to 2016, with 62,267 of these coming from Volusia County (40%), 71,460 from Brevard (46%), and 20,931 from Indian River County (14%). When restricting the population to properties located within 3 miles of the Indian River Lagoon, the sample size drops to 75,203 single-family homes, with 11,744 coming from Volusia County (16%), 51,725 from Brevard (69%), and 11,734 from Indian River County (15%). These proportions are similar to those in the unrestricted sample with a drop in Volusia County due to the fact that the Indian River Lagoon is only located near southern Volusia County, so the 3 mile restriction drops all of Volusia's northern properties. Figures 2 and 3 provide maps that show the selection of properties within 3 miles of the Indian River Lagoon. The dark purple dots represent properties, and the yellow and green shapes are portions of the Indian River Lagoon.

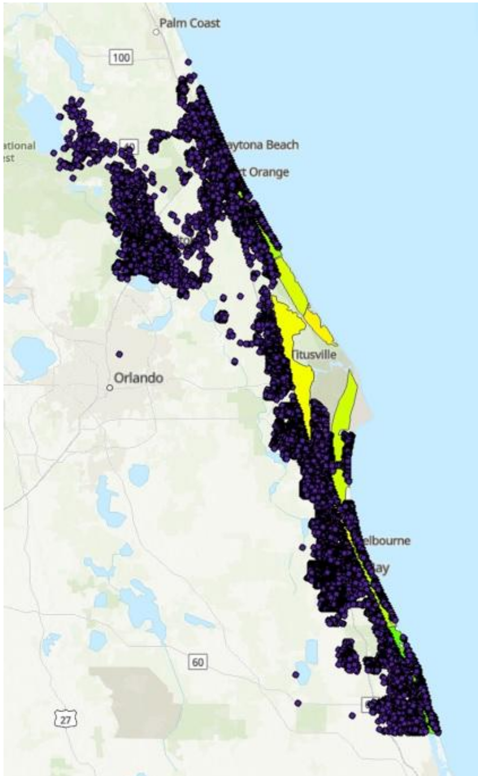

Fig 2: All properties

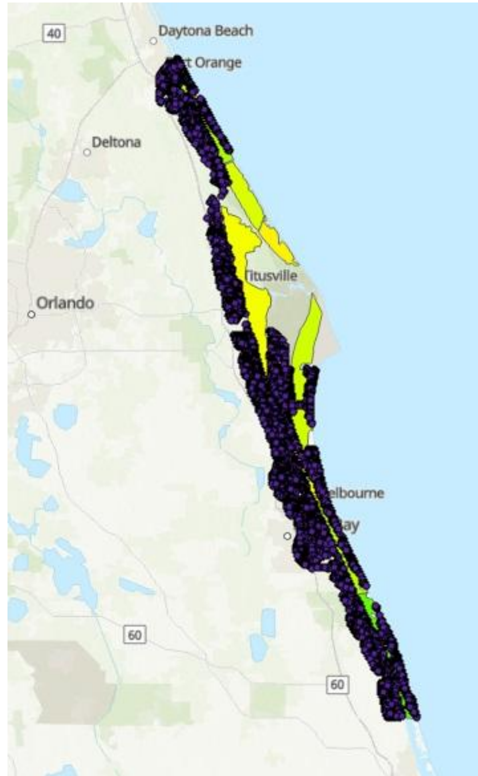

Fig 3: Exclusively properties within 3 miles of the Indian River Lagoon

3.2. Water Quality

Water quality data is important to establish when and where algae blooms were most prevalent, and to quantify the extent of the bloom. This is important because the severity of an algae bloom is closely connected with its impact on ecosystem deterioration, which is then very relevant to property values. My study takes data from the Marine Resources Council's "Ecological Health Assessment", which is a thorough analysis of water quality data on various metrics on a yearly basis from 1996 to 2019. This data source is very useful because it includes water quality scores from a scale of 0 to 100 for fifteen points along the Indian River Lagoon (all located within Volusia, Brevard, and Indian River Counties), allowing for granular assignment of water quality to properties. As discussed in the Section 3.3, a weighted average of the fifteen water qualities is calculated for each property for every year of the study. This study assigns weighted averages for water quality to each property because properties derive benefit from all portions of the Indian River Lagoon, not just the portion closest to them. For example, homeowners may use a boat ramp or beach located along a different river portion. In addition to the fact that a given property owner likely uses different parts of the river system for different recreational activities, the entire Indian River Lagoon is connected, and so the water quality along one portion will impact the health of another portion. That said, the importance of each river portion's water quality on property values will generally increase as the geographic proximity increases. Thus, a weighted average that relates water qualities with the inverse of distance (one divided by the distance squared) is an effective method to estimate the relationship.

Another unique element to this data set is that it compares the raw entries to benchmarks set by the EPA (United States Environmental Protection Agency) and SJRWMD (St. Johns River Water Management District). The Marine Resources Council combines four metrics (chlorophyll-a, nitrogen, phosphorus, and turbidity) to produce a water quality index. This places the data in context and gives an idea of how the water quality of each subsection of the Indian River Lagoon compares to other areas, and how these relationships vary over time. The water quality index is calculated by subtracting the actual levels from the designated target levels of chlorophyll-a, nitrogen, phosphorus, and turbidity, respectively, to get a score for each of these metrics, and then calculating the average of these scores, to assign an overall water quality grade for a given location. Scores of 0-49.999 are considered extremely poor, 50-59.999 are considered very poor, 60-69.999 are considered poor, 70-79.999 are considered average, 80-89.999 are considered good, and scores of 90-100 are considered very good.

I have provided some high level insights of this water quality data below that gives a solid foundational understanding of how algae blooms hit the Indian River Lagoon (IRL), and how the effects varied depending on the specific portion of the river system. Figure 4 shows the average water quality score (ranging from 0 to 100) for the entire study's period of 2007 to 2016 for each of the 15 IRL portions. They range from 34 (Big Flounder Creek) to 81 (Central Indian River Lagoon-South). Not surprisingly, the main portions of the river generally had higher water quality averages. This is likely because of their proximity to inlets. Figure 5 shows the effect of the algae bloom on water quality scores. The algae blooms began in the Indian River most significantly in the summers of 2009 and 2010, so the water quality values in 2007 represent the pre-algae bloom condition, when water quality values were at their peak, with no influence of the algae blooms. Figure 5 shows the water quality score in 2007 (pre-period) and 2016 (post-period) for each of the 15 Indian River Lagoon portions. The year of 2007 shows the highest water quality scores for each portion because it was before the algae blooms struck, and because the algae blooms hit significantly in the summers of 2009 through 2012, the year 2016 shows the water quality after they had sufficiently struck. The average decrease across all 15 portions of the Indian River Lagoon from 2007 to 2016 was 19.3 points. With no other immediate cause of the water quality decrease available in literature, it is fair to attribute most (if not all) of this nearly 20 point decrease to the algae blooms.

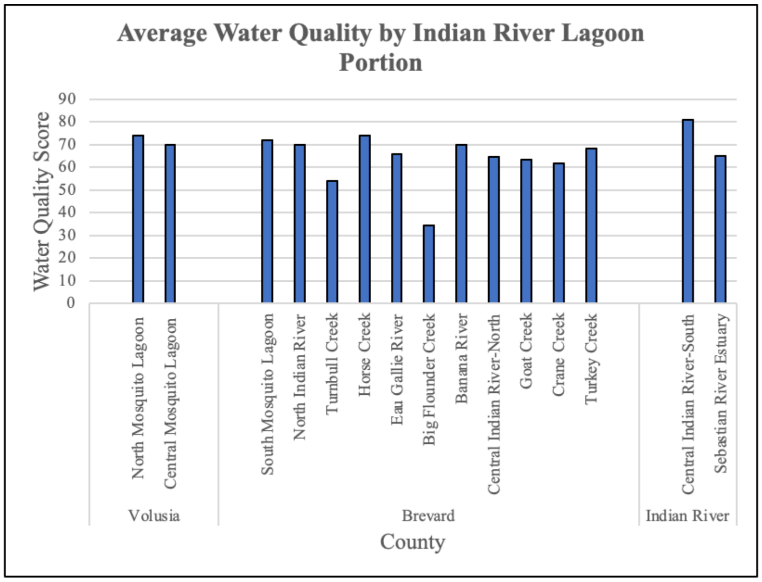

Fig 4: Average Water Quality for all 15 Indian River Lagoon (IRL) Sections

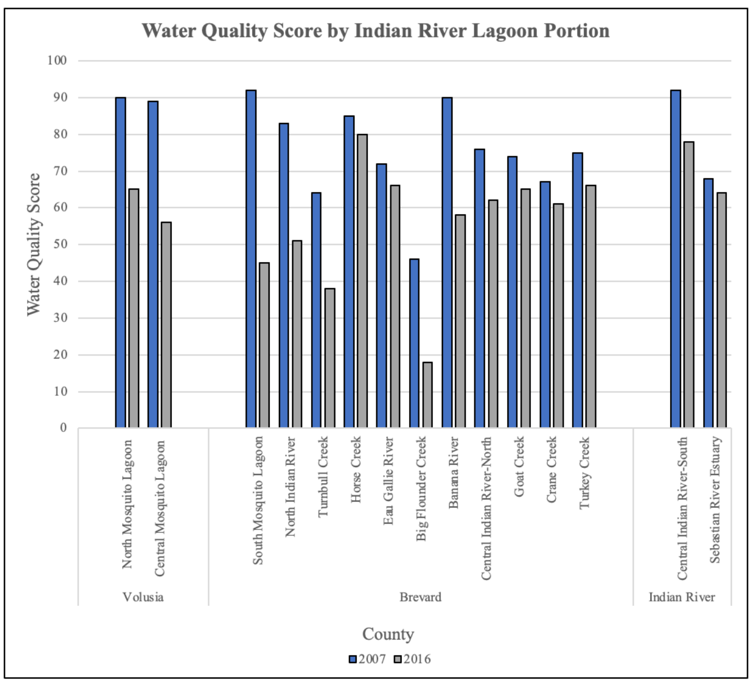

Fig 5: Water Quality in 2007 and 2016

Water quality dropped significantly from 2007 to 2016, and this effect was likely caused by the algae blooms. However, the river portions in Indian River County suffered less, and this is likely because of their close proximity to Sebastian Inlet, which exchanges water between the Indian River Lagoon and the Atlantic Ocean every day, minimizing the ability for algae-infested water to stagnate and linger in these portions of the Indian River Lagoon. Figures 6-8 have color-coded the Indian River Lagoon based on the water qualities of each river segment, where green represents stellar water quality, yellow represents mediocre water quality, orange represents poor water quality and red represents very poor water quality. These maps highlight that water qualities across all 15 segments of the Indian River were very strong in 2007, but were decimated by the algae blooms and had not recovered much at all by 2016. Within this larger trend, there are subtle differences in water quality across river portions as some parts fared better than others.

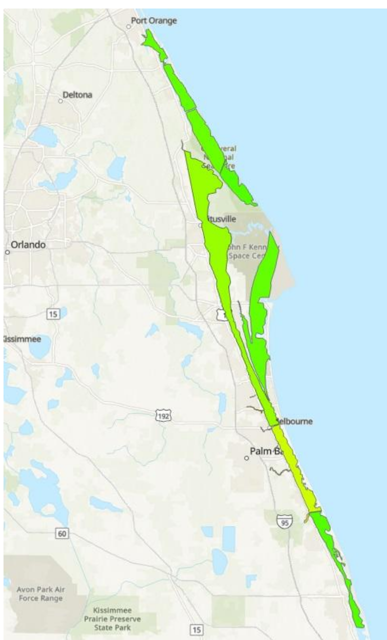

Fig 6: Indian River Lagoon in 2007

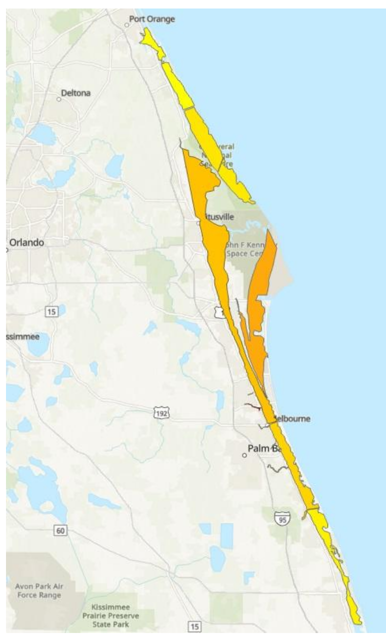

Fig 7: Indian River Lagoon in 2011

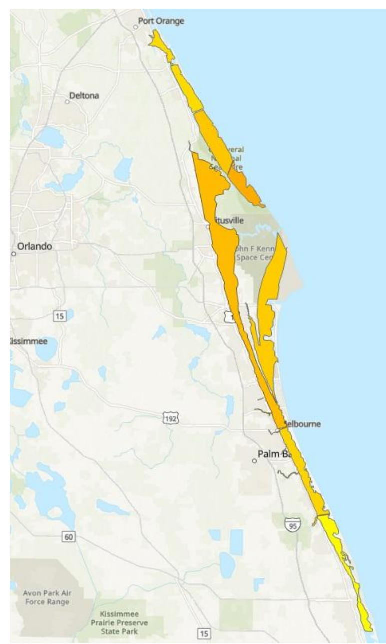

Fig 8: Indian River Lagoon in 2016

3.3 Weighted Average Calculation

To account for differences between river portions, my paper assigns a weighted average of water quality to each property based on its proximity to all fifteen portions of the Indian River Lagoon. There are fifteen portions of the Indian River Lagoon that touch Volusia, Brevard, and

Indian River Counties. Seven of the fifteen come from the main body of the Indian River Lagoon: the North Mosquito Lagoon, Central Mosquito Lagoon, South Mosquito Lagoon, North Indian River, Banana River, Central Indian River (North), and Central Indian River (South). The remaining eight portions come from the subsidiary waterways that are connected to the Indian River Lagoon. Of these eight tributaries, three come from the Central Indian River (North) and are known as Crane Creek, Turkey Creek, and Goat Creek. The fourth tributary comes from the Central Indian River (South) and is known as Sebastian River Estuary. The remaining four tributaries come from the North Indian River and are known as Horse Creek, Eau Gallie River, Turnbull Creek, and Big Flounder Creek. The Marine Resources Council provides yearly water quality data from each of these fifteen locations. Figure 9 provides a key that indicates which colors correspond to each river segment, and Figure 10 shows the map of these river segments.

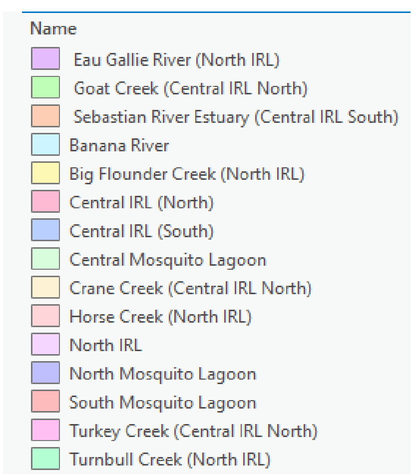

Fig 9: Color Key for IRL portions

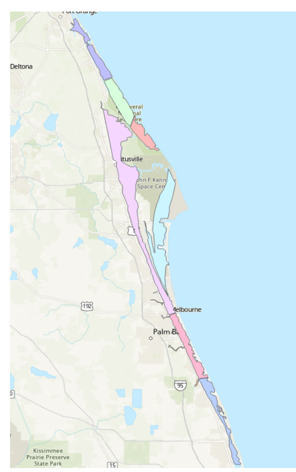

Fig 10: All 15 IRL portions

I plotted all of the properties from my SSRI data set into ArcGIS and generated the distance of each of these fifteen waterway segments to each property. I then calculated a weighted average of all fifteen water quality scores for each property using the house's proximity to each particular portion of the river system. The central equation for this weighted average is shown below:

Water Quality for Property i =

$$\frac{\sum_{j=1}^{15} (water\ quality_i * (\frac{1}{distance\ from\ i\ to\ j})^2)}{\sum_{j=1}^{15} ((\frac{1}{distance\ from\ i\ to\ j})^2)} \qquad (1)$$

where i = an individual property and j = an individual water quality testing station

For each property, the calculation of weighted average of water quality was a series of three steps. First, it multiplied the water quality of 1 individual river portion by (1/distance between property and river portion) squared. Next, it calculated this for each of the fifteen waterways and took the sum. Third, it normalized the weighted average by dividing by the sum of the inverse distances (1/distance) squared. This ensures that as the distance between a property and a portion of the river increases, my model's perceived influence of that portion's water quality on the property value decreases. The result of my calculations are individually calculated weighted averages of water quality, based on proximities to the fifteen portions, for each property. These weighted averages, like the original water quality scores, range from 0 to 100. This granular assignment of water quality should produce the most accurate results possible given the data available.

3.4. Property Data

Turning towards the property price data in my regression analysis, I used Duke's SSRI (Social Science Research Institute), which has proprietary data about all properties that were sold within Volusia, Brevard, and Indian River County from approximately 1990 (the year that the data starts varies slightly by county, with all beginning well before 2000) to 2016. My study focuses on single-family homes in this sample because they are the most comparable across counties. This data includes characteristics such as selling prices, homeowner names, house size, acres, mortgage information, and tax information. This data is preferable to Zillow's data because it includes more detailed information such as listing prices and times, which isn't available through ZTRAX (Zillow's Transaction and Assessment Database) anymore. This data is cross-sectional as it shows all properties available at specific points in time, and is also panel data, as it follows the same properties over time and will include all of their transactions over the study's time frame. The ability to see different homes at each point in time while also examining how a particular home price changes over time enhances my analysis. My regression models control for inflation and temporal differences in monetary value through yearly fixed effects and by adjusting prices with the consumer price index (CPI) for housing with the base year index of 1982-1984 as provided by the Federal Reserve Bank of St. Louis.

I have provided high level summary statistics of single-family homes that comprise my dataset. Table 1 compares the averages of sales price of properties in U.S. dollars (USD), the CPI-adjusted sales price of properties (in USD), the number of bedrooms, and acreage for each county before and after the algae blooms (2007 and 2016). All properties in the data set are very similar in terms of size, with between 2 to 3 rooms and a land area of approximately 0.3 acres. All properties generally dropped from $220,000 to $190,000 in terms of current U.S. dollars from 2007 to 2016, and this is likely due to various factors such as the algae blooms and the housing crash of 2008. Indian River County has the highest property sales prices of the group, with an average sale price of $280,000 in 2007. Holistically, the three counties have comparable property characteristics, indicating that these housing markets in different counties are very comparable in my data.

Table 1: Property Statistics by County

	Price USD	Price CPI	Bedrooms	Acreage
Volusia				
2007	$214,785	$102,481	2.69	0.31
2016	$193,752	$79,415	2.70	0.32
Brevard				
2007	$213,685	$101,956	3.05	0.29
2016	$188,501	$77,263	2.97	0.31
Indian River				
2007	$279,824	$133,513	2.86	0.28
2016	$228,080	$93,486	2.48	0.27
All Counties				
2007	$224,045	$106,899	2.97	0.29
2016	$193,141	$79,165	2.88	0.31

4. Empirical Specification

4.1. Empirical Strategy

I estimate the effect of water quality on the prices of properties located in Volusia, Brevard, and Indian River County, within 3 U.S. Survey Miles of the Indian River Lagoon, and sold between the years of 2007 and 2016. Since the Indian River Lagoon adds value to properties located on it through the recreation and views that it provides, people are willing to pay additional money for the trait of this Lagoon having clean, healthy water. As a result of these preferences, a decline in water quality should be reflected with a decline in property values. Declines in water quality are almost certainly caused by the algae blooms, so my model ultimately estimates the impact of the algae blooms on property values. I will use a hedonic regression model that employs identification on observables. By calculating a compensating price differential, my paper quantifies the true economic cost of algae blooms by estimating how much less people pay for homes that are affected by the algae blooms. I use the natural log of property price as the dependent variable because this allows for interpretation of coefficients as the percentage change caused by a one unit change in the independent variable. The period 2007 to 2016 was chosen because this gives a solid sample of water quality and property data for the three years before the algae blooms as a baseline, three years of the most severe onset of the blooms, and another four years reflecting the attempted ecosystem and economic recovery.

My regression model's equation is displayed below:

$$\begin{aligned} ln(\textit{property sale price})_{\mathrm{it}} = B_0 + B_1(\textit{water quality score})_{it} + B_2(\textit{bedrooms})_{it} + B_3(\textit{acres})_{it} \\ + B_4(\textit{county fixed effects})_{it} + B_5(\textit{year fixed effects})_{it} + \mu_{it} \end{aligned} \tag{2}$$

I expect the coefficient on water quality score (B_1) to be positive and statistically significant. In other words, as the water quality of the Indian River Lagoon improves, I expect the sales price of a property located within 3 miles of the waterway to increase. Economic theory has established that algae blooms and deterioration of water quality lead to decreases in property value. Although economic literature has not studied the Indian River Lagoon in-depth, I expect this same relationship to hold. The variable μ reflects the residuals, and B_0 reflects the constant.

In addition to the primary independent variable of water quality, my paper controls for house characteristics, county differences, and year differences. House characteristics are included because as the layout of the home varies, the impact of external factors such as water quality may vary as well. My paper includes the property's number of bedrooms and acres as controls. My paper includes county fixed effects in the regression because property values may vary across counties due to differences in the quality of public schools or downtown metropolitan areas. Fixed effects allow the model to compare homes within the same county over time, allowing us to isolate these potential confounders. Fixed effects for years are included as well to control for differences across years (i.e. effects from inflation, housing crisis) by comparing properties within the same year. My paper also includes a model that adjusts prices using the consumer price index (CPI) to control for inflation.

4.2. Results

Table 2 estimates five regression models. For all models, the dependent variable is the natural log of sales price, meaning that these regressions estimate the causal effect of different variables on the percentage change in the sale price of properties. The models vary in their inclusion or exclusion of controls and fixed effects. For completeness, each of them are described here. The control variable "wq_new" is the unique weighted average of water quality that was calculated for each property. This is representative of algae blooms, because as the algae blooms worsened, the water quality decreased. The control variable "number_of_bedrooms" is the number of bedrooms that a property has. The control variable "acreage" is the number of acres that a property's land area contains. Fixed effects for the fips code (the county) are employed in Models 3-5. Fixed effects for the year are employed in Model 5.

Table 2: Regression Results

VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4	(5) Model 5
wq_new	0.0101***	0.0107***	0.00891***	0.00980***	0.00967***
	(0.000271)	(0.000265)	(0.000290)	(0.000289)	(0.000594)
number_of_bedrooms		0.106***	0.109***	0.109***	0.109*
		(0.00177)	(0.00177)	(0.00177)	(0.0622)
acreage		0.0420***	0.0419***	0.0420***	0.0426*
		(0.00213)	(0.00212)	(0.00212)	(0.0258)
12061.fips_code			0.122***	0.114***	0.122***
			(0.00794)	(0.00792)	(0.0254)
12127.fips_code			0.0322***	0.0280***	0.0320
			(0.00736)	(0.00735)	(0.0199)
2008.sale_year_num					-0.108***
					(0.0131)
2009.sale_year_num					-0.331***
					(0.0127)
2010.sale_year_num					-0.315***
					(0.0171)
2011.sale_year_num					-0.184***
					(0.0227)
2012.sale_year_num					-0.282***
					(0.0160)
2013.sale_year_num					-0.236***
					(0.0134)
2014.sale_year_num					-0.207***
					(0.0111)
2015.sale_year_num					-0.0437***
					(0.0121)
2016.sale_year_num					0.0568***
					(0.0174)
Constant	11.13***	10.77***	10.87***	9.986***	10.98***
	(0.0195)	(0.0198)	(0.0208)	(0.0208)	(0.170)
Observations	75,148	75,148	75,148	75,148	75,148
R-squared	0.018	0.068	0.071	0.074	0.097

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Model 1 is the naive regression, and estimates the percentage difference in sales price associated with a one unit change in water quality score, for all properties, without taking into account house characteristics or county or year fixed effects. The coefficient is 0.0101 and is statistically significant at the 99% confidence level. This means that a one-unit increase in a property's water quality score was associated with a one percent increase in the sales price of that same property.

Model 2 is an alternate regression that estimates the effect of the same water quality scores on property sales prices, but it includes controls of house characteristics (number of bedrooms and acres). The coefficient on water quality (wq_new) is still positive and statistically significant at the 99% confidence level, with essentially the same magnitude: a one-unit increase in water quality score is associated with a 1.07 percent increase in the sales price of a property. The coefficients on the number of bedrooms and acres are positive and statistically significant at the 99% confidence level. The coefficient on the number of bedrooms indicates that when a property has one extra bedroom, it was associated with selling for 10.6 percent more. The coefficient on acres indicates that when a property's land area is one acre larger, it sells for 4 percent more.

Model 3 is another alternate regression with the same controls (water quality, number of bedrooms, acreage) and the additional inclusion of fixed effects by county. When comparing properties within the same county over time, these results are of similar magnitude, direction, and statistical significance as Models 1 and 2. The coefficient on water quality is .00891, indicating that a one-unit increase in water quality score is associated with almost a one percent increase in sales price. The coefficient on the number of bedrooms is 0.109, indicating an additional bedroom is associated with a 10.9 percent increase in sales price. The coefficient on acres indicates that adding one acre to a property was associated with it selling for 4 percent more. All of these coefficients are statistically significant at the 99% confidence level. For the county fixed effects, the coefficient on 12061 (Indian River County) is 0.122, indicating that being located in Indian River County was associated with a 12% increase in sales price. The coefficient on 12127 (Volusia County) is 0.0322, indicating that being located in Volusia County was associated with a 3% increase in sales price. These are both significant at the 99% confidence level and the probability of being greater than the F statistic is 0.0000, indicating that there is a significant clustering effect by county, so adding in the fixed effects improves the accuracy of Model 3. The fixed effects are helpful because they remove the impact of being located in a given county from the estimate of water quality's effect on property price (i.e. differing school quality, tax rates across counties).

Model 4 employs the same methods as Model 3 but uses a dependent variable with sales prices being adjusted using the consumer price index to control for inflation. The magnitude, direction, and significance of all variables is practically identical. A one unit increase in water quality was associated with approximately a one percent increase in the property's sale price.

Model 5 uses the same unadjusted property prices as Model 3, but adds year fixed effects. All of Model 5's coefficients indicate the same direction of influence (positive), similar magnitude as Models 1-4, and are all statistically significant at the 90% level or better. The coefficient on water quality is 0.00967, indicating that a one-unit increase in water quality score is associated with a 1% increase in sales price (and is significant at the 99% level). The coefficient on the number of bedrooms is 0.109, indicating that an additional bedroom is associated with a 10 percent increase in sales price. The coefficient on acres indicates that as a property is one acre larger, it sold for 4 percent more. The coefficients on county fixed effects are of the same magnitude and direction as in Model 3. All of the coefficients on yearly fixed effects are negative, except for 2016, indicating that the impact of being sold in each given year had a negative effect on sales price (except for 2016). This is likely because most of these years reflect years after the Housing Crisis. The yearly fixed effects isolate out the effect of being located in each year on sales price. This allows the model to control for yearly trends such as the Housing Crisis and inflation, ensuring that the coefficient on water quality shows only the association between water quality and property prices.

For context, the water quality score dropped on average by 20 points on the 0 to 100 scale as a result of the algae bloom across all 15 Indian River Lagoon portions. Since these models estimate that a 1 point decrease in water quality is associated with a 1 percent decrease in property values, this can be extended to estimate that the algae blooms caused somewhere close to a 20 percent decrease in property values. This fits well within the existing literature for other waterfront settings. As discussed in Section 2, Bechard (2021) studied the housing market in Southwest Florida and found that red tide was associated with a 30% decrease in property sale value. Wolf and Klaiber (2017) studied the housing market near Ohio lakes and found that algae blooms were associated with a 22% decrease in property sale value. My paper estimates that algae blooms have cost properties located along the Indian River Lagoon 20% of their original value. The settings of these three water quality events may vary, but the fact that all of these relationships are of sizable magnitude emphasizes their high severity and the need for environmental action.

This paper assumes that water quality enters the equation linearly, which is also consistent across the literature. Across all three counties, the average sale price for single-family homes was approximately $224,000 at the beginning of the study's period (2007) and $193,000 at the end (2016). The average property within 3 miles of the Indian River Lagoon was sold for about $180,000 over the whole period, and the average water quality drop over the period was 20 percent. Given this, my model estimates that algae blooms (through deteriorating water quality) are associated with a $36,000 decrease in value per property. Considering that my study found over 75,000 sales transactions of single-family homes located within 3 miles of the Indian River Lagoon between the years of 2007 and 2016, my model suggests that the housing market has lost $2.7 billion as a result of the algae bloom as of 2016.

It is worth noting, however, that if water quality's relationship with property prices is nonlinear, I would expect the marginal effect of water quality to decrease as water quality gets increasingly poor. For example, a small decrease in already poor water quality would probably have a smaller effect than a decrease of the same magnitude in previously healthy water quality. This would create a wider range of damage estimates depending on the location of properties.

4.3. Robustness Checks: Varying Distance Parameters

Given the immense magnitude of these economic losses, my study ensures their legitimacy by running the same regression models with different distance parameters. The first robustness check restricts the population to single-family homes located within one mile of the Indian River Lagoon, and the second robustness check restricts the population to those located within five miles of the Indian River Lagoon.

Table 3 shows the regression results for the first robustness check: the one mile distance parameter. The direction and significance of these results are practically identical to those found in Table 2. All of these water quality effects are significant at the 99% confidence level, and the percent change in sales price that is associated with a one unit change in water quality ranges from 0.5 percent to 1.5 percent. These findings are very similar to those from Table 2, indicating that restricting to homes located within one or three miles within the Indian River Lagoon did not have a significant effect on the impact of water quality on property values. The average property price in this smaller sample of homes located within 1 mile of the water dropped from $253,000 in 2007 to $221,000 in 2016, with an average over the entire period of $216,000. Multiplying this average price by the 0.5 to 1.5 percent coefficient and the average 20 point decrease in water quality leads my paper to estimate approximate per-property damages with a range of $21,600 to $64,800. Summing this over all 35,000 properties located within 1 mile of the Indian River Lagoon, my paper estimates total damages of this sample within a range of $756 million to $2.27 billion. Intuitively, it makes sense that the range would be wider for properties located within a narrower distance from the water because they are more affected by subtle changes in water quality.

Table 3: Regression Results with One-Mile Distance Parameter

VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4	(5) Model 5
wq_new	0.0132***	0.0145***	0.00669***	0.00747***	0.00525***
	(0.000418)	(0.000396)	(0.000421)	(0.000420)	(0.000752)
number_of_bedrooms		0.267***	0.282***	0.283***	0.286***
		(0.00428)	(0.00420)	(0.00418)	(0.0187)
acreage		0.0259***	0.0253***	0.0254***	0.0257
		(0.00256)	(0.00248)	(0.00247)	(0.0173)
12061.fips_code			0.614***	0.605***	0.639***
			(0.0132)	(0.0131)	(0.0173)
12127.fips_code			0.137***	0.135***	0.150***
			(0.0110)	(0.0109)	(0.0130)
2008.sale_year_num					-0.120***
					(0.0203)
2009.sale_year_num					-0.310***
					(0.0198)
2010.sale_year_num					-0.334***
					(0.0244)
2011.sale_year_num					-0.244***
					(0.0311)
2012.sale_year_num					-0.283***
					(0.0210)
2013.sale_year_num					-0.217***
					(0.0192)
2014.sale_year_num					-0.168***
					(0.0176)
2015.sale_year_num					-0.0419**
					(0.0195)
2016.sale_year_num					-0.0112
					(0.0256)
Constant	11.04***	10.17***	10.59***	9.713***	10.84***
	(0.0300)	(0.0316)	(0.0319)	(0.0318)	(0.0805)
Observations	34,359	34,359	34,359	34,359	34,359
R-squared	0.028	0.130	0.182	0.185	0.200

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4 shows the results from the same empirical specification as Tables 2 and 3, but with the population restricted to properties located within five miles of the Indian River Lagoon. The statistical significance, direction, and magnitude of these coefficients are also very similar to those from Tables 2 and 3. All coefficients for water quality across the five models are significant at the 99% confidence level, and the impact of a one percent change in water quality on sales price ranges from 0.9 to 1.1 percent. Thus, changing the population to properties located within 5 miles of the Indian River Lagoon did not have a notable impact on the regression results, but it does change the overall estimate of damages as a result of the algae blooms. The average property sales price of properties within 5 miles of the Indian River Lagoon dropped from $228,000 in 2007 to $192,000 in 2016, with an average of the entire period of $180,000. Multiplying this by the 1 percent coefficient and the 20 point decrease in water quality gives per-property damages of $36,000. Summing over the approximately 100,000 properties located within 5 miles of the river, our study's estimates of total damages increases to $3.6 billion.

Table 4: Regression Results with Five-Mile Distance Parameter

VARIABLES	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4	(5) Model 5
wq_new	0.0107***	0.0115***	0.00989***	0.0108***	0.00927***
	(0.000235)	(0.000228)	(0.000252)	(0.000251)	(0.000472)
number_of_bedrooms		0.116***	0.118***	0.119***	0.119**
		(0.00156)	(0.00156)	(0.00156)	(0.0570)
acreage		0.0450***	0.0449***	0.0449***	0.0452**
		(0.00186)	(0.00186)	(0.00185)	(0.0228)
12061.fips_code			0.0895***	0.0808***	0.103***
			(0.00648)	(0.00646)	(0.0188)
12127.fips_code			0.0614***	0.0572***	0.0678***
			(0.00579)	(0.00577)	(0.0128)
2008.sale_year_num					-0.130***
					(0.0108)
2009.sale_year_num					-0.342***
					(0.0103)
2010.sale_year_num					-0.335***
					(0.0133)
2011.sale_year_num					-0.230***
					(0.0169)
2012.sale_year_num					-0.305***
					(0.0125)
2013.sale_year_num					-0.253***
					(0.0103)
2014.sale_year_num					-0.209***
					(0.0119)
2015.sale_year_num					-0.0553***
					(0.0116)
2016.sale_year_num					0.0220
					(0.0140)
Constant	11.10***	10.70***	10.78***	9.893***	11.00***
	(0.0168)	(0.0172)	(0.0181)	(0.0180)	(0.171)
Observations	99,751	99,751	99,751	99,751	99,751
R-squared	0.020	0.077	0.079	0.084	0.108

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

It’s worth noting that the proportion of properties from each county did not vary significantly when changing the distance parameter, nor did the average property sales prices (although the average property sales price was highest in the one-mile distance parameter population, likely because it contained a higher proportion of waterfront properties). The results from Tables 3 and 4 further support the study’s findings by demonstrating that they are robust to changes in the distance parameter. Thus, the effects of algae blooms on property sales prices are consistent across different proximities to the waterway. So even if the paper’s selection of 3 miles is arbitrary, changing this number does not have a significant impact on the findings. The estimates of total value-lost vary more because the distance parameter changes how many properties are being included in the damage calculations.

Synthesizing all models and distance parameters, my study estimates the effect of a one-unit increase in water quality to be approximately a one percent increase in sales price of a single-family home.

5. Conclusion

This paper finds that as water quality increases, property values increase as well, by approximately one percent across all regression models. The average decrease in water quality from 2007 to 2016 across all fifteen portions of the Indian River Lagoon was 20 percent and literature suggests that algae blooms are the primary reason water quality values dropped over this time period. Given that the average price of properties in my study's setting of single-family homes within 3 miles of the Indian River Lagoon was $180,000, my paper suggests that algae blooms have reduced the sale value of homes along the Indian River by $36,000 per home, leading to a loss of $2.7 billion over this entire group of properties sold. When taking into account the variations in the distance parameter, my study estimates a range of losses from $756 million to $3.6 billion.

This is significant evidence that the algae blooms that initially hit the Indian River Lagoon in 2009 and 2010 have had, and will continue to have, significant consequences on the economic prosperity of the counties residing along it. This is clearly reflected in the decreases in property values of single-family homes that follow declines in water quality, which are caused by the algae blooms. These economic losses are significant underestimates because in order to estimate the entirety of economic consequences, one would need to also consider losses in commercial and recreational industries (i.e. tourism, seafood, fishing).

Property values are important economic indicators because they reflect the desirability of a particular location. For example, when properties in Volusia County are higher, this indicates that living there is seen by the housing market as more desirable. This has positive spillover effects on the shops, restaurants, and even public investment. As demand for a particular region increases, the sales price of homes increases, and the average wealth of its residents increases, which leads to more money flow within the local economy.

It is in the best interest of Volusia, Brevard, and Indian River Counties to invest in their waterways because they have significant economic effects as well as health and environmental effects. Because algae blooms are caused by the runoff of fertilizer and pollution into the waterways, all policy approaches should aim to reduce pollutants. There are two methods for doing this: regulations and market-based approaches. Regulations should come from government legislation on the federal and state level, and research conducted by the EPA to produce strict and specific regulations that restrict the level of pollution that each factory located near the Indian River Lagoon can produce. Market-based approaches could include a cap and trade system, where the government sets a maximum total amount of pollution, with smaller levels for each individual producer. If producers pollute under their limit, they can sell their excess credits for profit. Market-based policies struggle to eliminate nonpoint-sources of pollution because it's so difficult to determine the precise pollution emitters at each given point in time, so regulations on every producer may be the best option.

A combination of these methods is also possible, but the results of this study point to a clear positive and causal association between water quality levels and property prices. Action should be taken to improve the water qualities of the Indian River Lagoon to improve the prosperity of the economies located on the waterway.

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