

# The Economic Impact and Market Forces of Shellfish Harvesting

*Understanding Landings, Ex-vessel Prices, and Factors Impacting the Soft-Shell Clam Fishery and Market*

**Final Report • February 2026**

Authors:

Benjamin Cotton and Kanae Tokunaga,  
Gulf of Maine Research Institute

Report Prepared for Maine Department of Marine  
Resources Shellfish Advisory Council



**Gulf of Maine  
Research Institute**

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## Acknowledgements

We thank the following people for providing data and supporting the analyses conducted in the study. Hannah Baranes and Katie Giannakopoulos at GMRI's Coastal Dynamics Lab provided guidance and support for us to analyze sea level and storm impacts on the soft-shell and hard clam fisheries. Julia Victor, Undergraduate Student at Scripps College and Research Experience for Undergraduates (REU) intern at GMRI, shared her intern project findings that shaped the section on storm closure impacts in this report. We also thank the Maine Shellfish Advisory Council for providing valuable feedback and insight into the fishery. We also thank DMR staff for providing and facilitating data access throughout this project. This project was funded by Maine DMR and Shellfish Advisory Council.

## Suggested Citation

Cotton, Benjamin, and Kanae Tokunaga. 2026. *The Economic Impact and Market Forces of Shellfish Harvesting Understanding Landings, Ex-Vessel Prices, and Factors Impacting the Soft-Shell Clam Fishery and Market*. Report Prepared for Maine Department of Marine Resources Shellfish Advisory Council. Portland, ME: Gulf of Maine Research Institute. <https://doi.org/10.5281/zenodo.18319294>.

## Executive Summary

Soft-shell clam harvesting is one of Maine's most historically significant and economically important coastal fisheries. Rooted in Indigenous and early settler use of intertidal resources, the fishery remains highly accessible and continues to support coastal livelihoods. In 2024, soft-shell clams generated more than \$15.5 million in harvester revenue, representing the state's second most valuable fishery. Despite this importance, the fishery is experiencing *sustained declines* in landings, reaching a record low of 5.69 million pounds in 2023.

This report examines long-term trends in soft-shell clam landings, prices, and market volatility across Maine from 2006–2023. Additional analysis of quahogs and oysters helps contextualize broader shifts in the bivalve sector.

## Key Findings

### Declining Landings, Resilient Prices

- Soft-shell clam landings declined by approximately 41% between 2006 and 2023.
- Despite declining harvest volumes, total landed value increased slightly (9.2%), driven by higher ex-vessel prices.
- Prices spiked sharply in 2015 and 2021 and have stayed elevated since 2015.
- Emerging species are reshaping Maine's shellfish market, offering alternative income opportunities as soft-shell clam availability declines.

### Seasonality and Market Structure

- Prices consistently peak during summer months (July–August), coinciding with tourism-driven demand.
- Structural break analysis identified one major shift in landings (2015), but three distinct price regime shifts, indicating price dynamics are influenced by more than supply changes alone.
- Regional price trends move together over time, with only modest and consistent differences across Downeast, Midcoast, and Southern Maine.

### Price Volatility

- Inter-annual (year-to-year) price volatility is low (0.18), indicating a relatively stable long-run market.
- Intra-annual (week-to-week) volatility is moderate (0.38), reflecting seasonal demand and short-term supply disruptions.
- The most volatile years were 2020 (COVID-19 impacts) and 2023 (historically low landings).

### Environmental Impacts

- Rising sea levels are negatively associated with harvest levels. Each additional foot of mean lower low water (MLLW) is linked to a 19.2% decrease in weekly summer landings.
- Southern Maine shows a pronounced harvest decline at tidal heights above approximately 2.86 feet MLLW.

- Storms significantly reduce harvest activity; each additional storm in a week corresponds to a 15.6% decrease in weekly landings.
- Precipitation-based mudflat closures are recently concentrated in winter months, limiting their impact on annual landings.

### **Implications**

The soft-shell clam fishery remains economically viable but increasingly constrained by environmental change, access limitations, and declining biological productivity. Prices have partially compensated for reduced landings, but this trend may not be sustainable if supply continues to fall. Climate-driven shifts pose growing risks to harvest accessibility, especially during peak summer seasons.

### **Recommendations for Future Research and Policy**

- Improve understanding of harvester adaptation strategies in response to environmental and access constraints.
- Expand economic analysis of emerging bivalve species and stock enhancement programs.
- Integrate new environmental datasets into fisheries economics research.
- Enhance state data systems to better align landings, closures, and environmental variables for future analysis.

Overall, sustaining Maine's soft-shell clam fishery will require continued research, improved data infrastructure, and adaptive management that reflect both economic realities and environmental change.

## Introduction

Clam harvesting boasts a rich history in Maine, evidenced by more than 1,700 shell middens that span the coast (Spiess, 2017). Long before it evolved into a vital industry, clamming provided sustenance for families, as coastal settlements and Indigenous communities have used this resource for thousands of years (*The Mudflat*). Today, it remains accessible, requiring little more than a license, a bucket, and a clam fork. With this heritage and accessibility, soft-shell clams (*mya arenaria*) have remained one of the most valuable fisheries in the state, surpassing \$15.5 million to harvesters in 2024 (Maine DMR, 2024). While lobster remains the highest valued fishery in Maine, the soft-shell clamming industry has provided a strong market for decades in Maine, generating high economic impact for the state in the early 2000s (Athearn, 2008) and contributing about 60% of total US soft-shell clam production (Evans et al., 2016).

This fishery has been supported by Maine’s extensive and uniquely suited natural environment, including roughly 3,400 miles of jagged coastline, much of it composed of nutrient-rich mudflats that provide a suitable habitat for soft-shell clam growth (*The Mudflat*). Given this environment, Maine previously saw a booming wild-harvest shellfish industry through the 1970s and early 80s, reaching 38 million pounds harvested in 1977 (Figure 1). However, recent changes to both the physical, environmental, and socioeconomic landscape has presented new challenges for clambers and their ability to sustain a livelihood. Soft-shell clam landings have been declining in Maine, reaching a record low in 2023 of 5.69 million pounds harvested.<sup>1</sup> With these declining conditions, it is important to understand where the current state of the fishery lies and the factors that will shape the future of the industry.

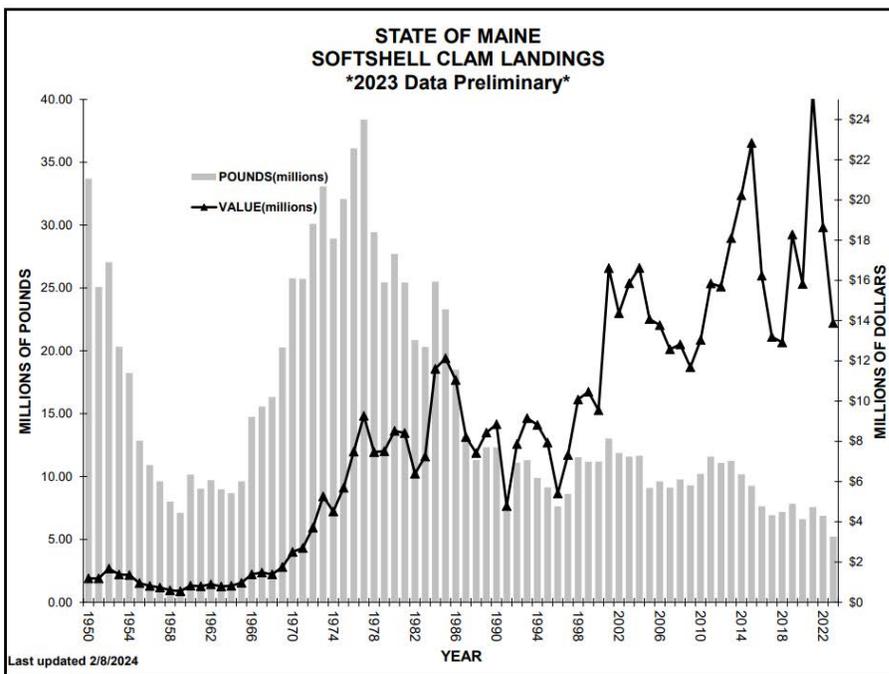


Figure 1: Maine Historical Soft-Shell Clam Landings and Value, 1950-2023. Maine Department of Marine Resources

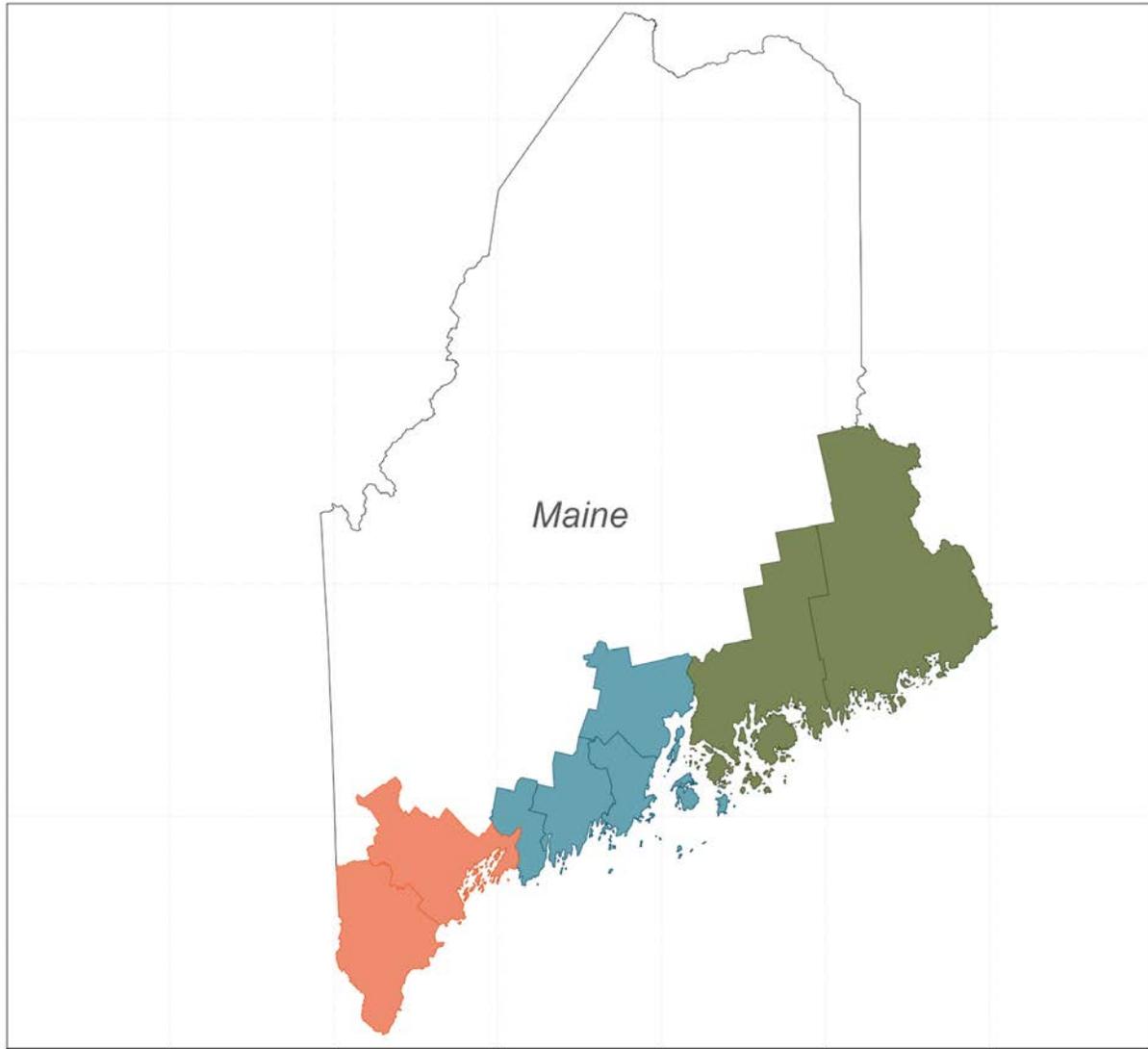
<sup>1</sup> DMR has provided historical yearly recorded landings for soft-shell clams since 1950 (Maine DMR, 2024)

This report summarizes findings from the project “The Economic Impact and Market Forces of Shellfish Harvesting: Understanding Landings, Ex-vessel Prices, and Factors Impacting the Soft-Shell Clam Fishery and Market”. The goal is to provide economic analysis and information to support a better understanding of soft-shell clam landing and price trends and fluctuations (i.e., volatilities) at regional (South coast, Midcoast, Downeast) and state levels. The project explored environmental and other socioeconomic factors impacting landings and prices. We begin with an overview of the soft-shell clam, hard clam (quahog), and oyster landings and values over the last two decades (Section 1), followed by a summary of key environmental and socioeconomic drivers identified in the literature to be impacting soft-shell clam fishery (Section 2). Then, we will describe changes in the shellfish market since 2006, assessing the soft-shell clam industry but also including analysis on the growth of emerging species such as oysters and quahogs (Section 3). We will then assess changing sea level, storms, and closure events to understand how they impact landings across the state (Section 4). We conclude by offering a synthesis discussion and suggestions for future studies (Section 5). Methodological details are provided in the appendix. All figures, data summaries, and statistical programming code are available through GitHub repository (<https://github.com/gulfofmaine/me-shellfish-econ-2025>).

01	Fisheries Overview	<ul style="list-style-type: none"> <li>• Soft-Shell Clam (pg. 11)</li> <li>• Quahogs (Hard-shell Clam) (pg. 16)</li> <li>• Oysters (pg. 17)</li> </ul>
02	Environmental & Socio-economic Drivers	<ul style="list-style-type: none"> <li>• Environmental Factors - Tidal Heights/Sea Level, Storms, Bacterial Pollutions and Biotoxin (pg. 18)</li> <li>• Socioeconomic Factors (pg. 20)</li> <li>• Knowledge Gaps (pg. 20)</li> </ul>
03	Landings & Market Trends (Soft-Shell Clam, Quahog)	<ul style="list-style-type: none"> <li>• Fish Price Index (pg. 22)</li> <li>• Time-Series Trends &amp; Structural Shifts (pg. 25)</li> <li>• Price Volatility (pg. 26)</li> </ul>
04	Sea Level, Storms, Closures (Soft-Shell Clam)	<ul style="list-style-type: none"> <li>• Sea Level Impacts (pg. 31)</li> <li>• Storm Impacts (pg. 32)</li> <li>• Closure Impacts (pg. 34)</li> </ul>
05	Synthesis Discussion	<ul style="list-style-type: none"> <li>• Significant Findings (pg. 36)</li> <li>• Future Research Needs (pg. 36)</li> </ul>

Figure 2: Technical Report Outline

Our analysis examines commercially important species of bivalves, primarily focusing on soft-shell clam. We also explore regional differences and similarities, splitting the state into three regions (Downeast, Midcoast, and Southern) for portions of the analysis to understand market changes and price volatilities among distinct parts of the state (Figure 3). The Downeast region includes Washington and Hancock counties, Midcoast region includes Waldo, Knox, Lincoln, and Sagadahoc counties, and the Southern region includes Cumberland and York counties. Where appropriate, county or municipal-level analyses were also conducted.



Region ■ Downeast ■ Midcoast ■ Southern

*Figure 3: Regional map of Maine. Downeast region includes Washington and Hancock counties, Midcoast region includes Waldo, Knox, Lincoln, and Sagadahoc counties, and Southern region includes Cumberland and York counties.*

### **Box 1. ShAC Consultation and Feedback**

While soft-shell clam harvesting ranks among Maine’s most valuable fisheries, it lacks a dedicated applied research fund in the state, thereby limiting the amount of available resources to investigate this industry further (McGreavy et al., 2018). With this in mind, this report made sure to take careful consideration of all resources and perspectives available in crafting the economic analysis and findings within this project.

Local knowledge is an important piece in understanding the harvesting efforts and market effects of the soft-shell clam industry in Maine. Soft-shell clam research in Maine has utilized the sustainability science approach, where stakeholders participate in collaborative space throughout the scientific study (Risley et al., 2025; Hillyer et al., 2021). By engaging community members and respective stakeholders, this study was equipped to provide accessibility to their work as well as support decision-making at the local scale. This work takes into consideration many aspects of sustainability science by incorporating shellfish harvesters, dealers, and researchers for knowledge sharing and project support.

This work was supported by the Maine Shellfish Advisory Council (ShAC). ShAC consists of harvesters, aquaculture leaseholders, certified shellfish dealers, municipal shellfish wardens, industry representatives, and interested citizens to maintain the quality of Maine’s shellfish harvesting mudflats and collaborate on solutions for issues pertaining to the industry. Research findings were presented quarterly to this group, receiving feedback on the current scope of work and generating new ideas that could be incorporated into this technical report. Direct feedback from ShAC allows this research to maintain local knowledge of this fishery and investigate key areas of concern by harvesters and decision-makers alike.

One major comment taken into consideration was the relationship between regional harvesting and prices in Maine. Maine’s coast spans over 3,400 miles, making it difficult for shellfish processing depending on the supply need and shipping location of soft-shell clam supply. Given this large area, regional changes in one area can affect the prices earned by harvesters in another region of the state, thereby increasing the importance to provide analysis of each region separately as well as with the combined data. Further, ShAC expressed interest in a seasonal analysis of shellfish harvesting in Maine to better understand seasonal price dynamics and variability. Much of this report will focus on the summer season, measuring harvesting efforts from July to October, as tourism boosts across the state increase the demand for shellfish, affecting the economic relationship between landings and received prices.

## Box 2. Economics Principles Applied in this Study

Throughout this report, we will apply conventional economics principles to study the market. The market is shaped by the relationship of supply and demand (Figure 4). Landed value is deemed to be the product of the landed volume and prices paid to the harvesters. In other words, landed prices used in this study were obtained by simply dividing the landed value by the landed volume. These prices are further assumed to be determined at the intersection of supply and demand (point A in Figure 4). This report includes analyses that use historical changes in prices. These prices, in our study, are deemed to be representing market equilibrium at scale of time (e.g., weekly, monthly, yearly, decadal) and space (e.g., municipality/port, county, region, entire state) specified. Following the logic of conventional economics principles, if the supply of clams decreases, the entire supply curve would shift left. If the demand remained constant, the situation would result in a higher price. In reality, there are multiple forces that are at play in the market. Each force can shift either or both demand and supply curves, making it difficult to track down the causal relationship between various factors and prices. Where appropriate, such causal relationships are discussed and explored.

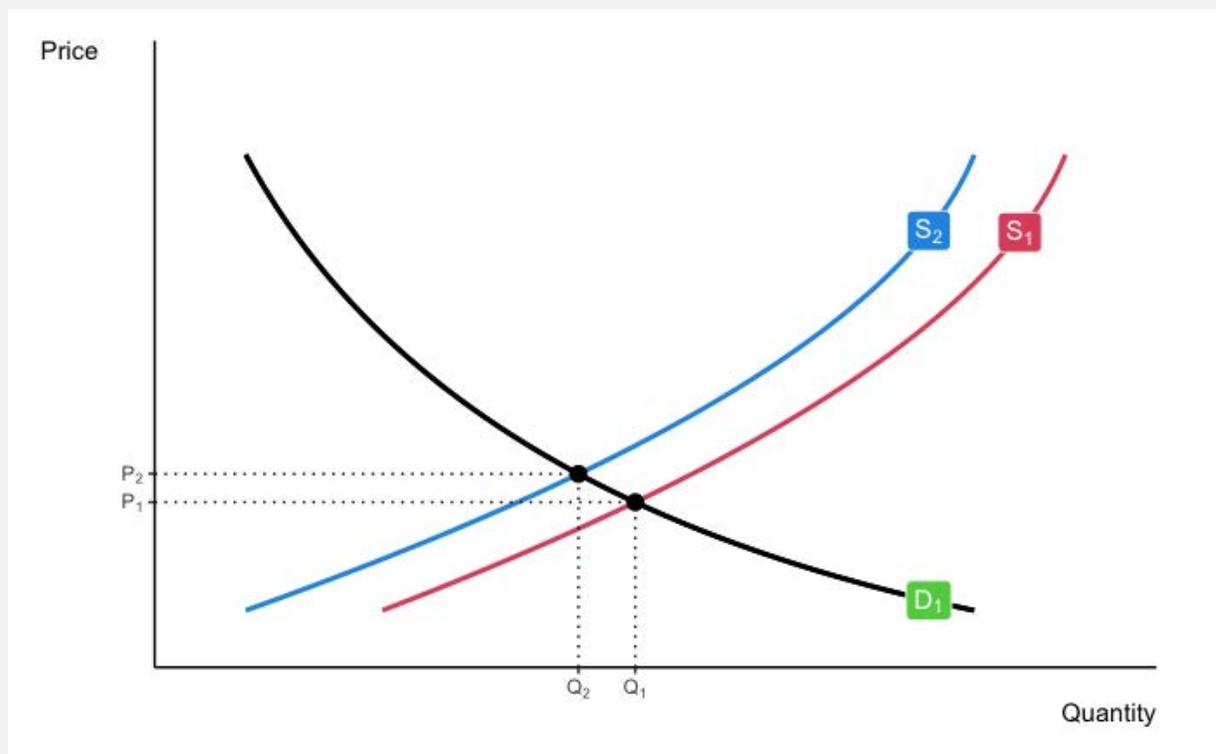


Figure 4: Economic Principle of Supply and Demand

## 1. Fisheries Overview

The bivalve industry in Maine (soft-shell clams, quahogs, oysters, sea scallops, blue mussels) has seen recent expansion across the state, shifting from primarily soft-shell clams (*Mya arenaria*) harvesting to a variety of shellfish species such as eastern oysters (*Crassostrea virginica*)/European oysters (*Ostrea edulis*) and quahogs/hard clams (*Mercenaria mercenaria*). Wild harvest opportunities remain abundant in the soft-shell clam fishery and are the primary form of landings in the state. However, the growth in aquaculture across Maine's coast has expanded oyster production, as well as increased mussel and scallop landings. Further, aquaculture has been used to support the wild quahog population in recent years, serving as a nursery to quahog seed before it is spread across mudflats to be harvested in future seasons.

In Maine, intertidal shellfish fisheries are governed under a co-managed arrangement. Co-management is a collaboration of user-groups, government officials, and scientists that provide regulatory decision-making for resource management (Webber et al., 2021; McClenachan et al., 2015; McGreavy et al., 2018; Miller et al., 2020). More specifically, it allows coastal municipalities to manage shellfish in their intertidal zone (licensing, time and area of digging, conservation activities, etc.) while the state imposes formal regulations, such as thresholds for high bacteria levels (discovered through water quality testing) and flat closures when shellfish are unsafe to consume from a public health perspective (Me. Rev. Stat. tit. 12, § 6671; Webber et al., 2021). As of 2024, 58 municipalities along Maine's coast provide a shellfish conservation ordinance on their website. Within this group, all 58 specifically list soft-shell clams in their ordinance, 26 list quahogs, and 19 list American or European oysters. This management method has been shown to provide a higher degree of stability and more consistent productivity, as well as an effective communication tool between municipalities, harvesters, and dealers within the soft-shell clam fishery (McGreavy et al., 2018; McClenachan et al., 2015).

### Soft-Shell Clam

From 2006-2023, the state of Maine has seen a decrease in total soft-shell landings, leading to the lowest reported landings on record in 2023 at 5,692,235 lbs, a decline of 40.8% since 2006 (Figure 5). While yearly landings have been slowly declining over the last decade, the value of these landings likely depend on market conditions and impacts among the broader seafood industry. The total value of landings has seen significant spikes in 2015 and 2021 (\$22 and \$25 million respectively); however, total value has only increased 9.2% since 2006, as the 2023 landings led to \$15 million in reported value.

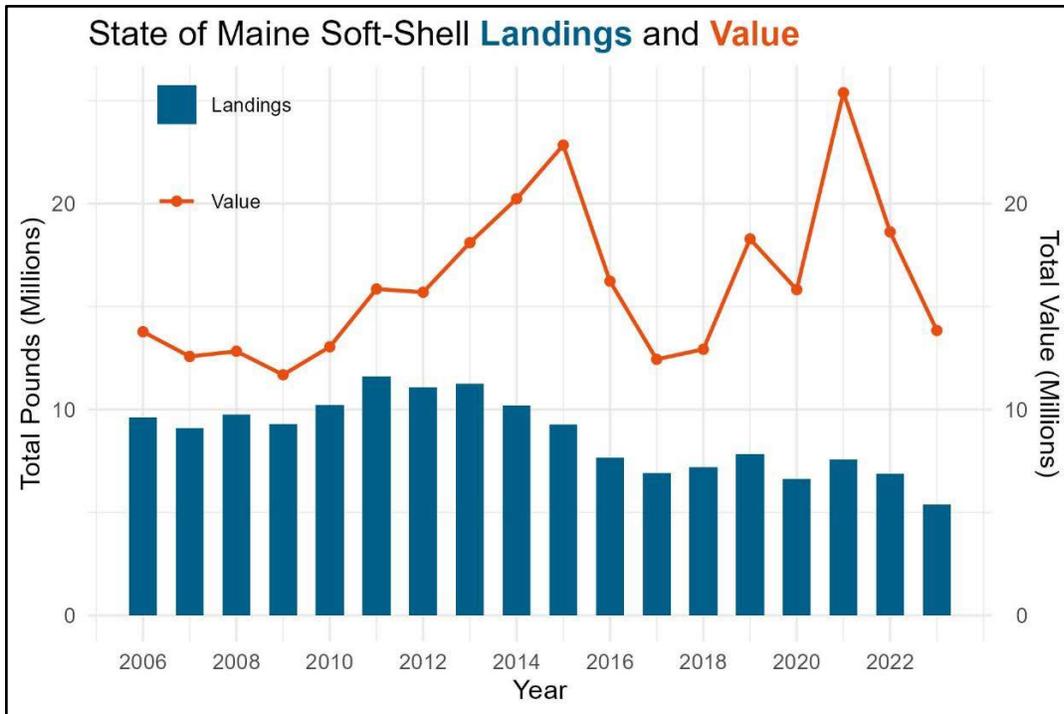


Figure 5: Soft-shell clam landings and value in Maine from 2006-2023. Landings have declined 40.76% since 2006

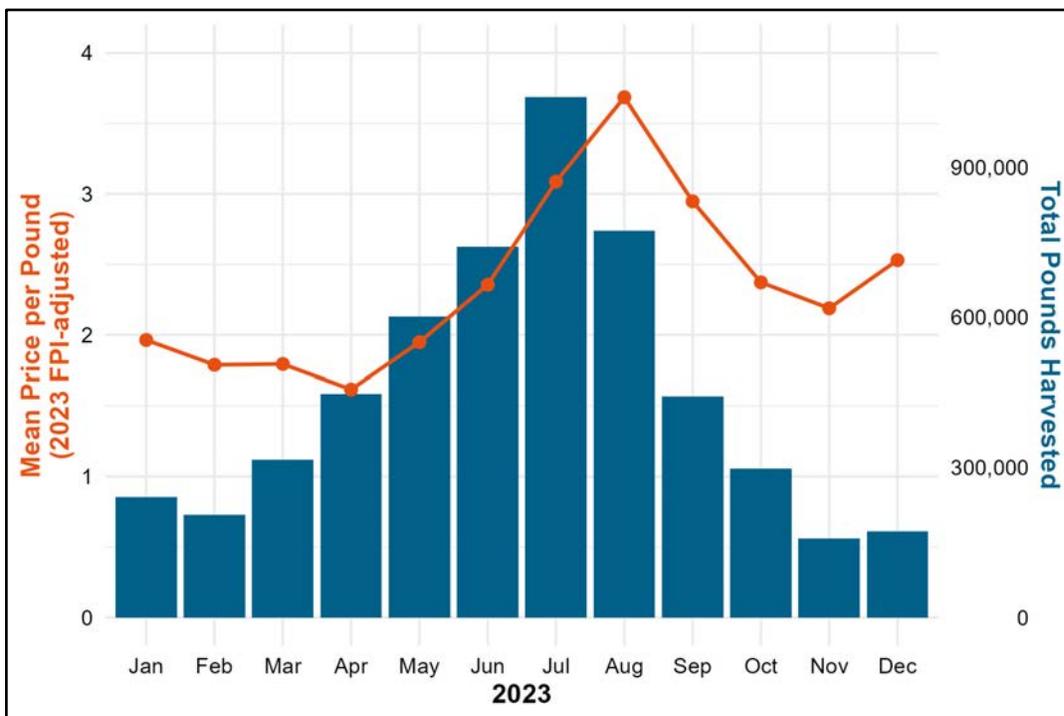


Figure 6: 2023 Monthly Soft-shell landings and mean price. Landings were the highest in July at 1,040,847 lbs and the lowest in November at 158,821 lbs. Conversely, prices were the highest in August at \$3.69/lb and the lowest in April at \$1.62/lb.

More closely examining 2023 soft-shell clam landings and prices, peak harvesting season (July-October) showed considerably lower landings than in prior years (Figure 6). While landings remained lower, prices steadily rose throughout the summer, increasing from \$1.62/lb in April to a peak of \$3.69/lb in August. These prices remained high through December (\$2.53/lb) as harvested landings continued to fall, reaching a yearly low in November of 158,821 pounds.

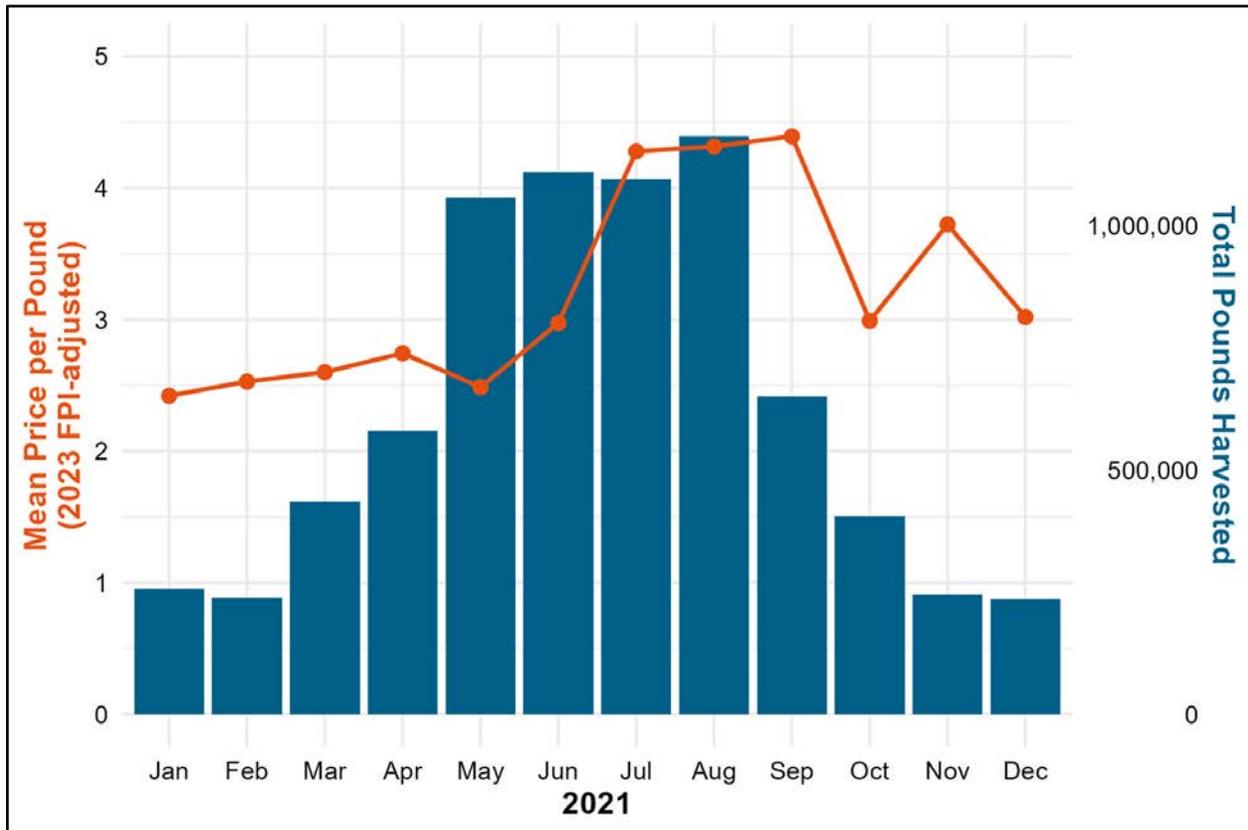


Figure 7: 2021 Monthly Soft-shell landings and mean price. Landings were the highest in August at 1,182,971 lbs and the lowest in December at 235,604 lbs. Conversely, mean prices were the highest in September at \$4.39/lb and the lowest in January at \$2.42/lb

Looking at the 2021 spike in prices, Figure 7 plots the total state landings and mean price per pound from January-December. The figure shows elevated landings from May through August, surpassing one million harvested pounds in each of those months. These landings coincide with higher average prices during the summer months, beginning at \$2.49/lb in May and reaching \$4.32/lb in August. One possible explanation for this price increase is the surge in coastal tourism along Maine’s shoreline in the summer of 2021, which likely drove up demand for soft-shell clams (Maine Office of Tourism, 2022). This increase in tourism could also explain the price surge in September, where prices averaged \$4.39/lb, the highest among all months in 2021. The price pattern in 2021 is uncommon among our sample, as July and August typically represent the highest prices for soft-shell clams within a given year.

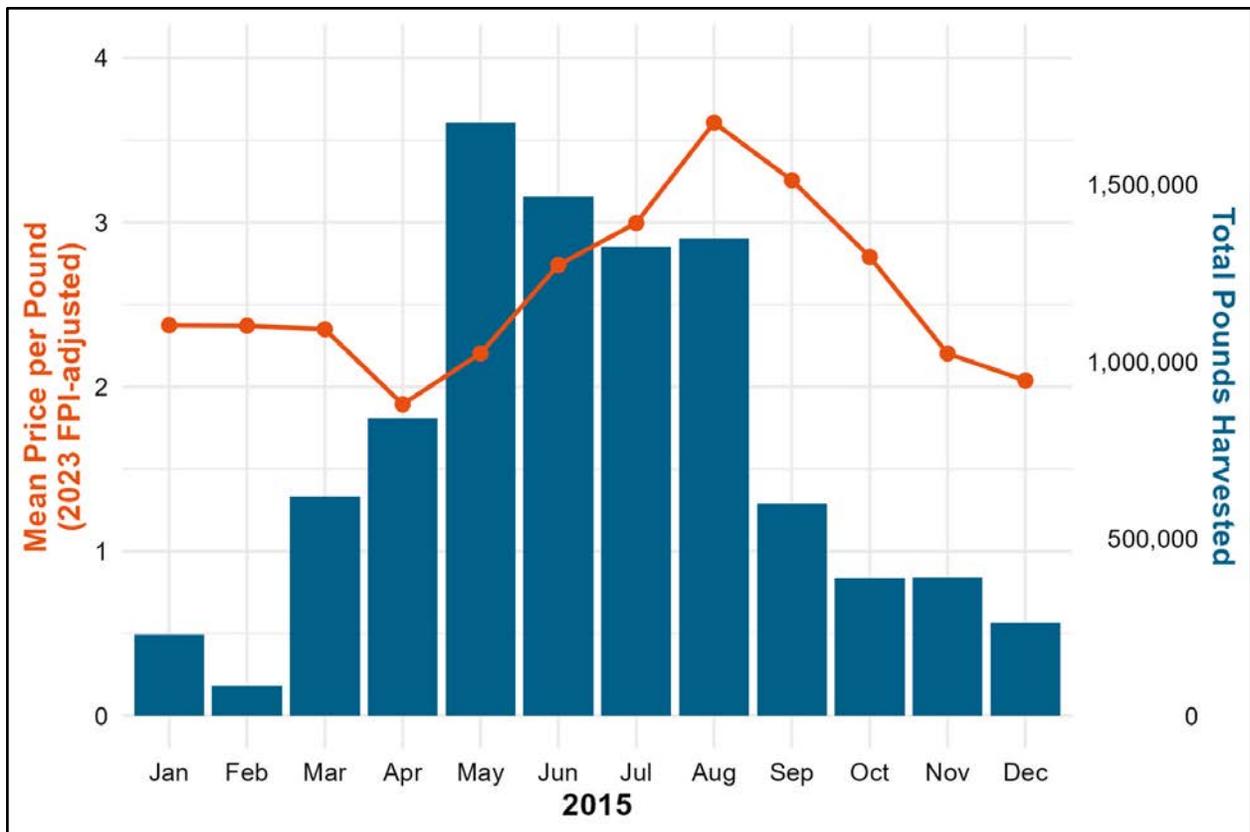


Figure 8: 2015 Monthly Soft-shell landings and mean price. Landings were the highest in May at 1,675,532 lbs and the lowest in February at 83,949 lbs. Conversely, mean prices were the highest in August at \$3.61 and the lowest in April at \$1.89.

Similar to 2021, 2015 also saw a large spike in mean price per pound through the summer months (Figure 8). However, the landings dynamics seen in 2015 differ from 2021, as landings surged in May (1,675,532 pounds harvested) but slowly declined the rest of the peak harvesting season.<sup>2</sup> Further, there was a precipitous drop from August-September when harvests fell from 1,348,698 to 599,255 pounds. What is consistent between all three years of interest (2015, 2021, 2023) is the rise in mean price per pound from May-August, suggesting a summer price increase regardless of harvested landings. This relationship signals strength in the soft-shell clam market over peak harvesting season, as product demand remains high in the summer months.

<sup>2</sup> This information is consistent with ShAC conversations regarding poor harvesting conditions throughout 2015

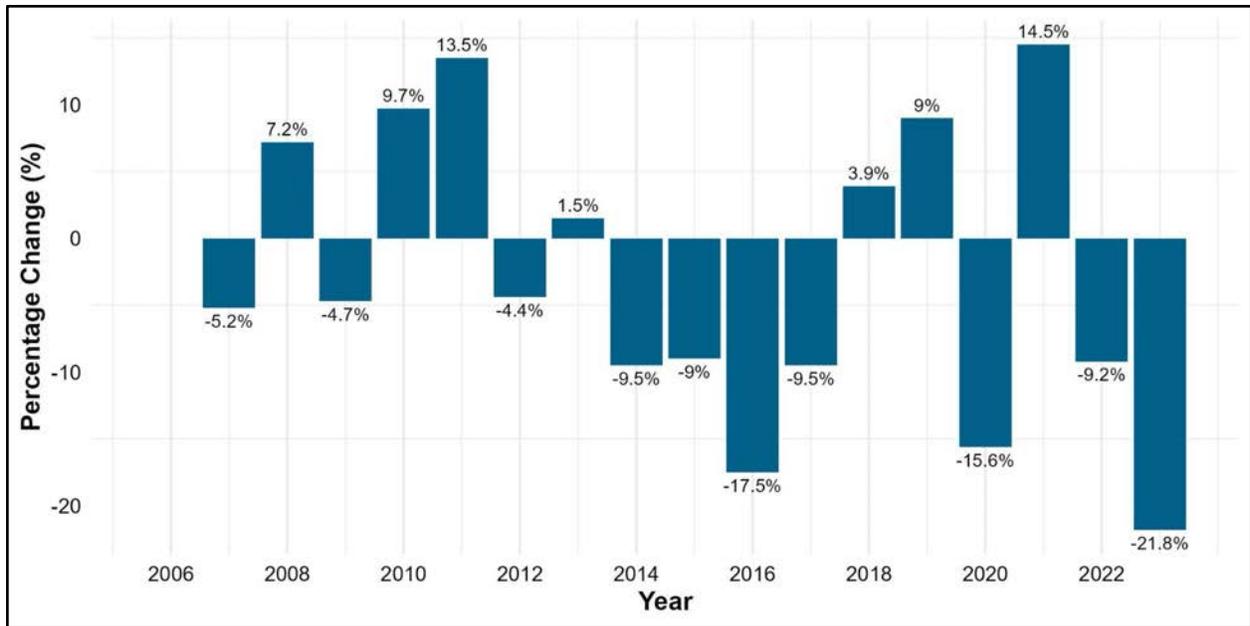


Figure 9: Year-over-Year percentage change in soft-shell clam landed pounds. The most significant percentage decrease in landed pounds occurred in 2023, where 21% lower landings were recorded than seen in 2021. Interestingly, 2021 saw the highest increase compared to 2020, which is likely due to the COVID-19 pandemic affecting harvesting capabilities.

To support further assessment of landings, year-over-year percentage changes in total landed pounds across Maine were calculated (Figure 9). These results find significant shifts in total landed pounds year-over-year, making pricing strategies hard for dealers to adjust with total supply shifting based on availability. Interestingly, 2021 saw the highest increase compared to 2020, which is likely due to the COVID-19 pandemic affecting harvesting capabilities. Further, when comparing large price spikes to year-over-year supply (2015 and 2021), there is evidence of significant decreases in total landings the year before (2014 and 2020). This may suggest a shortage-produced price increase, as prices increased due to expectations of a smaller total supply.

## Quahogs (Hard-shell Clams)

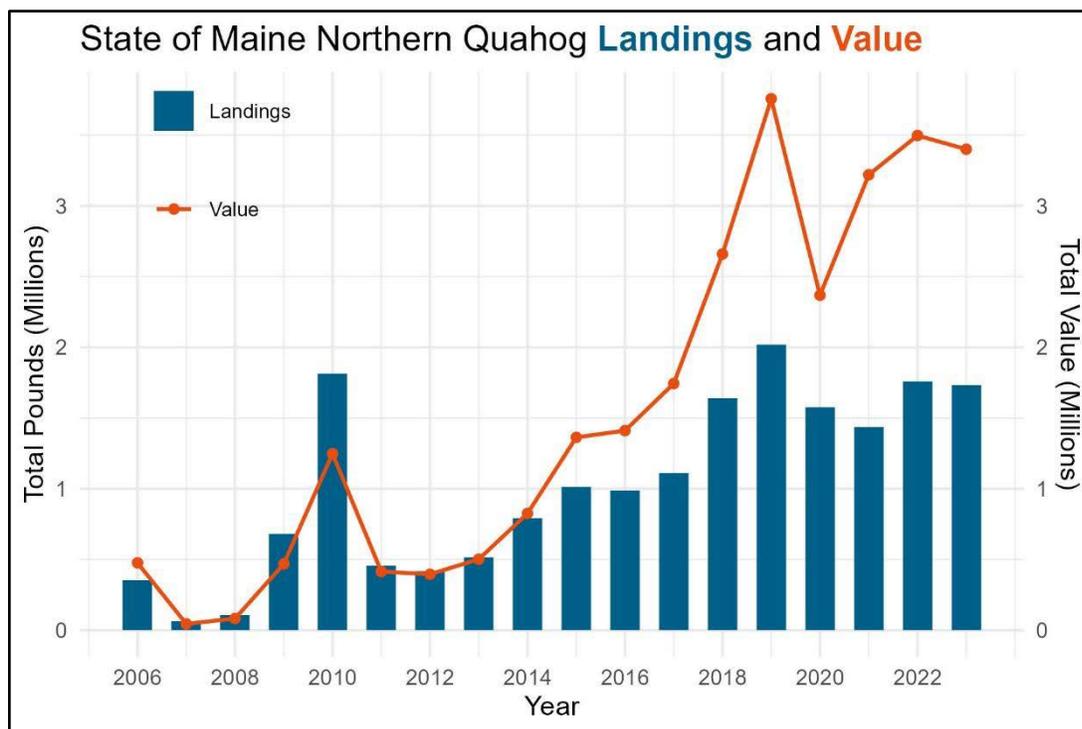


Figure 10: State of Maine Northern Quahog Landings and Value from 2006-2023. Total value has increased 621% since 2006, largely driven by higher landings and consumer demand.

Quahogs (*Mercenaria mercenaria*) have emerged as a prominent bivalve species in the Gulf of Maine, gaining popularity among clammers as another valuable product to harvest. The surge in quahog landings began in 2010, reaching 1.8 million pounds and earning harvesters about 1.2 million dollars in value. While landings significantly dropped in 2011, steady growth began shortly after, leading to a record 2 million pounds harvested in 2019. With this steady increase came market demand, as the state average price per pound surpassed \$1 in 2014 and peaked over \$2 in 2020 and 2021. This spike in landings is largely attributed to the Southern and Midcoast regions of the state, as the Downeast region only harvests an average of 110,824 pounds per year since 2010, accounting for less than 1% of total harvested quahogs. While not within our sample period, the Department of Marine Resources reported preliminary 2024 quahog landings with a value of \$3,438,410, the highest valuation for quahogs since recording began in 1950.

## Oysters

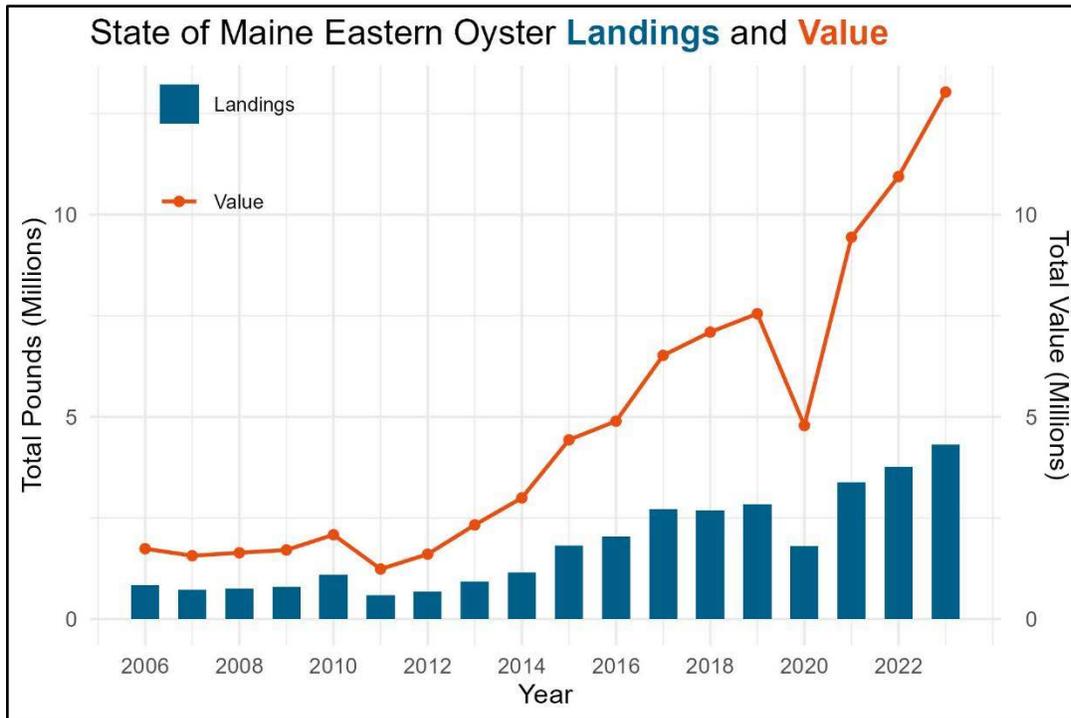


Figure 11: State of Maine Eastern/American Oyster Landings and Value from 2006-2023. Total value has increased 875% since 2006, largely driven by higher landings, growth of aquaculture, and increased consumer demand.

Oyster production in Maine has expanded, generating \$11 million in value in 2023 and placing it fourth among the state's fisheries by value (Figure 11). While this industry was partially interrupted by the COVID-19 pandemic, landings and value have exploded since 2010, reaching an all-time high in landed oysters in 2023. Further details about recent market trends for oysters and other shellfish products produced by aquaculture are reported in recently published *Farmed Shellfish Market Analysis* (Gulf of Maine Research Institute, 2023). This report highlights significant growth potential for the oyster industry in Maine, as the state maintains a competitive advantage based on locational availability, quality product output, clean water conditions, and close proximity to populations with high shellfish consumption behavior. The high demand for Maine oysters is positioned to exceed supply availability over the 5-year time horizon, suggesting that this large increase in production will only continue to grow. The accelerating growth of this new species in Maine signals a shifting dynamic, making it essential that this analysis accounts for how these expanding fisheries may be reshaping the bivalve market space.

## 2. Environmental and Socioeconomic Factors Impacting the Soft-Shell Clam Landings and Market

### Environmental Factors

Changing climate conditions in the Gulf of Maine are affecting the habitats of soft-shell clams and quahogs in multifaceted ways. Broadly, the Gulf of Maine is one of the fastest warming bodies of water in the world, affecting total clam growth and increasing mortality rates due to higher predation (Lutz and Jablonski 1978; Seitz et al. 2008). This can have a direct impact on Maine's fishery economy, as shifts in temperature and storm conditions affect a clammer's decision and accessibility to harvest.

Understanding these environmental shifts in Maine's coast will be imperative to mitigate the issues that affect the bivalve fishery, as well as the broader coastal economy.

### Tidal Heights/Sea Level Rise

Sea level rise has been increasing dramatically in the Gulf of Maine, as the rate of sea level rise has nearly doubled in the past 30 years (Maine Climate Council, 2024). Rising about 1.2 inches per decade, this increase can limit mudflat accessibility across Maine's coast, preventing harvesters from reaching clams due to low tides covering more area than before. While the state of Maine is organizing policy to mitigate these environmental threats, the loss of mudflat accessibility will continue to affect harvesters' ability to earn a living, pushing many out of the industry.

### Precipitation

Storms are projected to bring more intense rainfall to the State of Maine, posing a threat to the soft-shell clam industry (Maine Climate Office, 2023). An increase to the hydrologic cycle (water cycles faster through the atmosphere in response to warming) has led to 1-2 extra days of precipitation above 2", and 2-3 extra days of precipitation above 1" (Maine Climate Council, 2024). This increase can drastically impact the shellfish industry, as rain events with at least 2" of precipitation in a 24-hour period can prompt a mudflat closure (commonly referred to as an emergency or rainfall closure).<sup>3</sup> Further, extratropical storms, the weather systems that often drive this heavy rainfall, can also produce strong winds, which presents unfavorable and dangerous conditions for clam harvesting.

### Predation

Soft-shell clams and other bivalves in the Gulf of Maine, such as oysters, quahogs, mussels, and scallops, face numerous predators. Predators include land mammals like raccoons, otters, and muskrats, as well as marine species such as moon snails, starfish, and sunfish. Among these, two of the most well-studied and impactful predators are the European green crab (*Carcinus maenas*) and the milky ribbon worm (*Cerebratulus lacteus*).

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<sup>3</sup> The Maine Department of Marine Resources provides an [interactive shellfish map](#) on their website to track closures across the state.

An invasive species to the Gulf of Maine, European Green crabs (*carcinus maenas*) prey on the juvenile soft-shell clam population, reducing its abundance in mudflats across the state and affecting the overall growth rate of harvestable supply (Beal, 2023; Whitlow, 2009). The green crab species is able to tolerate high temperatures and span long lives, furthering their ability to decimate clam populations in any region they reside (Beal, 2023). While much research within Maine has been conducted on this species (Tan and Beal, 2015; Beal, 2023), few preventative trials have yielded successful mitigation methods to the clam population.

Another predator to soft-shell clams is the milky ribbon worm (*Cerebratulus lacteus*), which feeds on older soft-shell clam juveniles as well as adults (Beal, 2023). This predator has been able to avoid preventative measures, such as netting and other methods that protect clam populations among the mudflats (Beal, 2023). As temperatures continue to increase, predation among current and new species entering the Gulf of Maine will continue affecting soft-shell clam reproduction rates and availability.

### **Pollution**

Pollution of water quality concerns in the Gulf of Maine have been cited among a multitude of prior literature (Hillyer et al., 2021; Evans et al., 2016; McGreavy et. al., 2018). In Maine, the Department of Marine Resources monitors shellfish growing areas and post closure notices following the National Shellfish Sanitation Program guidance for water quality testing and closures (U.S. Food and Drug Administration, 2023). Bacteria levels can shift due to a variety of reasons but are largely affected by precipitation events<sup>4</sup> and sewage discharges that run off the coast. This format utilizes five classifications that determine ability to harvest: open, conditionally approved, conditionally restricted, restricted, and prohibited (U.S. Food and Drug Administration, 2023). When closures occur, harvesters are often left with few options to continue harvest, as licensing is municipal dependent. Closures have been found to have a significant effect on the shellfish market, as one study in Machias Bay Maine found temporary closures led to \$3.6 million dollars in foregone revenue, with \$2 million dollars of this due to sewage overflows from the Machias wastewater system (Evans et al., 2016). These losses often require harvesters to find alternative sources of income, including harvesting in other fisheries or finding non-fishing opportunities.

### **Biotxin/Harmful Algal Blooms**

There is limited information about how biotoxin events have impacted the shellfish fisheries in recent years. Previous study of the 2005 red-tide event estimated that it cost \$2.4 million (Jin et al. 2008) to Maine's commercial shellfish capture fisheries. Unprecedented biotoxin closures occurred in Maine in 2019, during which time shellfish farms were unable to sell any product. The unprecedented number and scale of regulatory closures and the introduction of new biotoxins in recent years pose severe challenges to both wild harvest and shellfish aquaculture in Maine.

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<sup>4</sup> Maine mudflats are closed when rainfall exceeds 2" in a 24 hour period (Maine Department of Marine Resources, 2024), with some municipalities including additional regulations.

## Socioeconomic Factors

Clamming heritage spans across many families for generations, but recent socioeconomic changes in many coastal communities have affected the ability to harvest in mudflats across the coast and threatened this livelihood for many harvesters.

### Coastal Access

One concern for Maine shellfish harvesters is the accessibility of mudflats along coastal communities. Harvesters rely on both public municipal and private land in order to access shellfish harvesting mudflats in Maine; however, coastal accessibility is becoming increasingly privatized. An inventory completed by Manomet between 2022 and 2023 found among six coastal communities, 65% of intertidal access points were on private property, and only 20% were municipal owned (Farr & McMahan, 2023).

When using private property to access intertidal zones, individual harvesters often rely on verbal agreements with landowners. While previously an effective measure for many, changes in homeownership of coastal lands has rendered many of these verbal agreements invalid, leaving harvesters with limited options to access their previous harvesting mudflats (Zoellick et al., 2023; McCreavy et al., 2018).

When utilizing municipal lands, license restrictions are often put in place to prevent non-residents from harvesting. In an effort to provide fair opportunity to residents of a community, many municipalities in Maine provide shellfish harvesting permits only to those with a physical residence, defining residency between three and twelve months prior to applying (Van Damme et al., 2022). While intended to provide equity among landowners, it can have negative impacts on those who cannot afford to live in these communities, as well as indigenous tribes from harvesting on land previously accessible. Research completed out of Bates College found the varying regulations could be restructured to better support the commercial harvesting of shellfish clammers and cultural interests of indigenous tribal people in Maine (Van Damme et al., 2022).

### Knowledge Gaps

Interestingly, few studies in the literature examine the effects of the COVID-19 pandemic on Maine's clamming industry. The rise in real estate prices during the pandemic, which shifted housing ownership across the state, has been cited as a factor in reduced access to Maine's mudflats (Farr & McMahan, 2023; Zoellick et al., 2023; Vultaggio et al., 2023). This housing boom additionally displaced harvesters, as they could no longer afford the rising housing costs associated with coastal communities in Maine (Van Damme et al., 2020). However, broader effects on the market for shellfish as well as the reduction in total landings due to the pandemic have yet to be analyzed within the academic literature. Presented with this gap, this analysis will provide further information regarding the effect of the COVID-19 pandemic on soft-shell clam landings and prices in Maine.

### 3. Landings and Market Trend

This project aims to enhance understanding of the soft-shell clam market, the factors that influence it, and the economic importance of bivalve fisheries in Maine. How did the landed value of soft-shell clam and other important bivalves harvested in Maine change over time? Are there any significant shifts in price patterns? Are there any regional differences? To approach these topics, econometric analysis approaches are applied to the dataset of soft-shell clam landings and prices. Further, a price index is created using a method developed and used specifically for seafood products (called “Fish Price Index”). This price information is used to examine time-series landed price patterns through unit root and structural break tests. Methodological details for each test are described in Appendix 5.

#### 2023 Soft-Shell Clam Landings and Prices by County

<b>County</b>	<b>Number of Towns with Port Landings</b>	<b>Total Yearly Landings (lbs.)</b>	<b>Mean Price (S.D)</b>	<b>Percentage Difference in Price (Washington County = Base)</b>	<b>Maximum Mean Weekly Price</b>	<b>Minimum Mean Weekly Price</b>
Washington	22	1,975,195	\$2.27 (0.68)	N/A	\$5.97	\$1.20
Hancock	22	720,356	\$2.43 (0.83)	6.86%	\$5.08	\$1.00
Waldo	2	15,198	\$2.66 (0.31)	17.23%	\$3.20	\$2.40
Knox	9	347,083	\$2.59 (0.75)	14.10%	\$4.20	\$1.30
Lincoln	17	705,813	\$2.38 (0.71)	4.85%	\$4.63	\$1.34
Sagadahoc	7	259,358	\$2.70 (0.73)	19.00%	\$4.89	\$1.08
Cumberland	11	1,306,197	\$2.60 (0.72)	14.42%	\$5.16	\$1.00
York	3	35,164	\$2.60 (0.70)	14.34%	\$4.03	\$1.50

Table 1. Soft-Shell Clam Total Landings and Average Prices by County, 2023

In the most recent year of the dataset (2023), there are large variations in landed volumes among counties (Table 1), while prices remain consistent across the state. The Downeast region (Washington and Hancock county) drives most of the landings in Maine, accounting for about 50% of all harvests in

2023. The number of municipalities with port landings is also higher in this region, as Hancock and Washington counties reported landings from 44 different locations, 36 more than the Southern region (Cumberland and York counties).

Prices remain relatively consistent throughout the state in 2023, with no significant price premium (increased price for the same product) in different regions. Sagadahoc and Waldo county report the highest average price per pound, likely due to the low volume of landings and central location in the state. Cumberland county harvests were the second highest in volume among all counties in Maine and received the third highest average price for their product. The data, including prices in York county, suggest that the Southern region of the state tends to receive higher prices for their harvest. This is likely due to a combination of factors, including a higher regional population that can support demand, as well as the region's proximity to major seafood distribution hubs like Portland and Boston. Seasonally, prices are higher over the summer months and are the lowest in the late winter/early spring (Figure 12).

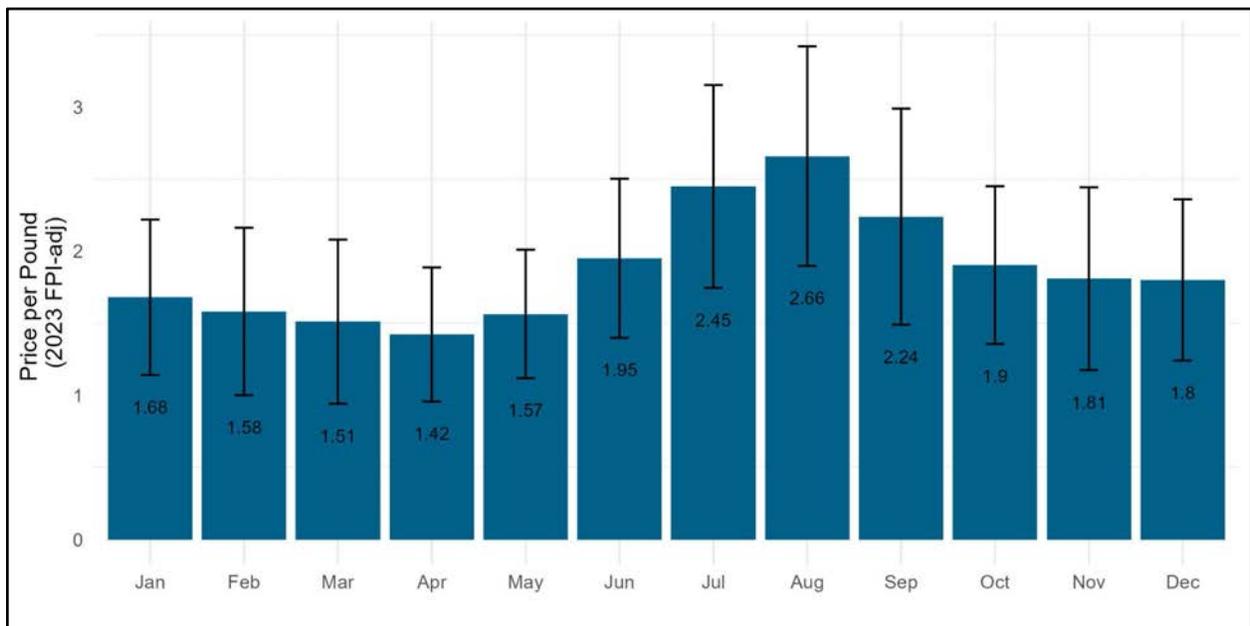


Figure 12: Mean soft-shell landing price/lb. by month. Across our sample (2006-2023), findings suggest highest mean prices occur in July (\$2.45) and August (\$2.66) while the lowest mean prices occur in March (\$1.51) and April (\$1.42). Error bars represent the variability in prices each month, suggesting larger variability in the summer and winter months.

### Adjusting for inflation by using Fish Price Index

Shellfish prices are affected by many different factors, including changes to inflation among the greater economy. One method to adjust for inflation and condense price and quantities to one metric is to use the Fish Price Index. The Fish Price Index (FPI), developed by Tveterås et al. (2012), has been used to account for inflation among different fishing sectors. FPI has several advantages over other indexing

methods. It is used to track changes in global (or regional) seafood availability.<sup>5</sup> FPI also enables analysis of the connections between soft-shell clam markets in different regions of Maine, as well as the potential influence regions may have on one another.

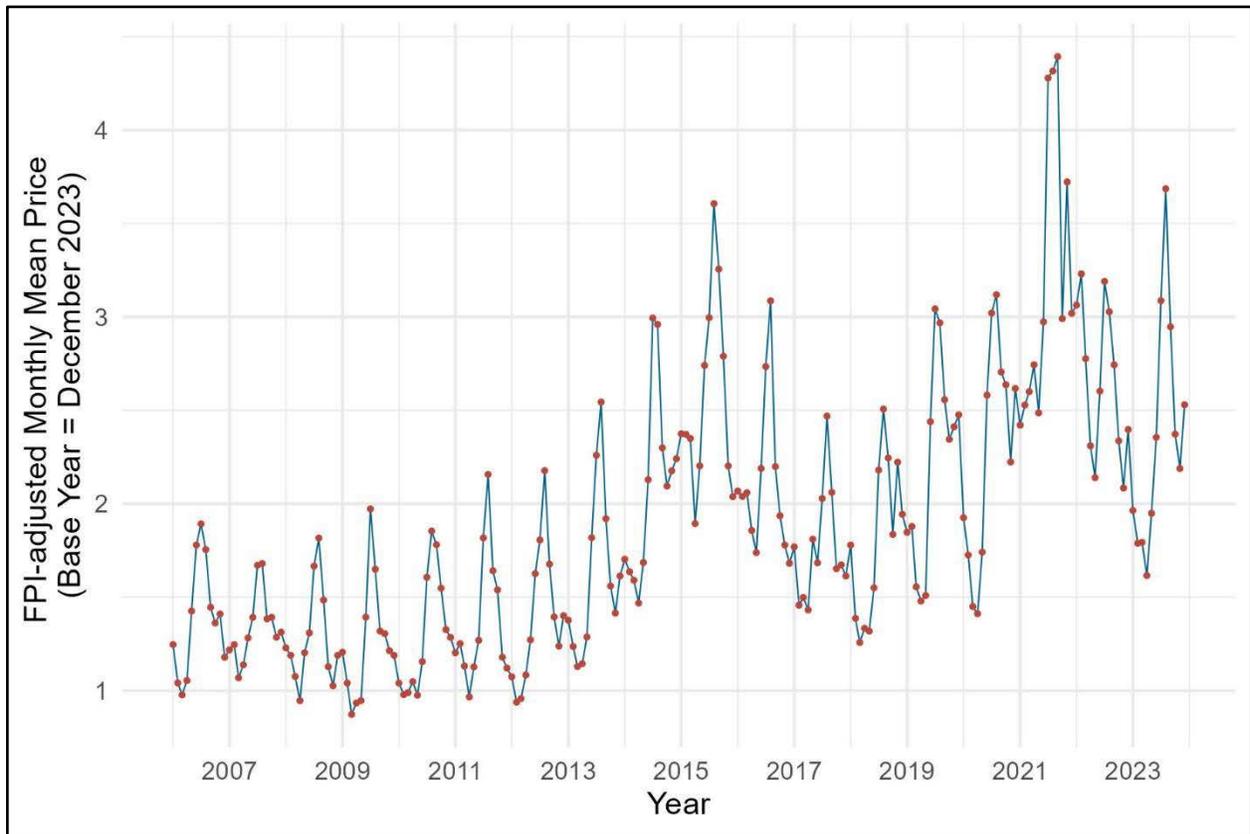


Figure 13: Monthly Fish Price Index from 2006-2023 for Soft-Shell clams. Price Index starts at \$1.25/lb and reflects FPI-adjusted prices in USD (base year = December 2023). Figure 11 depicts a sharp increase in FPI prices in 2015, which maintains this trend through 2023. The Price index reached an all-time high in 2021, where FPI-adjusted prices rose over \$4.

Figure 13 represents the FPI-adjusted soft-shell clam per pound ex-vessel prices in Maine from 2006-2023, using December 2023 as a base. There is a sharp increase in the price through the summer of 2015 and the summer of 2021, with subtle declines shortly after. However, the declines do not return to initial levels seen in the late 2000s, suggesting that price increases have sustained over time.

<sup>5</sup> Additional information on the Fish Price Index can be found in Appendix 4

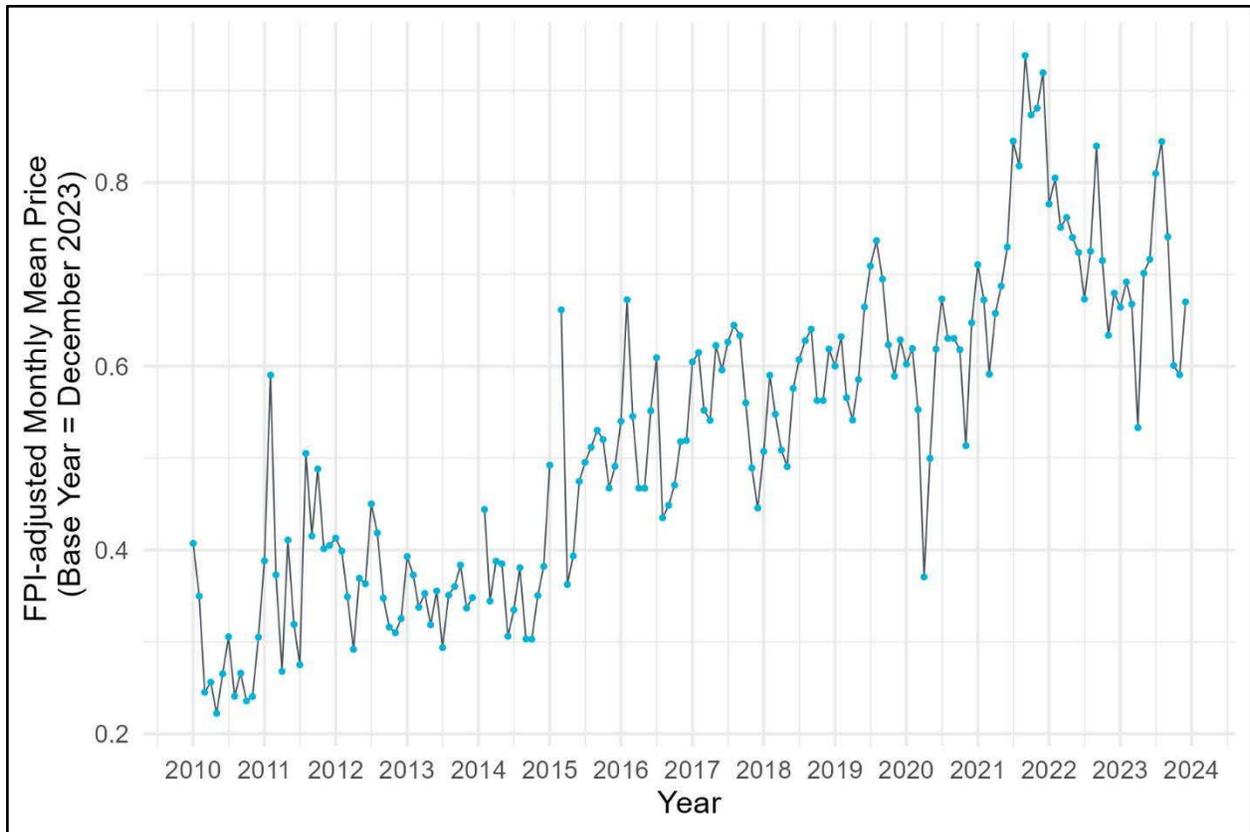


Figure 14: Monthly Fish Price Index from 2010-2023 for Northern Quahogs. FPI starts at \$0.67/piece and reflects FPI-adjusted prices in USD (base year = December 2023). Figure 12 depicts steady increase since 2010, with only one significant drop in April 2020 (\$0.37/piece). The price index reached an all-time high in September 2021, where fpi-adjusted prices peaked at \$0.94/piece.

Figure 14 depicts the Fish Price Index by month for quahog harvests in Maine from 2010-2023, using December 2023 as the base year. Quahogs have seen a linear growth in production since 2010, with steady increases in FPI-adjusted monthly prices and only one significant drop in April 2020, likely due to the COVID-19 pandemic shutdown. These prices peaked in September of 2021, reaching \$0.94/piece.<sup>6</sup>

<sup>6</sup> Price per Piece variable was utilized due to different measurement methods for each type of bivalve species. Conversion rates can be found in the [Rhode Island Department of Environmental Management Commercial Shellfish Conversion Factor](#).

## Time-Series Trends and Structural Shifts in the Soft-shell Clam Ex-Vessel Market<sup>7</sup>

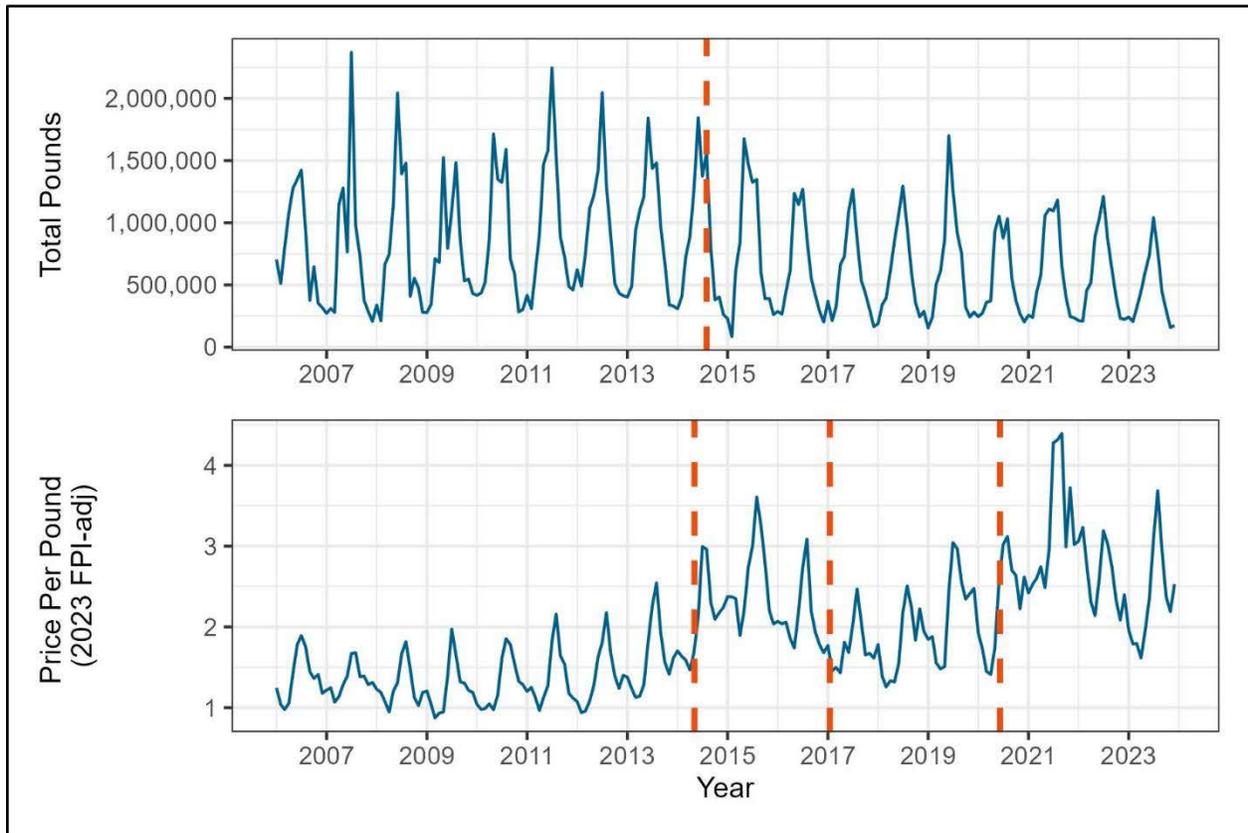


Figure 15: Total harvested pounds and nominal prices for soft-shell clams in Maine, 2006-2023. Significant seasonal variability among harvested landings in Maine. Structural breakpoints occur in August 2014 for Pounds and in May 2014, January 2017, and June 2020 for Price/lb.

As mentioned earlier, two notable peaks in the price per pound of soft-shell clams occur in 2015 and 2021. To see if there have been any structural shifts in the market, the Bai and Perron structural break test was implemented (Bai & Perron, 2003). This structural break test identifies the timing of fundamental shifts in landings or pricing patterns, which in turn can help us explore potential external shocks, such as environmental or economic shocks that cause permanent shifts in supply and/or demand. The top panel of Figure 15 shows monthly soft-shell clam landings in Maine. In this figure, a seasonal pattern shows consistently high landings during the summer months (July-October) in each year of our sample. The red dashed lines indicate the timing of structural breaks detected (occurred in August 2014). The structural break analysis of FPI-adjusted prices (Bottom Panel) also shows four distinct market regime shifts from 2006-2023 (January 2006-May 2014, June 2014-January 2017, February 2017-June 2020, July 2020-December 2023) and one landings regime shift (January 2006-May 2014, June 2014-December 2023). Interestingly, while there is one shift in monthly landings across the state occurring in 2015 (Top Panel), pricing dynamics shifted three times over our seventeen-year period. Different environmental and

<sup>7</sup> Time-Series stationarity and unit-root test information can be found in Appendix 5

socioeconomic threats outlined in the literature review have likely caused the shift observed in landings. These changes suggest that the soft-shell clam’s ex-vessel market shifts may be affected by more than changes in availability of supply, as there are three break points in the price data and only one break point in landed pounds. The shift in prices, which represent market-wide shifts (i.e., shifts in demand or both supply and demand). For example, the shift detected in 2020 is likely attributable to the impacts of the COVID-19 pandemic, which led to a large decline in demand from coastal tourism during peak harvesting season. Harvester and supply chain labor force may also have been impacted during this period by the pandemic, which in turn could have affected the supply. Comparing prices across regions, the data suggests regional price trends are consistent with each other (Figure 16), confirming our earlier assessment (Table 1) that there is no significant price difference between each region of the state.

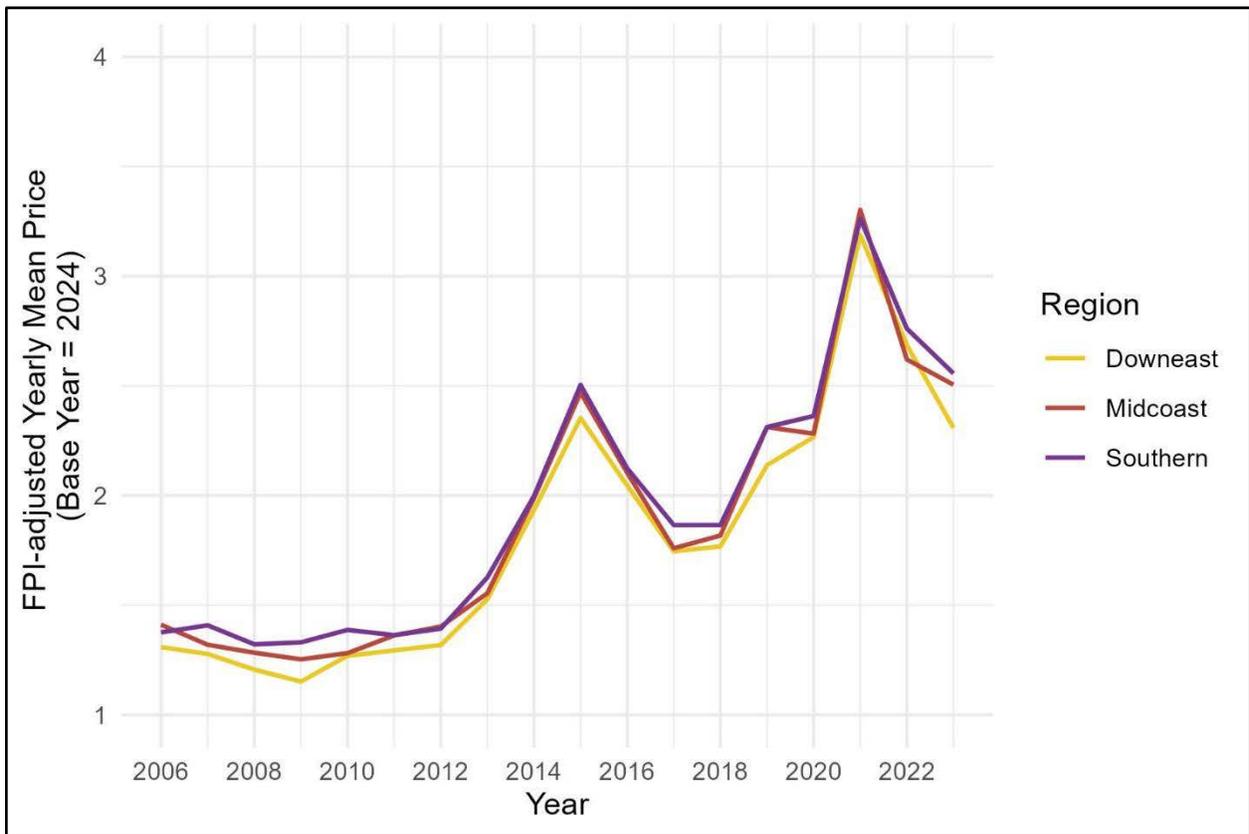


Figure 16: FPI-adjusted yearly regional landed price of soft-shell clam from 2006-2023. All three regions move in a consistent pattern, with the Southern region maintaining the highest index and the Downeast region recording the lowest index each year.

### Is the Soft-Shell Clam Market Becoming More Volatile?

Within the clamming industry comes inherent risk, as previously mentioned environmental and socioeconomic changes have impacted landings and shifted ex-vessel market prices in the state. These changing conditions can shift shellfish availability, making investment decisions for clammers difficult to

maintain due to future uncertainty of the resource. One way to further analyze economic risk in the soft-shell clam fishery is through examining price volatilities (Anderson et al., 2016).

To examine how prices fluctuate over a given period of time, we use two absolute volatility metrics. These metrics consider both inter-annual (year-to-year) and intra-annual (within-year, week-to-week) price fluctuations.<sup>8</sup> Using Anderson et. al (2016), volatility scores *below 0.13* are deemed to be *not volatile* while scores *above 0.85* are deemed to be *extremely volatile*. Both inter-annual and intra-annual volatility for the soft-shell clam market in Maine are explored further below.

### Inter-annual Price Volatility

**0.18**

2006-2023 Year-to-year Price Volatility

Inter-annual volatility measures the variation in annual mean landed prices across years to assess their year-to-year stability. The inter-annual (year-to-year) price volatility of soft-shell clam prices from 2006-2023 is estimated to be 0.18. This suggests that the soft-shell clam market in Maine is minimally volatile. Aside from the sharp increases in 2015 and 2021, prices went back down gradually after these price surges. Breaking the time series into overlapping two decades (2006-2016, 2013-2023), inter-annual price volatility increased slightly from 0.14 in 2006-2016 to 0.20 in 2013-2023, suggesting increased volatility in the most recent decade.

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<sup>8</sup> Full volatility calculation methods can be found in Appendix 3

## Intra-annual Price Volatility

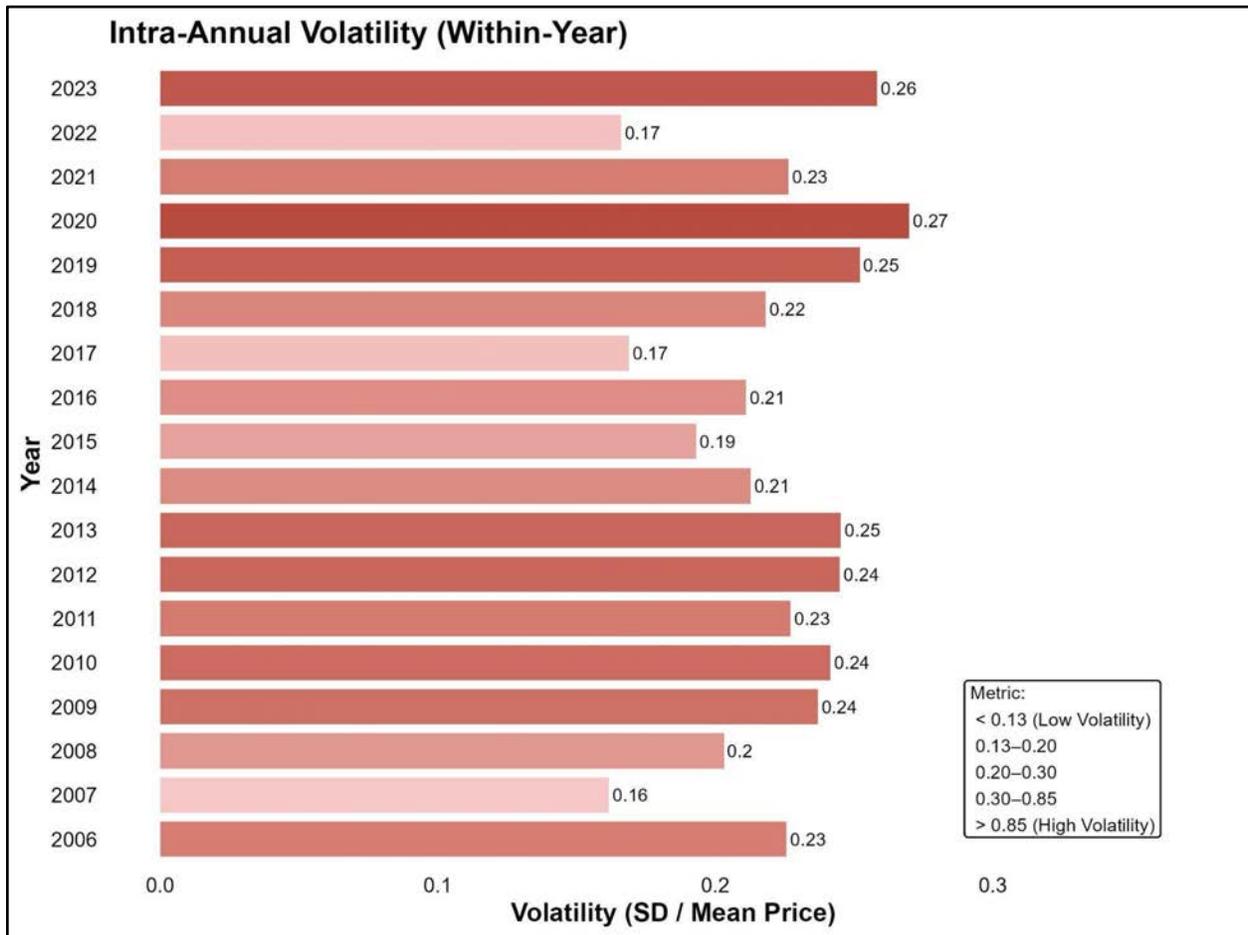


Figure 17: Intra-annual Price Volatility by Year. Volatility remains relatively consistent across the sample period. Most volatile years in the sample were 2020 (0.27) and 2023 (0.26).

Intra-annual (within-year, week-to-week) volatility calculates price shifts within each year to understand how shellfish value can fluctuate at a weekly level. Our previous time-series data suggests that the soft-shell clam market in Maine increases in both landings and average price in the summer months (Figure 15), as there is an increase in demand for fresh and locally caught seafood, such as Maine’s famous “steamers” or fried clams. Between 2006-2023, we find an intra-annual volatility of 0.38, suggesting moderate within-year volatility. Comparing week-to-week volatility for each year respectively, findings show moderate volatility, ranging from 0.16 (2007) to 0.27 (2020) (Figure 17). Higher volatility in 2020 can be explained by the COVID-19 pandemic, as demand for seafood significantly dropped due to supply-chain challenges and low tourism along Maine’s coast. Further, high volatility in 2023 is likely due to decreased supply (landings), impacting the ability for dealers to maintain a consistent source of product.

## Relative Price Volatility

Relative price volatility tracks how much the price of a specific product shifts with respect to other locations within the market (i.e. municipalities). The beta coefficient was used as a measure of relative volatility to explore whether some municipalities have more volatile ex-vessel price movements compared against the state average. The beta coefficient is a measure that is often used in the stock market to understand the performance of a specific stock relative to the full market performance (e.g., often compared against S&P 500). By adopting this metric for the soft-shell clam industry in Maine, we can better understand how a specific municipality performs relative to the state market for shellfish.

To characterize the state shellfish market, we used data from the Maine Department of Marine Resources containing weekly landings and value records for six bivalve species: soft-shell clams, eastern oysters, european oysters, surf clams, atlantic razor clams, and northern quahogs. For each week, the total landed value and total landed weight across all species were summed to obtain statewide totals. The nominal price per pound was then calculated as the ratio of total value to total landed weight, representing the nominal statewide shellfish market price. The beta coefficient for each port was subsequently calculated as the covariance between the port's weekly nominal average price and the statewide weekly nominal average price, divided by the variance of the statewide nominal average price.

A beta coefficient greater than 1 indicates that a municipality is more volatile and sensitive to changes in the state shellfish market. Conversely, a coefficient less than 1 indicates lower volatility relative to the state shellfish market, suggesting a more stable harvesting municipality. Finally, a volatility measure around 1 indicates that a municipality's price patterns closely track those of the state shellfish market.<sup>9</sup>

We focused on municipalities that have at least 1 week of landings recorded for each year of our sample (2006-2023). This included 62 municipalities across the state: 34 in Downeast, 22 in Midcoast, and 6 in Southern Maine.

The statewide shellfish market exhibited relatively low-price variability, with a standard deviation of 0.18. Beta coefficients ranged from 0.52 to 1.68, indicating that some municipalities' prices fluctuated less than the statewide average, while others showed substantially greater sensitivity to overall market changes. (Table 2). Consistent with expectations, municipalities who harvest higher landings maintain similar volatility trends to the entire shellfish market. For example, Brunswick has remained in the top five highest landing municipalities since 2016 (Town of Brunswick, 2024), and its beta coefficient of 0.90 suggests that volatility is consistent with the overall market. This may also suggest that municipalities with large harvesting production can drive shifts in the overall market. The full municipality list of beta coefficients can be found in Appendix 3.

The higher beta coefficients reflect municipalities that have more volatile ex-vessel markets, potentially being more susceptible to local supply shocks. Sorrento Maine reported the highest beta coefficient of

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<sup>9</sup> Additional information on this calculation can be found in Appendix 3

1.68 (Table 2), which suggests this location has the most volatile ex-vessel market. This can be seen in 2021, when the average price/lb. in Sorrento was \$2.85, but the state average was \$3.35. Similarly, Damariscotta reported the third lowest beta coefficient of 0.55 and in 2021, the average price/lb. was \$3.20, consistent with the state shellfish market.

<b>Relative Volatility Beta Coefficients</b>		
<b>5 Municipalities with Highest Beta Coefficients (n = 62)</b>		
<i>Municipality</i>	<i>Region</i>	<i>Beta Coefficient</i>
Sorrento	Downeast	1.68
Georgetown	Midcoast	1.35
South Thomaston	Midcoast	1.30
St. George	Midcoast	1.26
Jonesboro	Downeast	1.24
<b>5 Municipalities with Lowest Beta Coefficients (n = 62)</b>		
<i>Municipality</i>	<i>Region</i>	<i>Beta Coefficient</i>
Edgecomb	Midcoast	0.52
Brooksville	Downeast	0.55
Damariscotta	Midcoast	0.66
West Bath	Midcoast	0.72
Newcastle	Midcoast	0.73

Table 2.) Relative Volatility Beta Coefficients.

## 4. Sea Level, Storm, and Closure Impacts

Recent studies, reports, and ShAC conversations indicate that sea level, storms, and closures are major threats to the shellfish fisheries. This section explores to what extent these factors are impacting the soft-shell clam fishery in the state.

### How Has Recent Changes in Sea Level Impacted Soft-Shell Clam Harvesting?

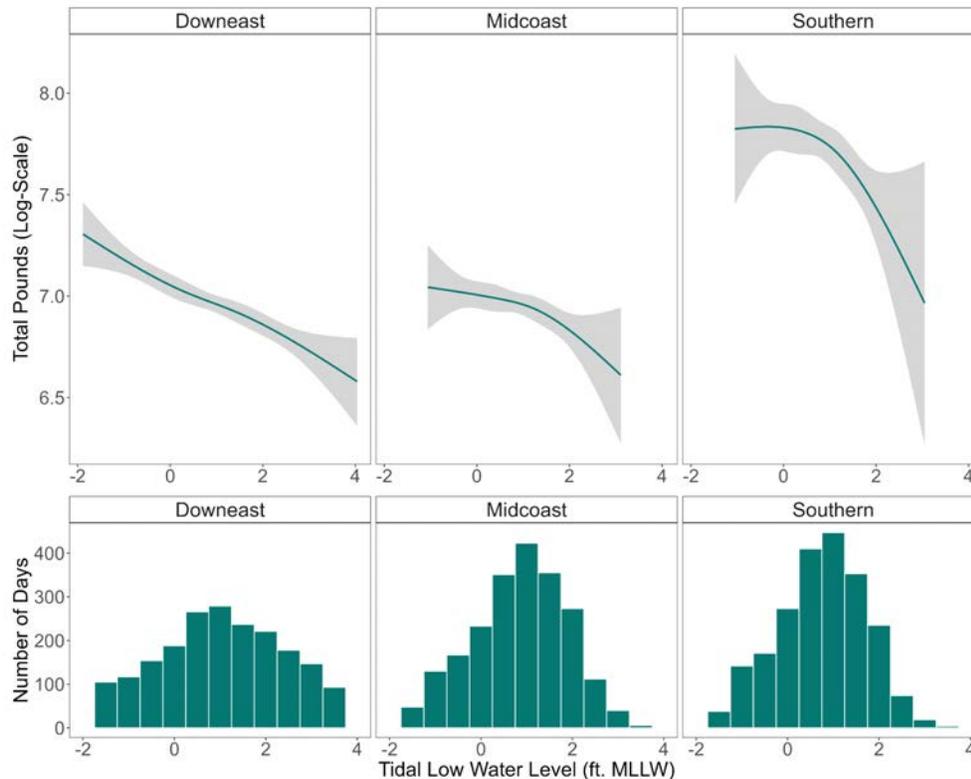


Figure 18: Natural spline relationship between landed pounds and tidal height over the summer harvesting season (July-October). There is a negative relationship as tidal heights increase across all regions, with a more precipitous drop in the Southern region at ~2.86 ft.

Over the past decade, mean lower low water level has increased in Maine. This increase is due to astronomical and atmospheric conditions aligning to cause sea levels in this region to rise. Currently, we have a few days of high tide flooding in a year; however, by 2050, predictions suggest a potential 70 days of high tide flooding. Increased tidal heights can have a strong impact on soft-shell clam harvesting, providing an opportunity for further exploration on the possible impacts of sea-level rise on the soft-shell clam fishery.

Figure 18 shows the relationship between regional landed pounds of soft-shell clams and tidal low water level. The lower the tidal water level, the more days and hours the flats are accessible for harvesting. The top panel depicts the logged weekly landed pounds at each port. A natural spline method was used to show the trend line. The grey shaded area represents the standard error in the natural spline estimate,

showing the potential uncertainty from modeling this relationship. The bottom panel shows the distribution of daily MLLW levels. For this figure, only summer landings from July to October were used, as this season represents “peak” harvesting season, as well as consistent weather. The figure examines the relationship between water level and clam landings in log-scale, allowing the variance to be stabilized as well as providing an easier interpretation of the relationship between landings and MLLW levels.

The trend line indicates that while tidal height is negatively associated with total landings in each region, the strength and curvature of this relationship varies, suggesting region-specific sensitivity to tidal changes. The southern region of Maine sees a tidal threshold of about 2.86 feet MLLW, with a sharp decrease in landings. The Downeast and Midcoast regions of Maine present a linear negative relationship between tidal height and total landings, depicting no distinct tidal height threshold. It is also important to note that the Downeast region has higher variability in tidal height, with an increased amount of lower and higher tide days. This could suggest that harvesters in this region have higher adaptation-levels to tidal patterns and can adjust on days with higher MLLW.

An exploratory analysis using the ordinary least squares (OLS) regression model indicates each additional foot of mean lower low water is associated with about a 19.2% decrease in weekly summer harvested pounds, on average.

### How are Storms Impacting Soft-Shell Clam Harvesting?

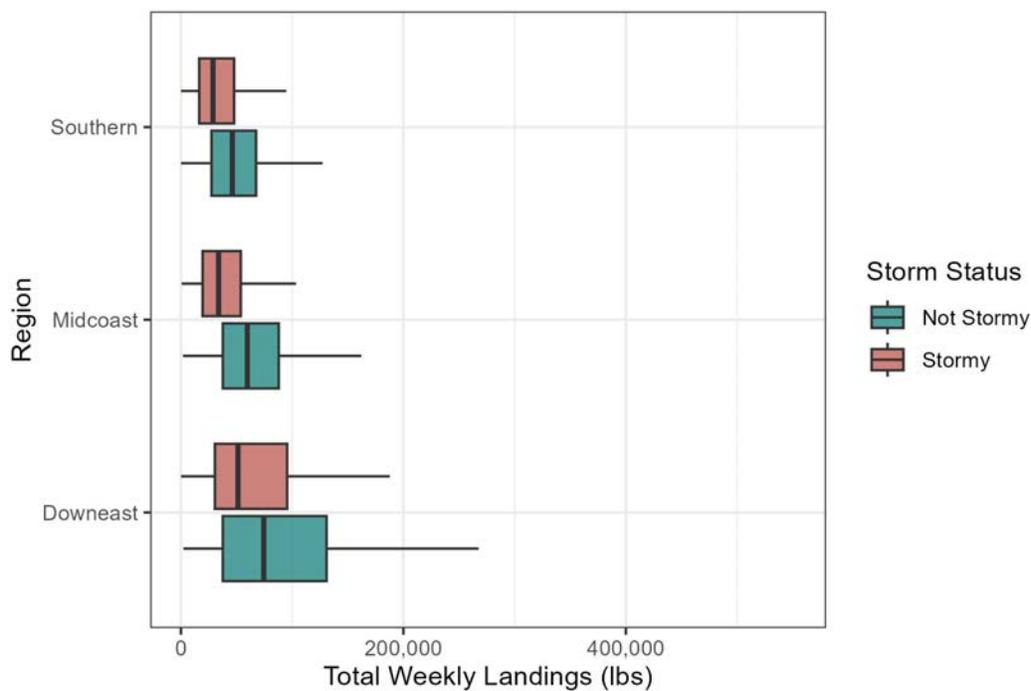


Figure 19: Box-and-whisker plot of weekly regional landings by storm occurrence. We see a statistically significant difference in total landings on non-stormy weeks.

Storms can have a large impact on a clammer's ability to harvest, as precipitation closures or poor weather conditions can prevent accessibility to mudflats across the state. Across all regions, landings are higher in weeks with no storms compared to weeks with at least one storm occurrence.<sup>10</sup>

An ordinary least squares (OLS) regression model finds each additional storm in a week is associated with about a 15.6% decrease in weekly harvested pounds, on average. This model also finds that harvests vary widely by season and region.

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<sup>10</sup> T-test levels of significance were completed

## What is the Impact of Mudflat Closures on Soft-Shell Landings?

Julia Victor, Scripps College

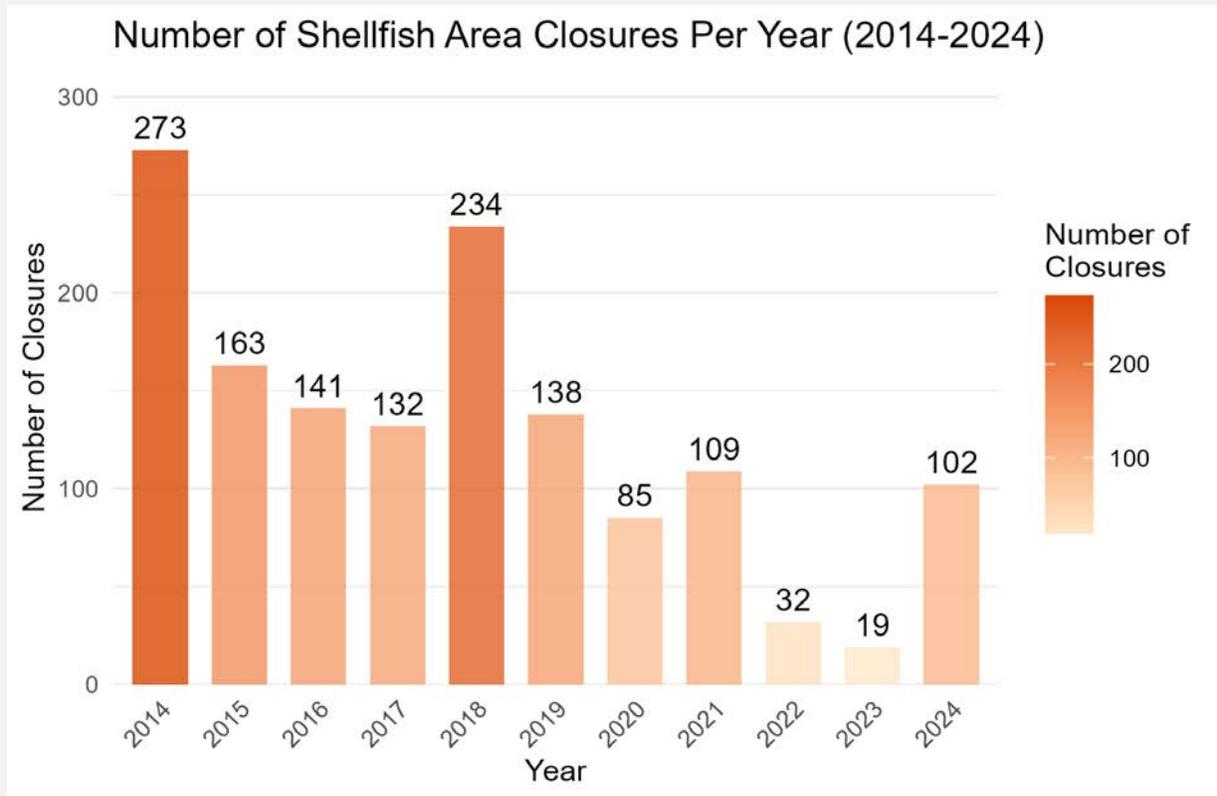


Figure 20: Closures per year based on closure data from Maine DMR. Closures were calculated to account for the number of mudflats affected by each closure event. Analysis only includes precipitation closures to quantify climate-based impacts to soft-shell clam landings.

The Maine Department of Marine Resources posts precipitation closures to mudflats after two or more inches of rainfall within a 24-hour period. This automatic threshold prevents shellfish harvesting when contamination from runoff could pose a health danger. In past years, mudflats remained closed until water quality tested at safe levels, but in 2024 DMR adopted a standardized approach of closing flats for between three to five days depending on the amount of rainfall. This analysis focuses on precipitation closures using the approximate number of closed days based on the automatic closure threshold (as in Figure 20). Yearly trends in rainfall closures can highlight how changing weather patterns might be impacting shellfish harvest.

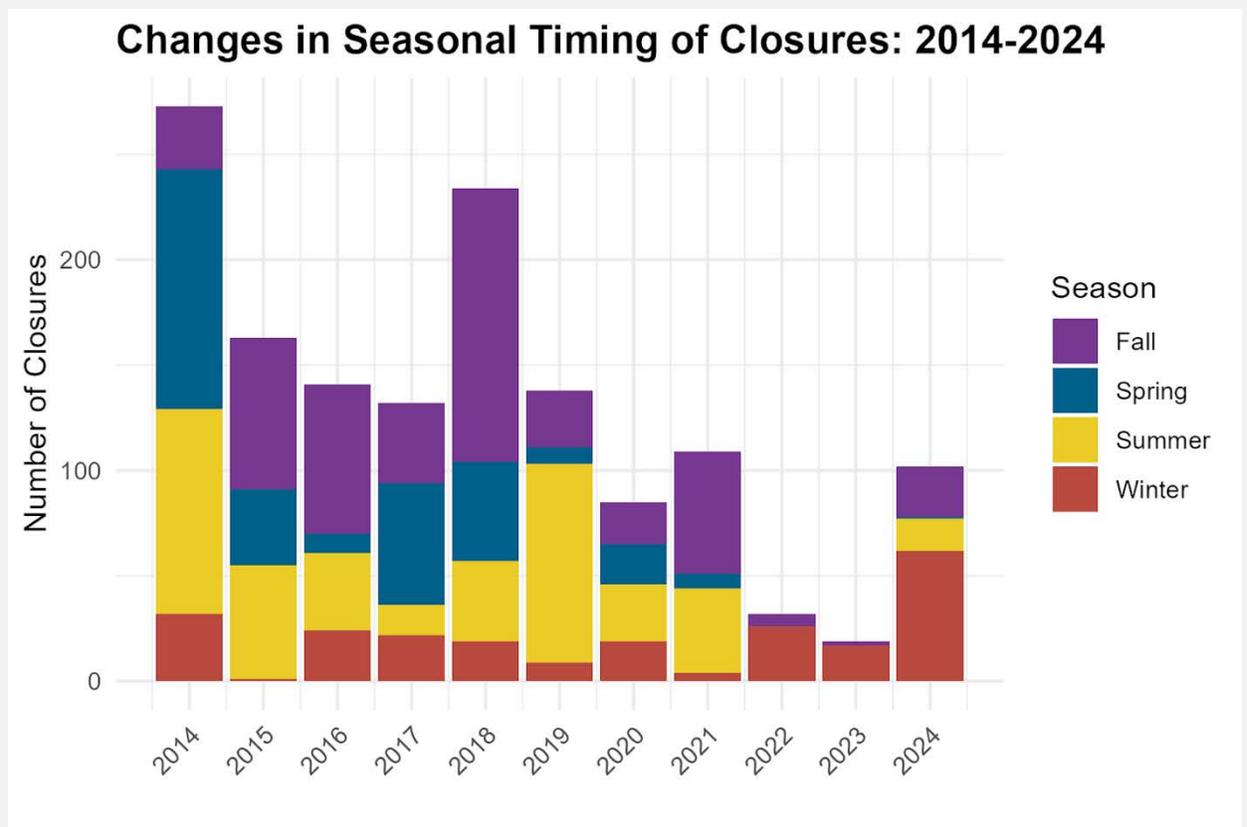


Figure 21: The total count of closures occurring during each season based on yearly data from 2014-2024. The total number of closures in Spring and Fall has decreased in recent years.

Contrary to the expectation that more closed mudflats would result in less soft-shell clams landed, there was no visible relationship between closed days per year and annual soft-shell clam landings (Figure 20). This non-relationship points to the importance of seasonality. Since 2022, the total number of closures has been concentrated in the winter months when harvesting levels are lower (Figures 21), therefore limiting impact on overall landings.<sup>11</sup>

<sup>11</sup> Understanding of the relationship between closures and landings would be facilitated by the standardization of closure reporting in DMR datasets, as there were some assumptions made about the lengths of closures due to inconsistent reporting and coded adjustments in data analysis to account for changes in reporting over the years.

## 5. Discussion & Conclusions

This study aimed to deepen the understanding of soft-shell clam landings and price fluctuations across Maine's coast. By examining both economic trends and environmental influences, we sought to identify the key drivers behind changes in the soft-shell clam fishery over time. Our findings reveal that while landings have been declining this past decade, prices have remained relatively stable, and in some cases drastically increased. These trends are contextualized within broader patterns observed in Maine's bivalve fisheries, which continue to play a significant role in the state's coastal economy.

Other significant findings include:

- Price shifts are affected by more than just the shifts in supply of soft-shell clams
  - The Southern region (Cumberland and York counties) receives higher prices, likely due to their location to seafood markets and large summer tourism demand.
  - Price trends across each region follow a similar pattern in the long-run.
- Absolute price volatility metrics suggest a stable soft-shell clam market in Maine both inter-annual (year-to-year) and intra-annual (within-year).
  - The highest level of intra-annual volatility (within-year) occurred in 2020 and 2023.
    - 2020 can be explained by the COVID-19 pandemic, which shocked all markets.
    - 2023 is likely due to significantly decreased landings across the state, impacting prices across the shellfish market.
- The COVID-19 pandemic affected the soft-shell clam market in Maine, increasing price volatility, demand for soft-shell clams, and coastal accessibility to mudflats across the state.
- Each additional foot of mean lower low water leads to a 19.2% decrease in weekly summertime landings.
  - Weekly landings drop more significantly in Southern Maine at around 2.86-foot MLLW.
- Each additional storm in a week is associated with a 15.6% decrease in weekly harvested pounds.
  - Mudflat closures do not appear to affect state-wide soft-shell clam landings and prices. Since 2022, most closures occur in the winter season when there are smaller harvests across the state.

### Areas Requiring Further Investigations and Future Recommendations

#### 1.) *Further research into the behaviors of harvesters when faced with environmental changes and decreased accessibility*

Clammers in Maine are facing increased harvesting barriers from a variety of environmental and socioeconomic factors, limiting harvests in recent years and raising concerns for the future of the industry. Many of these changes have created pressure on harvesters to change their prior behaviors and find creative solutions to the challenges in front of them. Given these changing conditions, understanding harvester adaptation through qualitative and quantitative metrics will provide further evidence and insight for the harvesting trends we have identified in our report.

2.) *Further investigation into the growth of other important bivalves*

This project emphasizes the growth of emerging shellfish industries across Maine's coastal mudflats. Increasing the scope of research among emerging bivalve species and their harvests will support a greater understanding of the natural resources available and what additional harvesting opportunities remain for clammers, as the soft-shell clam population continues to decline. Further, many communities across the coast of Maine utilize stock enhancement in their mudflats to support the wild harvest populations. Understanding the economic benefits of these seed dispersal methods can provide concrete and quantifiable justification for their use in future implementation efforts.

3.) *Future research on environmental effects to bivalve habitats*

New opportunities in scientific research are providing additional data to explore current environmental threats to soft-shell and broader bivalve habitats. For instance, local observations between ice cover and soft-shell clam population density suggest a possible relationship that could be further examined through innovations in satellite data at different sites in Maine. Novel dataset and data products that show ice cover and coastal water temperatures can be useful in the future economic assessments to further investigate the impacts of climate change on intertidal shellfish fisheries.<sup>12</sup> While this example is largely anecdotal and based on local knowledge, it illustrates the types of relationships that warrant further study.

4.) *Improved data collection methods of soft-shell clam industry information for the state of Maine*

The Department of Marine Resources organizes public landings information for soft-shell clam landings among municipalities in the state of Maine (Maine Department of Marine Resources, 2025). This information provides a baseline understanding of the industry and the revenue generated from bivalve harvesting; however, the current structure does not provide opportunities to examine external factors affecting the industry in an efficient manner. This could include aligning closure notices to match landings structure, such as comparable date formatting and organization of type of closure as well as adding a municipality column alongside growing areas. Additions to this dataset could allow closure data to be easily extracted into a spreadsheet format for future quantitative analysis.

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<sup>12</sup> See [Copernicus Browser](#) for ice cover along rivers/lakes/oceans.

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## Appendix 1: Literature Review Methods and Materials

In an effort to further understand the soft-shell clam industry in Maine, we conducted a hybrid systematic review of academic literature to assess current journal articles and other scholarly publications. We began our review by searching “Maine shellfish market,” refining our search to articles from 2003-2024 and importing the first 110 articles for further review. We further simplified these 110 articles down to 22, removing publications that did not qualify specific information in Maine’s shellfish market. Additionally, we collected shellfish harvesting information from technical reports and additional documents provided through local and regional resources, such as coastal town websites, regional working groups, newspaper articles, and other organizations that support shellfish research. The soft-shell literature can be summarized into three main themes: Environmental, Socioeconomic, and general shellfish harvesting.

### Maine Soft-Shell Clam Article List

Article Title	Type of Article	Year	Keywords	Citation
<b>Environmental Factors</b>				
Measuring the impact of pollution closures on commercial shellfish harvest: The case of soft-shell clams in Machias Bay, Maine	Journal Article	2016	Soft-shell clams, Fisheries management, Pollution closures, Water pollution	Evans, K. S., Athearn, K., Chen, X., Bell, K. P., & Johnson, T. (2016). Measuring the impact of pollution closures on commercial shellfish harvest: The case of soft-shell clams in Machias Bay, Maine. <i>Ocean &amp; Coastal Management</i> , 130, 196–204. <a href="https://doi.org/10.1016/j.ocecoaman.2016.06.005">https://doi.org/10.1016/j.ocecoaman.2016.06.005</a>
Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England	Journal Article	2008	Harmful algal bloom, Economic impact, commercial shellfish fisheries	Jin, D., Thunberg, E., & Hoagland, P. (2008). Economic impact of the 2005 red tide event on commercial shellfish fisheries in New England. <i>Ocean &amp; Coastal Management</i> , 51(5), 420–429. <a href="https://doi.org/10.1016/j.ocecoaman.2008.01.004">https://doi.org/10.1016/j.ocecoaman.2008.01.004</a>
The Value of Harmful Algal Bloom Predictions to the Nearshore Commercial Shellfish Fishery in the Gulf of	Journal Article	2008	Fisheries, Forecast, Harmful algal bloom, Marine scientific research, red	Jin, D., & Hoagland, P. (2008). The value of harmful algal bloom predictions to the nearshore commercial shellfish fishery in the Gulf of Maine. <i>Harmful Algae</i> , 7(6), 772–781.

Maine			tide, value of information	<a href="https://doi.org/10.1016/j.hal.2008.03.002">https://doi.org/10.1016/j.hal.2008.03.002</a>
Comparative, Large Scale Field Trials Along the Maine Coast to Assess Management Options to Enhance Populations of the Commercially Important Soft-Shell Clam, <i>Mya Arenaria</i> L.	Journal Article	2016	Softshell clam, <i>mya arenaria</i> , Maine, intertidal aquaculture, manipulative field experiment, predator-deterrent netting, clam farming	Beal, B. F., Nault, D.-M., Annis, H., Thayer, P., Leighton, H., & Ellis, B. (2016). Comparative, Large-Scale Field Trials Along the Maine Coast to Assess Management Options to Enhance Populations of the Commercially Important Softshell Clam, <i>Mya arenaria</i> L. <i>Journal of Shellfish Research</i> , 35(4), 711–727. <a href="https://doi.org/10.2983/035.035.0401">https://doi.org/10.2983/035.035.0401</a>
Using a Stakeholder-Engaged Approach to Understand and Address Bacterial Transport on Soft-Shell Clam Flats	Journal Article	2022	Stakeholder engagement, Soft-shell clam, Bacteria pollution, Estuarine circulation, Lagrangian drifters	Hillyer, G. V., Liu, W., McGreavy, B., Melvin, G., & Brady, D. C. (2022). Using a Stakeholder-Engaged Approach to Understand and Address Bacterial Transport on Soft-Shell Clam Flats. <i>Estuaries and Coasts</i> , 45(3), 691–706. <a href="https://doi.org/10.1007/s12237-021-00997-0">https://doi.org/10.1007/s12237-021-00997-0</a>
Spatial Variability in Recruitment of an Infaunal Bivalve: Experimental Effects of Predator Exclusion on the Softshell Clam Along Three Tidal Estuaries in Southern Maine	Journal Article	2018	<i>mya arenaria</i> , post-settlement mortality, spatial variability, predator exclusion, field experiment	Beal, B. F., Coffin, C. R., Randall, S. F., Goodenow, C. A., Pepperman, K. E., Ellis, B. W., Jourdet, C. B., & Protopopescu, G. C. (2018). Spatial Variability in Recruitment of an Infaunal Bivalve: Experimental Effects of Predator Exclusion on the Softshell Clam ( <i>Mya arenaria</i> L.) along Three Tidal Estuaries in Southern Maine, USA. <i>Journal of Shellfish Research</i> , 37(1), 1–27. <a href="https://doi.org/10.2983/035.037.0101">https://doi.org/10.2983/035.037.0101</a>
Trends in Maine Soft-Shell Clam Landings	Journal Article	2006	Clam landings, Gulf of Maine, green crabs, shellfish management	Congleton, W. R., Vassiliev, T., Bayer, R. C., Pearce, B. R., Jacques, J., & Gillman, C. (2006). Trends in Maine Soft-Shell Clam Landings. <i>Journal of Shellfish Research</i> , 25(2), 475–480. <a href="https://doi.org/10.2983/0730-8000(2006)25[475:TIMSCL]2.0.CO;2">https://doi.org/10.2983/0730-8000(2006)25[475:TIMSCL]2.0.CO;2</a>

Changes in survivorship, behavior, and morphology in native soft-shell clams induced by invasive green crab predators	Journal Article	2010	Soft-Shell Clam Predators, Burrowing depth, crab, inducible defense, invasive species	Whitlow, W. L. (2010). Changes in survivorship, behavior, and morphology in native soft-shell clams induced by invasive green crab predators. <i>Marine Ecology (Berlin, West)</i> , 31(3), 418–430. <a href="https://doi.org/10.1111/j.1439-0485.2009.00350.x">https://doi.org/10.1111/j.1439-0485.2009.00350.x</a>
Crabs, Clams, and the Corps: Regional Realities and the Federal Framework	Journal Article	2016	Soft-Shell Clam Predation, Soft-Shell Clam Aquaculture, Logistical Restrictions	Jessica Hollenkamp, <i>Crabs, CLams, and the Corps: Regional Realities and the Federal Framework</i> , 21 <i>Ocean &amp; Coastal L.J.</i> 221 (2016). Available at: <a href="http://digitalcommons.maine.gov/oclj/vol21/iss1/13">http://digitalcommons.maine.gov/oclj/vol21/iss1/13</a>
<b>Socioeconomic Factors</b>				
Mapping local knowledge supports science and stewardship	Journal Article	2025	Fisheries management, Local knowledge mapping, Social-ecological systems	Risley, S. C., Britsch, M. L., Stoll, J. S., & Leslie, H. M. (2025). Mapping local knowledge supports science and stewardship. <i>Ambio</i> , 54(10), 1648–1665. <a href="https://doi.org/10.1007/s13280-025-02170-4">https://doi.org/10.1007/s13280-025-02170-4</a>
Mapping Access to the Intertidal in Six Towns in Casco Bay: <i>An inventory by Manomet</i>	Technical Report	2023	Coastal Access, Intertidal Access Challenges	Farr, E., & McMahan, M. (2023). Mapping Access to the Intertidal in Six Towns in Casco Bay: <i>An inventory by Manomet</i> . <a href="https://www.manomet.org/wp-content/uploads/2023/12/MappingAccessstoIntertidal-122023.pdf">https://www.manomet.org/wp-content/uploads/2023/12/MappingAccessstoIntertidal-122023.pdf</a>
Getting to the Shore on Foot: Sustaining Harvester Access	Journal Article	2023	Coastal Access, Access Challenges	Zoellick, Bill, Pauline V. Angione, Emily Farr, Ada Fisher, Jessica G. Joyce, B Lauer, Marissa McMahan Ph.D., Michael Pinkham, and Vicki Rea. "Getting to the Shore on Foot: Sustaining Harvester Access." <i>MainePolicyReview</i> 32.2 (2023) : 100 - 103, <a href="https://digitalcommons.library.umaine.edu/mpr/vol32/iss2/16">https://digitalcommons.library.umaine.edu/mpr/vol32/iss2/16</a> .
Residency and Access to Commercial Shellfish Licenses	Technical Report	2023	Shellfish Management, Access to	Vultaggio, C., Hawkins, V., Joyce, J., Farr, E., McMahan, M., Sutton, A., <i>Residency and Access to Commercial</i>

			Working Waterfronts, License Allocation/Equity	<i>Shellfish Licenses</i> . Casco Bay Regional Shellfish Working Group. <a href="https://static1.squarespace.com/static/6026cbaf8dfa6838a1b67b5e/t/6543a529b84462676576ba5c/1698932016115/SWG_ResidencyGuidanceDoc-110123.pdf">https://static1.squarespace.com/static/6026cbaf8dfa6838a1b67b5e/t/6543a529b84462676576ba5c/1698932016115/SWG_ResidencyGuidanceDoc-110123.pdf</a>
Exploring Shellfish Harvesting Accessibility in Maine's Municipal Shellfish Ordinance Laws	Technical Report	2022	Shellfish Accessibility, Maine Shellfish Laws	Van Damme, Charles; Lacey, Megan; McLain, Findley; and Hoag, Sophia, "Exploring Shellfish Harvesting Accessibility in Maine's Municipal Shellfish Ordinance Laws" (2022). Community Engaged Research Reports. 90. <a href="https://scarab.bates.edu/community_engaged_research/90">https://scarab.bates.edu/community_engaged_research/90</a>
Adaptive capacity of co-management systems in the face of environmental change: The soft-shell clam fishery and invasive green crabs in Maine	Journal Article	2015	Adaptive management, Coastal fisheries, Environmental change, Invasive species, Local management, Stewardship	McClenachan, L., O'Connor, G., & Reynolds, T. (2015). Adaptive capacity of co-management systems in the face of environmental change: The soft-shell clam fishery and invasive green crabs in Maine. <i>Marine Policy</i> , 52, 26–32. <a href="https://doi.org/10.1016/j.marpol.2014.10.023">https://doi.org/10.1016/j.marpol.2014.10.023</a>
Supporting Municipal Co-Management of Shellfish and Community Engagement in Casco Bay, Maine	Technical Report	2020	Co-Management	Miller, S., Carter, J., & Moon, N. (2020). Supporting Municipal Co-Management of Shellfish and Community Engagement in Casco Bay, Maine. <a href="https://static1.squarespace.com/static/58b5a5a7cd0f6887943919df/t/5efd467842cc9218e811af5/1593701480663/Final_Mgmt_Report_Full_revised_062520.pdf">https://static1.squarespace.com/static/58b5a5a7cd0f6887943919df/t/5efd467842cc9218e811af5/1593701480663/Final_Mgmt_Report_Full_revised_062520.pdf</a>
Enhancing Adaptive Capacities in Coastal Communities Through Engaged	Journal Article	2018	Co-Management, Socio-environmental changes	McGreavy, B., Randall, S., Quiring, T., Hathaway, C., & Hillyer, G. (2018). Enhancing adaptive capacities in coastal communities through

Communication Research: Insights from a Statewide Study of Shellfish Co-Management				engaged communication research: Insights from a statewide study of shellfish co-management. <i>Ocean &amp; Coastal Management</i> , 163, 240–253. <a href="https://doi.org/10.1016/j.ocecoaman.2018.06.016">https://doi.org/10.1016/j.ocecoaman.2018.06.016</a>
Communicating Care in Coastal Fisheries	Journal Article	2023	Environmental communication, Media representation,	McGreavy, Bridie, Gabrielle V. Hillyer, Jessica G. Joyce, Emily Farr, B Lauer, Anthony Sutton, Katie Moody, Jessica P. Batchelder, Ishani Jayamaha, and Marissa McMahan Ph.D.. "Communicating Care in Coastal Fisheries: Restoration, Adaptation, and Collaborative Policy Change." <i>Maine Policy Review</i> 32.2 (2023) : 91 -99, <a href="https://digitalcommons.library.umaine.edu/mpr/vol32/iss2/15">https://digitalcommons.library.umaine.edu/mpr/vol32/iss2/15</a> .
<b>Shellfish Harvesting</b>				
The Maine Shellfish Handbook	Technical Report	2021	Shellfish Harvesting, Maine Shellfish Market	Webber, Michelle Mason et al. (2021). <i>The Maine Shellfish Handbook</i> . <a href="https://repository.library.noaa.gov/view/noaa/48049">https://repository.library.noaa.gov/view/noaa/48049</a>
Maine Shellfish: An Analysis of the Market & An Exploration of Trade-Based Associations	Technical Report	2010	Shellfish Aquaculture, Shellfish Market	Palmer, Stephanie and Theriault, Ross (2010). <i>Maine Shellfish: An Analysis Of The Market And An Exploration Of Trade-Based Associations</i> . <a href="https://repository.library.noaa.gov/view/noaa/39369">https://repository.library.noaa.gov/view/noaa/39369</a>
Maine Clammers Association Economic Impact of Maine's Shellfish Industry January 2008	Economic Impact Report	2008	Economic Impact, Maine Clam Market,	Athearn, Kevin, "Maine Clammers Association Economic Impact of Maine's Shellfish Industry January 2008" (2008). <i>DocumentsfromEnvironmentalOrganizations</i> . 173. <a href="https://digitalcommons.library.umaine.edu/maine_env_organizations/173">https://digitalcommons.library.umaine.edu/maine_env_organizations/173</a>

Adding Value to Live, Commercial Size Soft-Shell Clams in Maine, USA: Results from Repeated, Small-Scale Field Impoundment Trials	Journal Article	2002	Soft-Shell Clam Aquaculture	Beal, B. F. (2002). Adding value to live, commercial size soft-shell clams ( <i>Mya arenaria</i> L.) in Maine, USA: results from repeated, small-scale, field impoundment trials. <i>Aquaculture</i> , 210(1), 119–135. <a href="https://doi.org/10.1016/S0044-8486(02)00016-9">https://doi.org/10.1016/S0044-8486(02)00016-9</a>
Interactions Between the Invasive European Green Crab and Juveniles of the Soft-Shell Clam in Eastern Maine, USA	Journal Article	2015	Predator-prey interactions, Predator-exclusion, Growth & Survival	Tan, E. B. P., & Beal, B. F. (2015). Interactions between the invasive European green crab, <i>Carcinus maenas</i> (L.), and juveniles of the soft-shell clam, <i>Mya arenaria</i> L., in eastern Maine, USA. <i>Journal of Experimental Marine Biology and Ecology</i> , 462, 62–73. <a href="https://doi.org/10.1016/j.jembe.2014.10.021">https://doi.org/10.1016/j.jembe.2014.10.021</a>
Building a Sustainable Seafood System for Maine	Journal Article	2011	Sustainable Fisheries, Maine Seafood Systems, Aquaculture, Equity	Alden, Robin. "Building a Sustainable Seafood System for Maine." <i>MainePolicyReview</i> 20.1 (2011) : 87 - 95, <a href="https://digitalcommons.library.umaine.edu/mpr/vol20/iss1/16">https://digitalcommons.library.umaine.edu/mpr/vol20/iss1/16</a> .

## Appendix 2: Data

### Landings Data

This study uses Commercial Fisheries Landings Data compiled by the Maine Department of Marine Resources, which reports port-level commercial fisheries landed volume and values. Landings data in this project utilizes three key bivalve species in Maine: soft-shell clams (*mya arenaria*), northern quahogs (*mercenaria mercenaria*), and eastern oysters (*crassostrea virginica*). For analysis, the data has been aggregated into weekly, monthly, and yearly time frames, spanning from January 2006 through December 2023. Maine was additionally split into three distinct regions (Downeast, Midcoast, and Southern) for portions of the analysis in an effort to understand market changes and price volatilities in different coastal parts of the state. The Downeast region includes Washington and Hancock counties, Midcoast region includes Waldo, Knox, Lincoln, and Sagadahoc counties, and the Southern region includes Cumberland and York counties.

### Storm Data

This study used data from the University of Manitoba's Northern Hemisphere Extratropical Cyclone Tracking dataset to study storm effects on soft-shell harvesting across the coast of Maine (Crawford et al., 2025). The data provided consisted of extratropical storms recorded at weather stations located in Portland, Rockland, Bar Harbor, and Eastport. These weather events were considered a storm if they (1) had four consecutive hours of wind speeds greater than 12 knots, (2) storms were at least 48 hours apart from each other, and (3) there was an extratropical cyclone within 1200km of the wind station.<sup>13</sup>

### Tidal Data

Tidal height data was collected from the NOAA Center for Operational Oceanographic Products and Services (CO\_OPS).<sup>14</sup> The definition of Mean Lower Low Water (MLLW) is used to measure the height of the water in the mudflats during low tide, which is defined as the average of the lower low water height of each tidal day (NOAA, 2025). Historical tide gauge data from Portland, Bar Harbor, and Eastport was analyzed to record daily measurements of the minimum lowest tidal height during daylight hours (dawn to dusk). With these recordings, the weekly average for each region is pulled to analyze the relationship between total landings and tidal heights. It is important to note that mudflats vary significantly across the state and tidal heights are dependent on a flat by flat basis. Based on tidal gauge locations, there is an assumption that average tidal heights are consistent across spatial regions (Downeast, Midcoast, Southern); however, these recordings may not reflect the exact height within each regional flat.

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<sup>13</sup> Database utilized only considered extratropical cyclones, and did not include any tropical storms (hurricanes)

<sup>14</sup> Data was collected from Portland (8418150), Bar Harbor (8413320), and Eastport (8410140)

## Appendix 3: Absolute and Relative Volatility

### *Absolute Volatility*

The absolute volatility metric is a ratio of the standard deviation of the first differences. The annual price volatility can be expressed as:

$$sd(P_{t+1} - P_t) / \text{mean}(P_t) \text{ for } t = [1, \dots, N-1]$$

where  $t$  represents the year.

For the inter-annual (i.e., year-to-year) volatility, the notation  $t$  in the equation represents the year, and  $P$  is the mean price recorded for year  $t$ . For the intra-annual (i.e., within-year) volatility, the notation  $t$  represents the week and,  $P$  is the mean price recorded for week  $t$ . Intra-annual volatility metric was calculated for each year.

### *Beta Coefficients by Municipality*

The beta coefficient is a ratio of covariance between the price (value/pounds) of an arbitrary municipality  $A$  for soft-shell clams and the price (value/pounds) overall landed species in Maine to the variance of the price (value/pounds) of all landed species in Maine. Beta coefficient can be expressed as:

$$\beta_{\text{Port,Mkt}} = \frac{\text{Cov}(P_{\text{Port}}, P_{\text{Mkt}})}{\text{Var}(P_{\text{Mkt}})}$$

where  $P$  is a weekly mean price for each port for the four market categories.

Volatility measures over 1 indicate higher volatility relative to the entire shellfish market. This suggests that municipalities with a volatility measure above 1 are more sensitive to changes in the overall market. Conversely, volatility measures under 1 indicate lower volatility relative to the entire shellfish market, providing a more stable harvesting town. Finally, volatility measures in line with a value of 1 reflect connections with the overall state market, as trends in this municipality tend to move in the same direction as overall state trends.

**>1: Higher Volatility Relative to Overall State Market**

**=1: Connected to Overall State Market (i.e. follows state volatility trends)**

**<1: Lower Volatility Relative to Overall State Market**

### Relative Volatility: Beta Coefficients by Municipality

<i>Town</i>	<i>Region</i>	<i>Beta Coefficient</i>
Sorrento	Downeast	1.68
Georgetown	Midcoast	1.35
South Thomaston	Midcoast	1.30
St. George	Midcoast	1.26
Jonesboro	Downeast	1.24
Machias	Downeast	1.24
Trescott	Downeast	1.20
Sullivan	Downeast	1.19
Vinalhaven	Midcoast	1.18
Beals	Downeast	1.18
Roque Bluffs	Downeast	1.17
Eastport	Downeast	1.16
Addison	Downeast	1.16
Jonesport	Downeast	1.16
Freeport	Southern	1.15
Machiasport	Downeast	1.15
Steuben	Downeast	1.15
Thomaston	Midcoast	1.14
Woolwich	Midcoast	1.14
Lamoine	Downeast	1.14
Lubec	Downeast	1.14
Wiscasset	Midcoast	1.13
Whiting	Downeast	1.12
Cutler	Downeast	1.12

Harrington	Downeast	1.12
Perry	Downeast	1.11
Boothbay Harbor	Midcoast	1.11
Boothbay	Midcoast	1.11
Gouldsboro	Downeast	1.11
Milbridge	Downeast	1.10
Cushing	Midcoast	1.10
Phippsburg	Midcoast	1.09
Scarborough	Southern	1.09
Pembroke	Downeast	1.09
Waldoboro	Midcoast	1.08
Blue Hill	Downeast	1.08
Friendship	Midcoast	1.08
Hancock	Downeast	1.07
Bremen	Midcoast	1.07
Franklin	Downeast	1.06
Deer Isle	Downeast	1.06
Bristol	Midcoast	1.06
Swans Island	Downeast	1.05
Yarmouth	Southern	0.98
South Bristol	Midcoast	0.98
Sedgewick	Downeast	0.95
Westport Island	Midcoast	0.95
Tremont	Downeast	0.95
Biddeford Pool	Southern	0.95
Brooklin	Downeast	0.94

North Haven	Midcoast	0.94
Surry	Downeast	0.93
Stonington	Downeast	0.92
Bar Harbor	Downeast	0.91
Brunswick	Southern	0.90
Trenton	Downeast	0.90
Harpswell	Southern	0.86
Newcastle	Midcoast	0.73
West Bath	Midcoast	0.72
Damariscotta	Midcoast	0.66
Brooksville	Downeast	0.55
Edgecomb	Midcoast	0.52

## Appendix 4: Fish Price Index

The Fish Price Index adopts a price indexing method called the Fisher Index, which is calculated as the geometric mean of the Laspeyres Index and Paasche Index. Laspeyres Index and Paasche Index are both calculated as the ratio of product sums of price and quantities by using different base periods, and the FPI index is calculated as the geometric mean of these two indices. Our base month represents a stable time in our sample, where prices and landings are less volatile, allowing the analysis to accurately measure economic trends. We further match our base to the average value per pound of soft-shell clams in this month (\$1.25), extrapolating the average price index to match the average value per month across our time-series.

### Laspeyres index:

The Laspeyres index assumes that the quantities (harvested landings) are fixed in a base period (December 2023) ( $t = 0$ ), allowing this index to maintain landings and only update price information throughout the time-period (2006-2023).

$$I_t^L = \frac{\sum p_{it}q_{i0}}{\sum p_{i0}q_{i0}}$$

### Paasche index:

The Paasche index utilizes quantities (harvested landings) within each period. Therefore, this index is influenced by both the changes in total landings as well as changes in mean price over time.

$$I_t^P = \frac{\sum_i p_{it}q_{it}}{\sum_i p_{i0}q_{it}}$$

### Fish index:

The Fish index utilizes both the Laspeyres and Paasche index, taking the geometric mean of these two indices.

$$I_t^F = \sqrt{I_t^L I_t^P}$$

## Appendix 5: Time-Series Analysis

An important feature of the time-series data to check before using time-series data in the analysis is the stationarity. The data is deemed stationary when the statistical measures of a dataset (mean, variance, and covariance) remain constant across a period of time. Consider for example a historical record of prices. If the price data is stationary, that means that the prices can be expected to revert back to the mean and move within expected ranges over time. If the data is not stationary, the mean and variance of the dataset is changing over time, making it challenging to determine the influence of an event on the time series with statistical analyses such as regression analysis. Without stationarity, statistical models can lead to unreliable outputs and inaccurate predictions; therefore, it is important for us to confirm stationarity before we begin analyzing our soft-shell clam dataset.

Unit root test is the common approach to check stationarity of the time-series data. A unit root is a feature within a time-series dataset that is influenced by random processes, making the trend unpredictable with common economic analysis. This effect from a single event (or shock) in a dataset can influence the process indefinitely, leading to unreliable and non-stationary data. For our analysis, unit root tests were conducted to confirm stationarity before beginning to model. There are multiple ways to test for a unit root and stationarity of the dataset. We conducted two unit root tests and one stationarity test among our weekly and monthly landings data on clam harvesting in Maine. We report the results of the augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1981), the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test (Kwiatkowski et al., 1992), and the Zivot-Andrews (Z-A) test (Zivot & Andrews, 2002). Each test addresses a hypothesis to determine different types of non-stationarity that may be present in the time-series data. ADF is the most commonly used to test for the existence of a unit root (i.e., non-stationary). KPSS test is the stationarity test that is often complementary to ADF and used to test for the stationarity of the dataset. The ADF and KPSS may indicate the data to be non-stationary even if in fact the data is stationary. This can occur if the dataset includes structural breaks (i.e., sudden jumps in the dataset where means and variance become stable after the jump). Therefore, Z-A tests for unit root while detecting and accounting for such structural breaks to avoid misspecifying a structural break for an existence of a unit root.

### Unit-Root Test Results

	ADF Test Stat. (Level)	ADF Test Stat. (Trend)	ADF Test Stat. (1 <sup>st</sup> Difference)	KPSS Test Stat. (Level)	KPSS Test Stat. (1 <sup>st</sup> Difference)	Zivot-Andrews Test Stat.
Full Sample Pounds	-4.99***	-10.38***	-35.31***	0.05	0.01	-16.48***
Soft-Shell Clam Pounds	-5.42***	-10.38***	-35.32***	0.95	0.01	-16.67***
Downeast SS Pounds	-6.19***	-10.65***	-35.32***	0.21	0.01	-17.50***
Midcoast SS Pounds	-4.75***	-9.51***	-33.34***	2.57***	0.01	-15.16***
Southern SS Pounds	-5.96***	-11.17***	-34.26***	1.54***	0.01	-17.49***
Full Sample Price per Pound	-0.87	-5.86***	-21.78***	4.16***	0.01	-5.88***
Soft-Shell Clam Price per Pound	-1.50	-6.50***	-21.31***	4.16***	0.01	-5.51**
Downeast SS Price per Pound	-1.47	-6.22***	-21.63***	4.30***	0.01	-5.64***
Midcoast SS Price per Pound	-1.64*	-6.94***	-22.08***	4.00***	0.01	-6.24***
Southern SS Price per Pound	-1.39	-6.53***	-21.82***	4.53***	0.01	-6.54***

## Appendix 6: OLS Regression Models

### *Tidal OLS Regression Model*

To evaluate the influence of tidal changes and regional variation on summer soft-shell clam landings in Maine, an ordinary least squares (OLS) linear regression model was estimated using data from 2006 to 2023. The dependent variable was the natural logarithm of soft-shell clam landings, measured in pounds, which allows the coefficients to be interpreted as approximate percentage changes in landings. The primary explanatory variable represents the average weekly daytime mean lower low water levels. One categorical covariate, Region, is included to account for spatial differences in tidal levels across different locations in Maine (Southern, Downeast, Midcoast).

Linear Regression of Total Pounds on MLLW & Region

Variable	Estimate	Std. Error	t-value
Intercept	11.34471	0.04746	239.013***
mean_MLLW	-0.19264	0.02533	-7.605***
RegionMidcoast	-0.34500	0.05843	-5.905***
RegionSouthern	-0.47193	0.05847	-8.071***
Residual Std. Error: 0.7323 (df = 940)			
Multiple $R^2$ : 0.1127    Adjusted $R^2$ : 0.1098			
F-statistic: 39.78 on 3 and 940 df $p < 2.2 \times 10^{-16}$			

### *Storm OLS Regression Model*

To evaluate the influence of storm activity, regional variation, and seasonal patterns on Maine's soft-shell clam landings, an ordinary least squares (OLS) linear regression model was estimated using data from 2006 to 2023. The dependent variable was the natural logarithm of soft-shell clam landings, measured in pounds, which allows the coefficients to be interpreted as approximate percentage changes in landings. The primary explanatory variable represents the total number of storm events occurring each week of our sample. Two categorical covariates, Region and Season, were included to account for spatial and seasonal differences in clam landings across Maine.

Linear Regression of Total Pounds on Storms, Region, and Season

Variable	Estimate	Std. Error	t-value
Intercept	11.67841	0.03792	307.954***
num_storms	-0.15567	0.02208	-7.050***
RegionMidcoast	-0.34837	0.03361	-10.364***
RegionSouthern	-0.56283	0.03405	-16.530***
SeasonMarch–June	-0.40598	0.04150	-9.783***
SeasonNovember–February	-1.41560	0.04248	-33.322***
SeasonSeptember–October	-0.78084	0.04680	-16.684***
Residual Std. Error: 0.7175 (df = 2810)			
Multiple $R^2$ : 0.4282    Adjusted $R^2$ : 0.4270			
F-statistic: 350.7 on 6 and 2810 df $p < 2.2 \times 10^{-16}$			