An Economic Analysis of Shellfish Harvests Regulations for Food Safety

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1. Introduction

Consumption of raw and undercooked shellfish is associated with outbreaks of food-borne illnesses (FBI) resulting in hundreds of reported cases and multiple fatalities each year. The link between shellfish consumption and FBI has been recognized since 1816, when the French physician Pasquier described cases of typhoid fever in people who had consumed oysters harvested from waters contaminated with raw sewage (Rippey 1994). The bacteria *Vibrio vulnificus* has been identified among main causative agents of food-borne illness associated with shellfish consumption. Worldwide production of shellfish has increased dramatically since 1950 (Figure 1, Sergio could it be possible to add to this graph the annual number of reported outbreaks of FBI associated with shellfish consumption), increasing the risk for FBI associated with consumption of shellfish. This dramatic rise in shellfish consumption has been accompanied by an increase in the number of reported outbreaks of FBI associated with shellfish consumption (Potasman et al. 2002), although it is unclear whether the rise in reported outbreaks can be attributed to increased consumption of shellfish or better reporting and attribution systems for FBI (Rippey 1994, Potasman et al. 2002). The USDA estimated the economic cost associate to Vibrio vulnificus is approximately $319 million a year (USDA-ERS, 2014).

Conversely, seafood production is also an important economic driver in the U.S., especially among resource-dependent coastal communities (Evans et al. 2016). The National Marine Fisheries Service (2015) shows that the ex-vessel value of oysters landings in the U.S. totaled $240 million. Historically, Florida has been a major contributor to oyster production in the U.S., where oysters are harvested primarily by independent fishers using low-tech and low-cost harvesting techniques. This low-cost fishing opportunity provides an important source of income for close to 1,000 state-licensed shellfish harvesters in Florida (Pine et al. 2015).

Apalachicola Bay, located in Franklin County on the Florida Panhandle, has historically been one of the most productive oyster fisheries in the US, supplying close to 10% of all domestically produced oysters (Pine et al. 2015). In 2015, the legal daily (how about a footnote about the illegal harvest) harvest period for summer oyster harvest was reduced by 4 hours in order to prevent the incidence of FBI, in particular infections of *Vibrio vulnificus*. While vessels with on-board cooling systems are allowed to harvest for a longer period of time, the fishery is composed predominantly of small owner-operated vessels with the same harvest technology in use since the late 1800s. Franklin County is also one of the most economically depressed counties in the state of Florida, as evidenced by the lagging poverty rate (25.3%), child poverty rate (37.1%), and median household income ($36,788) for 2014, all of which are well below the rates for the state of Florida as a whole (poverty 16.6%; child poverty 24.2%; median household

income $47,439). In recent years, the fishery has experienced an unprecedented collapse, endangering the sustainability of the fishery and the well-being of one of Florida's few remaining working waterfront communities. In this context, a food safety regulation that keeps oyster harvesters off the water for a majority of the day raises concerns as it could potentially be the nail in the coffin for this struggling waterfront community.

In this study we use a non-linear dynamic bioeconomic model informed by cutting-edge fisheries biology research on the state of the Apalachicola Bay oyster stock (Camp et al. 2015; Pine et al. 2015). We use this model to analyze the potential impacts to oyster harvesters from a recent change in the legal daily harvest period during the summer months. We focus on oysters, rather than on a wider group of shellfish, because more than 98% of food borne *Vibrio* infections are associated with oysters (Rippey 1994), and the regulation is designed to reduce the legal daily harvest period for summer oysters in Apalachicola Bay only. Oysters are not harvested anywhere else in Florida during the summer months. The model is constructed using detailed summer oyster trip ticket harvest data from Apalachicola Bay, and is used to analyze the impact of the harvest time regulations in terms of landings and revenues on a daily basis. Further, we use data from before and after the regulatory change to confirm the forecasts developed with the bioeconomic model that uses ex-ante data. To our knowledge, there are no published studies that use bioeconomic modeling to analyze the consequences of food safety regulations in fisheries.

2. Foodborne Illness in Shellfish

For culinary purposes, shellfish can be divided into two groups: crustaceans and molluscan bivalves[1]. Crustaceans include shrimp, crabs, and lobsters, and are characterized by having an exoskeleton that is molt as the animal grows. Crustaceans are generally consumed in cooked form. Molluscan bivalves include clams, mussels, oysters, and scallops, and are characterized by a laterally compressed body enclosed by a shell that is composed of two hinged parts. This study focuses on food safety issues associated with harvest and consumption of molluscan bivalves, hence when the term 'shellfish' is used, we are referring to molluscan bivalves.

Shellfish are commonly found and harvested in areas close to the shoreline, where the waters are sheltered and nutrient levels tend to be higher than in open waters. In many cases, these areas also correspond to those that are more likely to be contaminated with human sewage and other man-made wastes. Shellfish are filter feeders, that is, they feed by pumping large volumes of water across specialized gills and capturing phytoplankton and other microscopic food particles, including organic

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[1] Less common seafood related to these two groups include shelled mollusks such as conchs and snails, cephalopods such as squids and octopi, and echinoderms such as sea cucumbers and sea urchins.

materials. When pathogenic microorganisms are present in the water, they are filtered by the gills and become highly concentrated in the shellfish's digestive glands (Potasman et al. 2002).

There are two major types of food borne pathogens associated with shellfish consumption. The first type includes bacteria and viruses that thrive in human sewage and other human wastes. Among the viruses in this group, the most common are the Norwalk family of viruses, which include the winter vomiting virus and cause gastroenteritis in humans. Other important viral agents of FBI associated with shellfish include hepatitis A virus, hepatitis E virus, small round-structured viruses, and poliovirus, all of which are intestinal viruses. The bacterial agents in this group include *Salmonella* spp., *Shigella* spp., *Campylobacter* spp., *Plesiomonas* spp., *Aeromonas* spp., and *Escherichia coli*, all of which cause human gastroenteritis or similar illnesses (Rippey 1994; Potasman et al. 2002).

A second type of food borne pathogen includes naturally occurring bacteria that are present in marine and estuarine environments, specifically members of the genus *Vibrio* such as *V. vulnificus*, and *V. cholerae*, among others. Densities of these pathogens are related to water temperatures and salinity (Rippey 1994), and most cases of *Vibrio* infection occur when the water temperature and weather are warmer (Weis et al. 2011; Figure 2). Illnesses associated with this type of bacteria are generally more serious than those associated with the first type, with conditions ranging from gastroenteritis to septicemia, and in some cases resulting in death (Rippey 1994; Potasman et al. 2002; Weis et al. 2011).

Of all the pathogens associated with shellfish consumption, *V. vulnificus* leads to the most serious health outcomes. While only a few dozen cases a year are reported throughout the US, the mortality rate associated with *V. vulnificus* infections is much higher than for other shellfish related FBIs. For example, the case fatality rate for *V. vulnificus* in Florida between 1998 and 2007 was 27.5%, which dwarfs those for other causative agents of FBI such as *Salmonella* (0.4%), *Campylobacter* (0.1%), *Shigella* (0.1%), and *E. Coli* (0.2%) (Weis et al. 2011). *V. vulnificus* is particularly dangerous for individuals suffering from conditions such as liver disease, diabetes, and immune disorders (Rippey 1994; Potasman et al. 2002). For individuals suffering from any of these conditions, the case fatality rate in Florida between 1998 and 2007 was 96.1% (Weis et al. 2011).

To minimize the incidence of shellfish associated FBI in the US, the regulatory framework has relied on three major components. The first involves water sampling and monitoring in areas where shellfish are harvested. Regulatory entities conduct water sampling exercises throughout the year and test water samples for fecal coliform, which indicate the presence of untreated sewage or other human wastes in the water. If water testing indicates the presence of fecal coliform beyond a pre-specified threshold, the area will be closed for harvest until further testing indicates that the concentration of fecal coliform has

decreased. In combination with nationwide adoption of sewage treatment standards, this component has been very effective at reducing the risk from pathogens associated with raw sewage. Since shellfish harvest generally takes place close to shore, this component is generally carried out by state agencies that have jurisdiction in these waters.

The second regulatory component involves handling requirements to ensure food safety once the shellfish are removed from the water. Handling requirements include rapid cooling capabilities for primary processors of shellfish, the establishment of Hazard Analysis and Critical Control Points (HACCP) plans by seafood dealers, processors, distributors, and retailers; tagging programs that differentiate between shellfish that can be eaten raw and shellfish that must be cooked before eating, and the use of labels that will allow traceability if FBI or other issues are identified. In addition, shellfish harvesters must follow refrigeration requirements, and harvesters who are unable to meet refrigeration requirements must deliver shellfish to a processing facility in a specified period of time. Refrigeration requirements are particularly important to prevent FBI, including *Vibrio* infections, as bacterial densities can increase if shellfish are held at temperatures above 45C (Rippey 1994). This component is enforced by state agencies in collaboration with the US Food and Drug Administration.

The third regulatory component involves conducting epidemiological studies for all outbreaks that implicate shellfish so that the sources of these outbreaks can be identified, and measures to prevent further cases can be taken. This component relies heavily on the appropriate use of tags and labels that are part of the seafood handling requirements, and is particularly difficult to achieve when shellfish are transported across state borders or are intermingled in large processing and distribution facilities. Epidemiological studies of FBI outbreaks associated with shellfish consumption are completed in close collaboration between state and Federal authorities.

To prevent the incidence of *Vibrio* infections, the US Food and Drug Administration requires shellfish producing states to develop a *Vibrio* control plan and conduct an annual risk evaluation. In Florida, the result of this process has been the enactment of regulations that reduce the legal daily harvest period to minimize the length of time between shellfish harvest and processing. The amount of time allowed between harvest and delivery to a processing facility varies by season, and the specific requirement that each harvester must follow depends on whether the individual vessel contains on-board cooling capabilities.

3. Fishery and Data Description

3.1. Apalachicola Bay's Oyster Fishery

Apalachicola Bay, located in the Florida Panhandle along the Gulf Coast, has traditionally supported a vibrant oyster industry whose product is marketed by name for its distinctive size and flavor. The harvesting technology used in Apalachicola Bay today is not very different from that used 100 years ago, and simple individual-operator small vessels using hand tongs dominate the fishery (Pine et al. 2015). In addition, Franklin County's coastline is dotted with small seafood dealers and processors where vessels deliver oysters and other fish products on a daily basis. Apalachicola Bay has been a highly productive oyster fishery since at least the 1890s (Pine et al. 2015), but in recent years it has experienced a drastic resource collapse (Camp et al. 2015). Between 1992 and 2012, oyster harvests in Apalachicola Bay ranged between 1 million and 3 million pounds, with an average of 1.98 million pounds (Figure 3). During this time period, Apalachicola Bay was the source of 85% of all Florida oysters, and 8% of all US oysters, on average (Figure 4). The fishery's collapse began in 2013, and by 2015 landings had decreased to 520,910 pounds, representing 58% of Florida's oyster production and 2% of all oysters landed in the US. At its height in 2012, the dockside value of the fishery was just over $9 million.

Individuals harvesting oysters in Apalachicola Bay must possess a general saltwater products license for the state of Florida in addition to an Apalachicola Bay oyster harvesting license. Other than an annual fee, there are no major requirements for the general saltwater products license. However, to obtain an Apalachicola Bay oyster harvesting license, all applicants must complete a shellfish harvest education training every year. The training requirement is designed to educate fishers on sanitary shellfish harvesting, handling, and transportation practices, and can be completed in person or online. When the licenses are purchased in conjunction, the fee for the saltwater products license is waived.

Oyster harvesting in Apalachicola Bay is managed by opening and closing harvest areas on a seasonal basis. The winter oyster reefs are open for harvest between October 1 and May 30, while the summer oyster reefs are open between June 1 and September 30 (Figures 5-6). In addition, the Florida Department of Agriculture and Consumer Services monitors the water quality in shellfish harvest areas throughout the year, and may close individual harvest areas on a temporary basis if the fecal coliform counts are found to be higher than a pre-specified threshold. To maintain the integrity of the resource, the Florida Fish and Wildlife Conservation Commission has also enacted a daily bag limit that is changed regularly depending on stock assessments, and a minimum size limit of three inches or more.

After the 2014 summer harvesting season, significant changes to the legal daily harvest period were enacted. Prior to this change, all summer oyster harvesters in Apalachicola Bay were allowed to fish from sunup until 2pm, at which time all shellfish harvested that day had to be delivered to a certified seafood dealer for rapid cooling, a process that reduces the internal temperature of oysters to 12C within two

hours. Vessels equipped with an on-board cooling option, in which oysters are cooled immediately using an ice and saltwater slurry mix, could harvest from sunup until 4pm. The regulatory change that took effect in 2015 reduced allowed fishing time from 2pm to 11am for traditional vessels, and from 4pm to 3pm for vessels equipped with an on-board cooling option. It is important to note that the traditional oyster vessel in Apalachicola Bay is not equipped to maintain ice or any other temperature control device.

3.2. Data

The state of Florida has been collecting landings and fishing effort data since 1984, and Florida law requires the reporting of all sales of seafood products harvested in state waters using a marine fisheries trip ticket at the time of sale. Trip tickets include information about the harvester, the dealer who purchases the product, the date of the transaction, the county in which the product was landed, and the weight of the product (Solis et al. 2013). In the past, trip tickets were completed and mailed to the Florida Fish and Wildlife Conservation Commission, but recently the system has also become available as an online platform where seafood dealers can input the necessary information.

This study uses all Apalachicola Bay oyster trip ticket records from June 1 to September 30 for years 2014 and 2015. The harvest areas open during this period of the year are different from those open throughout the rest of the year (Figures 5-6). While shellfish all throughout the bay can be expected to interact through recruitment, as oysters from one reef can produce oyster larvae that could be moved to another reef by water flows, the oyster reefs are in essence fixed in space and oysters do not move throughout the year as part of their life cycle or to avoid areas that are being fished heavily. Thus, a bioeconomic model could include both summer and winter reefs that are connected through biological dispersal (Sanchirico and Wilen 2005), but the loss of realism by including only the summer reefs in our model is minimal.

On plain view, the summer fishery appears to have adjusted dramatically between 2014 and 2015 when the new time requirements were put in place. Figure 7a and 7d shows the daily participation level between the first and last days of the summer harvest in 2014 and 2015, respectively. Prior to the policy change, participation in the fishery was highest during the first day of the fishery, then remained somewhat stable between 100 and 150 vessels per day, and finally plummeted during the last 20 to 25 days in which the summer reefs were open. These dynamics contrast drastically with those seen in 2015, when an overall lower participation was observed but stayed relatively stable throughout the summer season.

The contrasting effort dynamics seen in 2014 and 2015 translate into equally contrasting dynamics for oyster landings and dockside value of the harvest. As seen in Figures 7b and 7c, oyster landings and their

associated dockside value in 2014 were very high on the first day of the summer season, but then decrease steadily throughout the rest of the summer harvest season. Figures 7a – 7c suggest a typical open access scenario where virtually all the oysters above the minimum size requirement are harvested by the end of the season, and where fishing effort decreases as the available resource dwindles. In contrast, the daily landings and associated dockside value shown in Figures 7d and 7e remained relatively high throughout the season, even though there were two multi-day periods towards the end of the season with relatively high fishing effort but very low levels of landings. Aside from these anomalous periods, Figures 7d – 7f suggest a scenario where the resource is not being depleted by the end of the harvest season.

4. Methods

We aggregate Apalachicola Bay oyster summer harvest trip tickets into daily observations of fishing effort, landings, and the associated value of landings. While shellfish grow and reproduce throughout the year, a majority of the growth and recruitment of oysters in Apalachicola Bay takes place in late spring (March-May) and in the month of October, all of which are outside of the summer harvest period of interest in this analysis (Pine et al. 2015). Hence, it is reasonable to assume that daily growth and recruitment are negligible.

With this consideration in mind, our model starts by calculating X_0, or the pounds of oysters available for harvest at the opening of the summer season, as the sum of all summer landings by the end of the season. In other words, we assume that we can know X_0 retroactively after the oyster reefs are fished to exhaustion throughout the harvest season. Natural mortality through the season is also assumed to be negligible, and the daily change in the biomass stock is therefore given by

$$X_{t+1} = X_t - H_t$$

$$X_0 = \sum_{t=1}^{T} X_t, \tag{1}$$

where X_t represents the standing biomass at day t, and H_t represents the harvest in day t. In turn, the daily harvest is modeled using a Schaeffer catch equation (Conrad 1999; Clark 2006) given by

$$H_t = E_t q X_t, \tag{2}$$

Where E_t is the fishing effort, measured as the aggregate number of hours that all individual harvesters participated in the fishery on day t, and q is the catchability coefficient, a parameter that captures the efficiency of the harvest technology. We arrive at an hour-based measure for E_t by multiplying the number of participating fishers by an assumed seven hours on the water per fishing day (7am – 2pm) for the 2014 season, and four hours per fishing day (7am – 11am) for the 2015 season. Given the

homogeneity of the fishing fleet and considering that all oyster harvesters use hand tongs, it is reasonable to assume that q is constant.

Using the daily biomass and harvest model as a basis for calculating daily biomass stock and landings, and using the aggregated trip tickets to obtain the daily effort levels, we obtain enough information to estimate the catchability coefficient, q, using non linear least squares regression (Gallant 1975; Amemiya 1983). The non-linear least squares estimator, $\hat{q}$, is the value of q that minimizes the sum of squared residuals, which is given by

$$S_T(q) = \sum_{t=1}^{T}[H_t - (E_t q X_t)]^2. \tag{3}$$

To estimate the impacts of the legal daily harvest period changes enacted in 2015, we develop a counterfactual scenario. This counterfactual scenario uses the model of the 2014 season, but the legal daily harvest period used to calculate E_t is decreased from seven to four hours. In the counterfactual scenario, the decreased level of effort, the estimated catchability coefficient, and the stock differential equation (Equation 1) are used to predict daily landings. The impact of the policy becomes evident when the three scenarios, two factual (2014 and 2015), and one counterfactual (2014 with reduced legal daily harvest period), are compared in terms of expected and observed landings and dockside value.

5. Preliminary Results

The nonlinear model predicting landings during 2014 fits the data reasonably well. A plot of landings against harvestable biomass shows that the model tracks the observed data well even in the presence of daily variation in fishing effort, and also follows its overall downward path as the size of the remaining harvestable stock declines through the fishing season (Figure 8).

The counterfactual model's prediction, where the reduced legal daily harvest period is simulated, yields interesting results. Figure 9 shows the observed daily landings in 2014, when fishers are allowed 7 trip hours per day (solid black line). The solid black line follows the exact path as Figure 7b, where landings were strangely high the day the season opened, then decreased and stabilized for a good portion of the season, and finally declines steadily until the season closure. The dashed grey line shows the predicted daily landings in 2014, in a counterfactual scenario were fishers are allowed 4 trip hours per day to prevent cases of *Vibrio* infections. The dashed grey line follows a similar path as the solid black line, except that landings are consistently lower during the early part of the season due to the decreased amount of time that fishers are allowed on the water. This result also implies landings that are consistently higher during the latter part of the season, as the oysters that were not harvested during the early portion of the

season are now available for harvest. Overall, the effect is a small reduction in total landings of 1,766 pounds of oysters over the entire 4 month summer harvest season, or a 0.52% loss in landings.

The predicted change in the fishery as a result of the decrease in the legal daily harvest period is an adjustment in the timing of landings across time and a negligible change in the overall level of landings or value of the fishery. Whether the model accurately predicts future conditions and drivers within the fishery, however, is not necessarily clear. Obviously, the observed landings and fishing effort in 2015 differ from those predicted in the model; that would be the case with every other model, as the future cannot be accurately predicted. The pertinent question is whether the model is useful in informing the course of public policy.

To answer this question, we can take a fresh look at the observed effort, landings, and dockside value shown in Figures 7c – 7e, which correspond to 2015, when the regulatory change was first implemented. The initial spike in effort to inaugurate the summer fishing season is not a feature of the 2015 data, nor is the final decline in landings that occurred in 2014 evident in the year 2015. The overall level of landings, however, is much smaller in 2015 (177,648 lbs) than in 2014 (338,305 lbs), suggesting that there is a much deeper adjustment taking place. Specifically, it appears that individuals are leaving the fishery—but perhaps only temporarily. The underlying reason for this shift, however, is probably more due to the stock's collapse than to the new legal daily harvest period regulation. Nonetheless, a determination as to which factor is most at fault requires research that seems to be beyond the scope of this paper, as it would necessitate a manuscript that deals not with food safety, but with rebuilding fisheries (Larkin et al. 2011).

6. Future Research

Our results indicate that fishers will experience reduced harvests early in the season due to the shorter length of the harvest days, but this initial loss will be recouped later on in the season as harvests remain high for longer than they would have if the harvest time regulations were not in place. The current research addresses the question of whether the new legal daily harvest period regulation would have an economic impact on the fishery. The regulation appears not to have a significant impact on the fishery, but a conclusive answer cannot be reached with the current analysis.

However, the current analysis does lend itself for a cost-benefit analysis of the impacts the regulation may have on food safety (Antle 1999; Antle 2001). Reduction of mortality by even one case would result in net benefits to society, according to the model discussed here. Quantification of a series of scenarios exploring these net benefits would make this an interesting addition to the literature.

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Figures
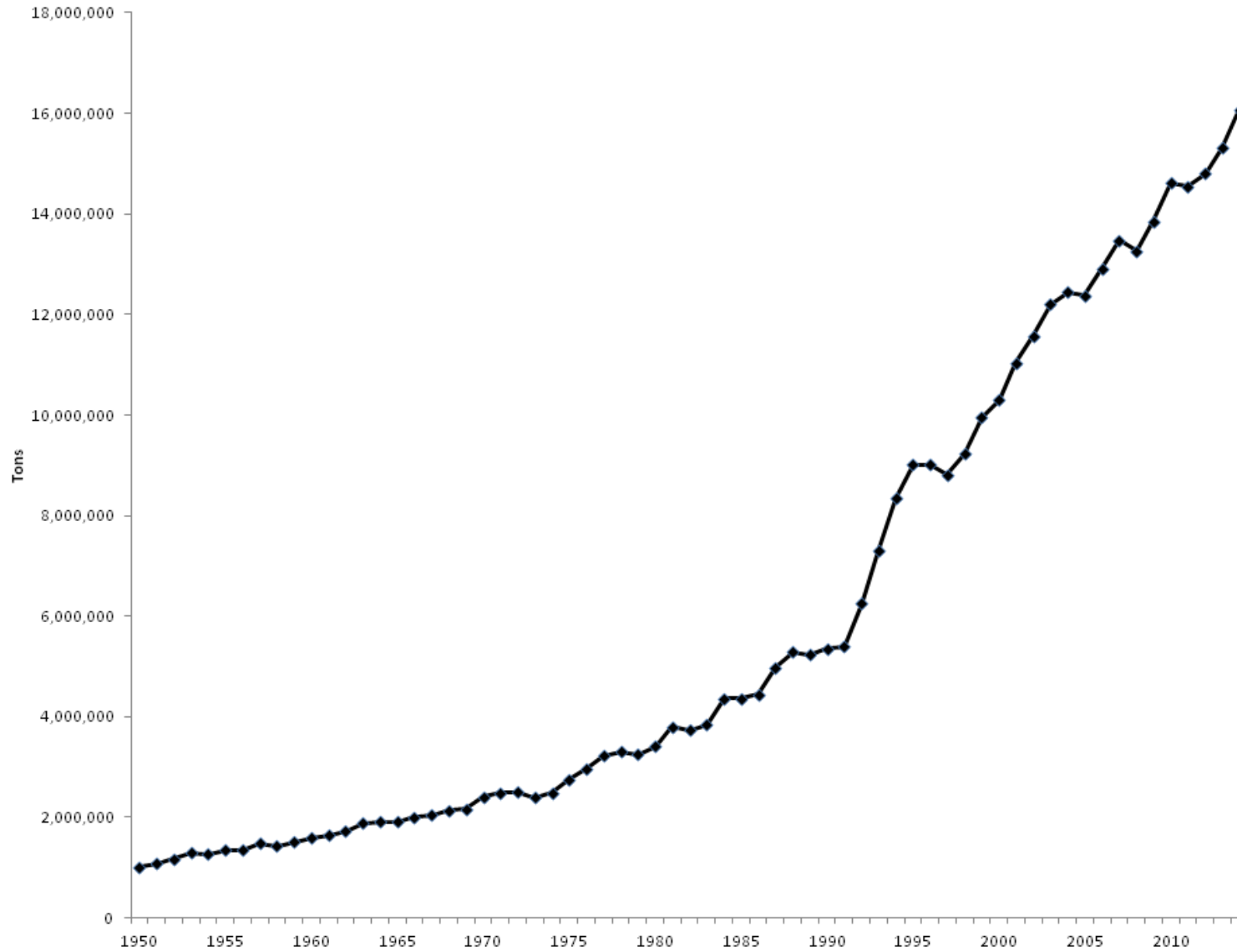
Figure 1. Global production of bivalve shellfish, including clams, cockles, arkshells, mussels, oysters, and scallops. Source: FAO Fisheries and Aquaculture.
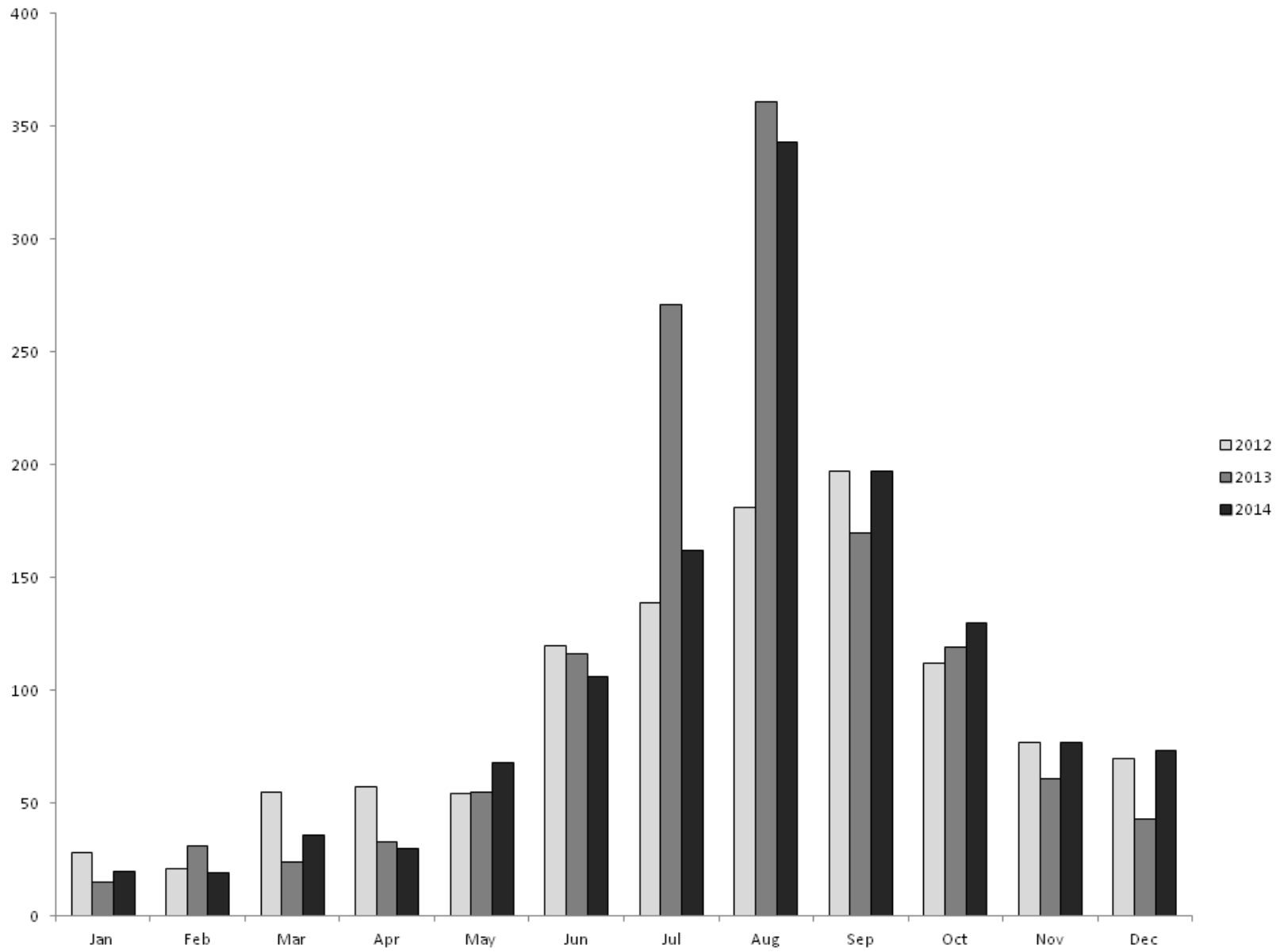
Figure 2. Monthly reported cases of *Vibrio* related illnesses in the US (2014), with the exception of cholera. Source: Centers for Disease control and Prevention.
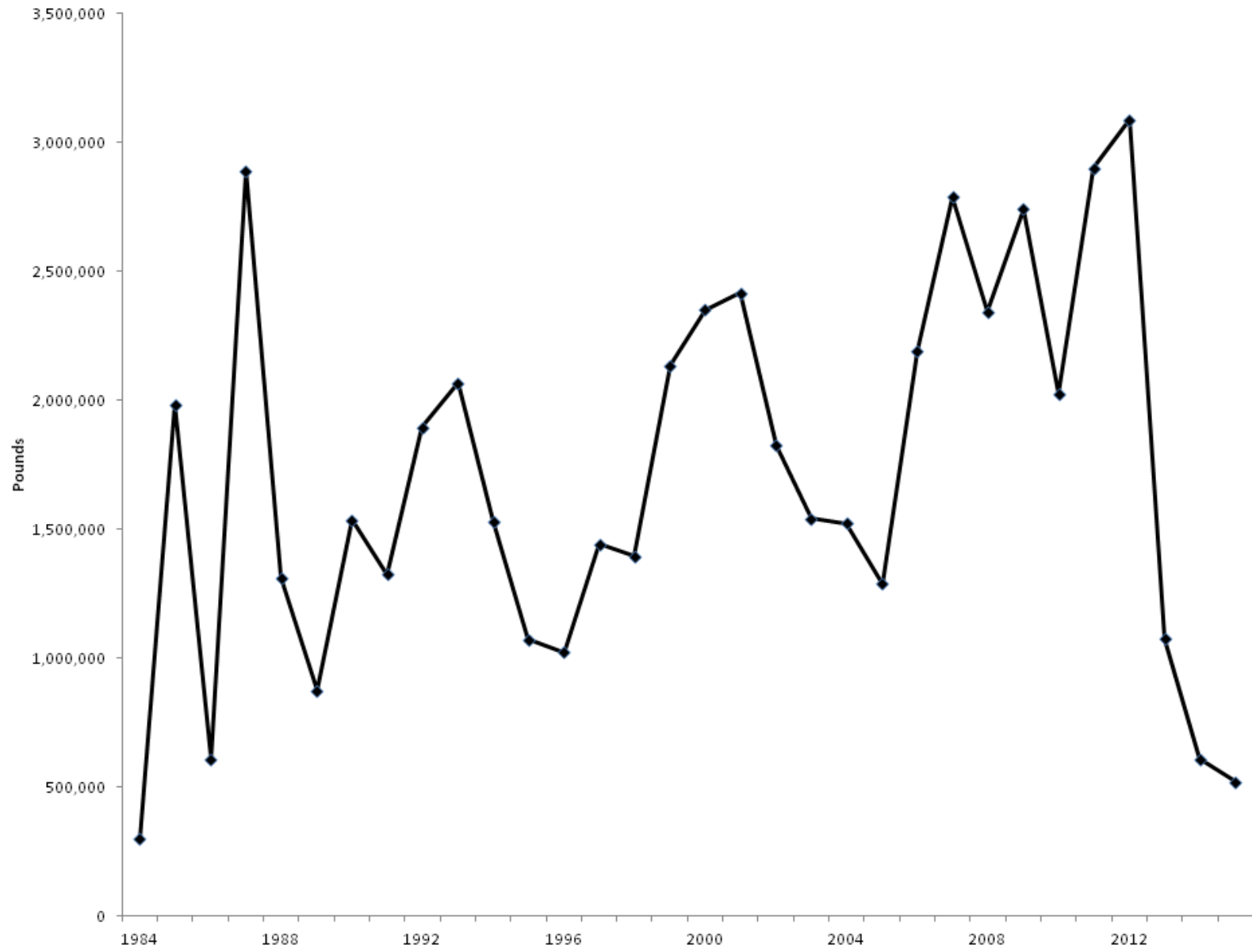
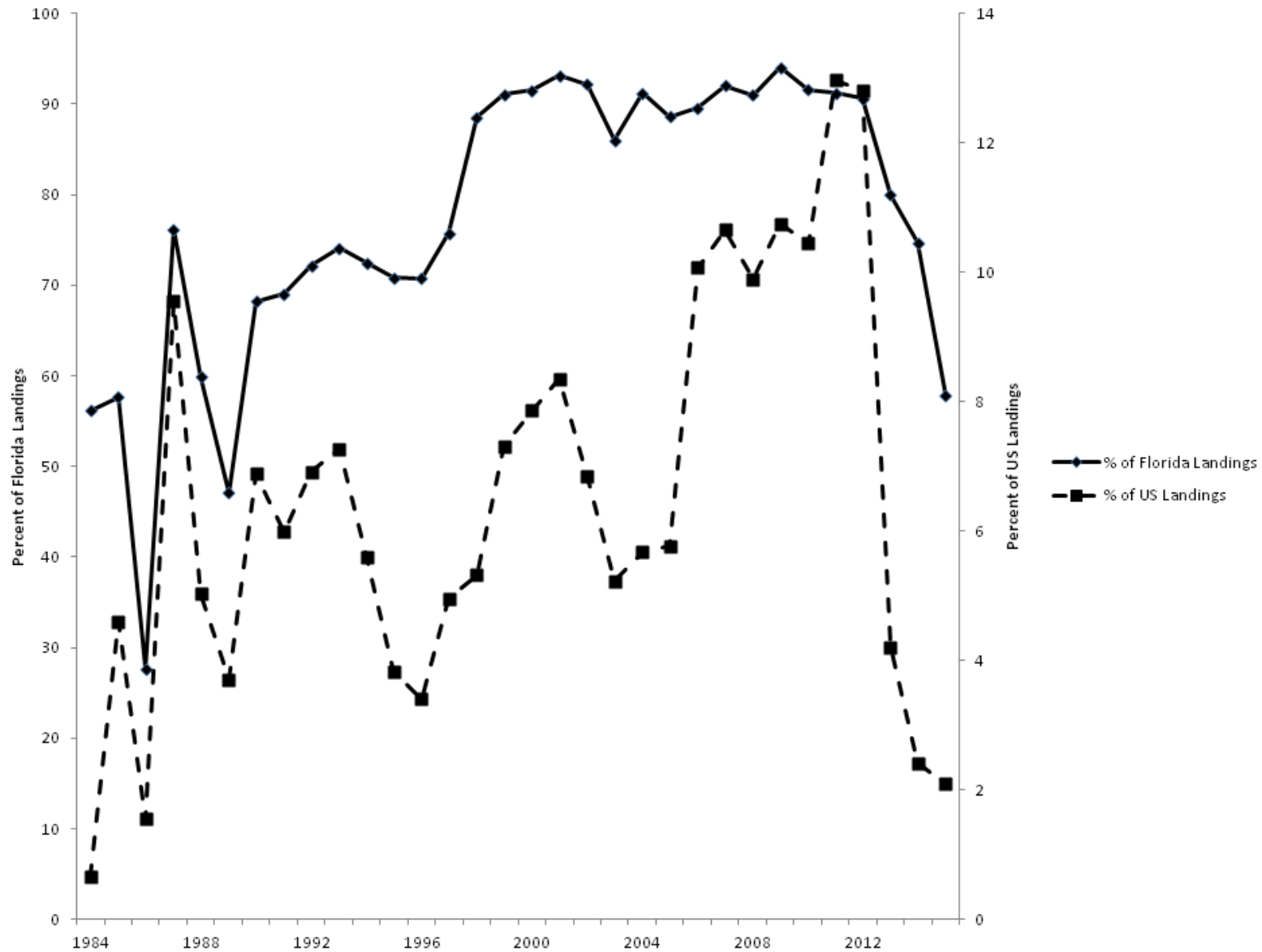Figure 3. Historic oyster landings in Apalachicola Bay. Source: Florida Fish and Wildlife Conservation Commission.

Figure 4. Apalachicola oyster production as a percentage of Florida and US oyster production. Sources: Florida Fish and Wildlife Conservation Commission and National Marine Fisheries Service.
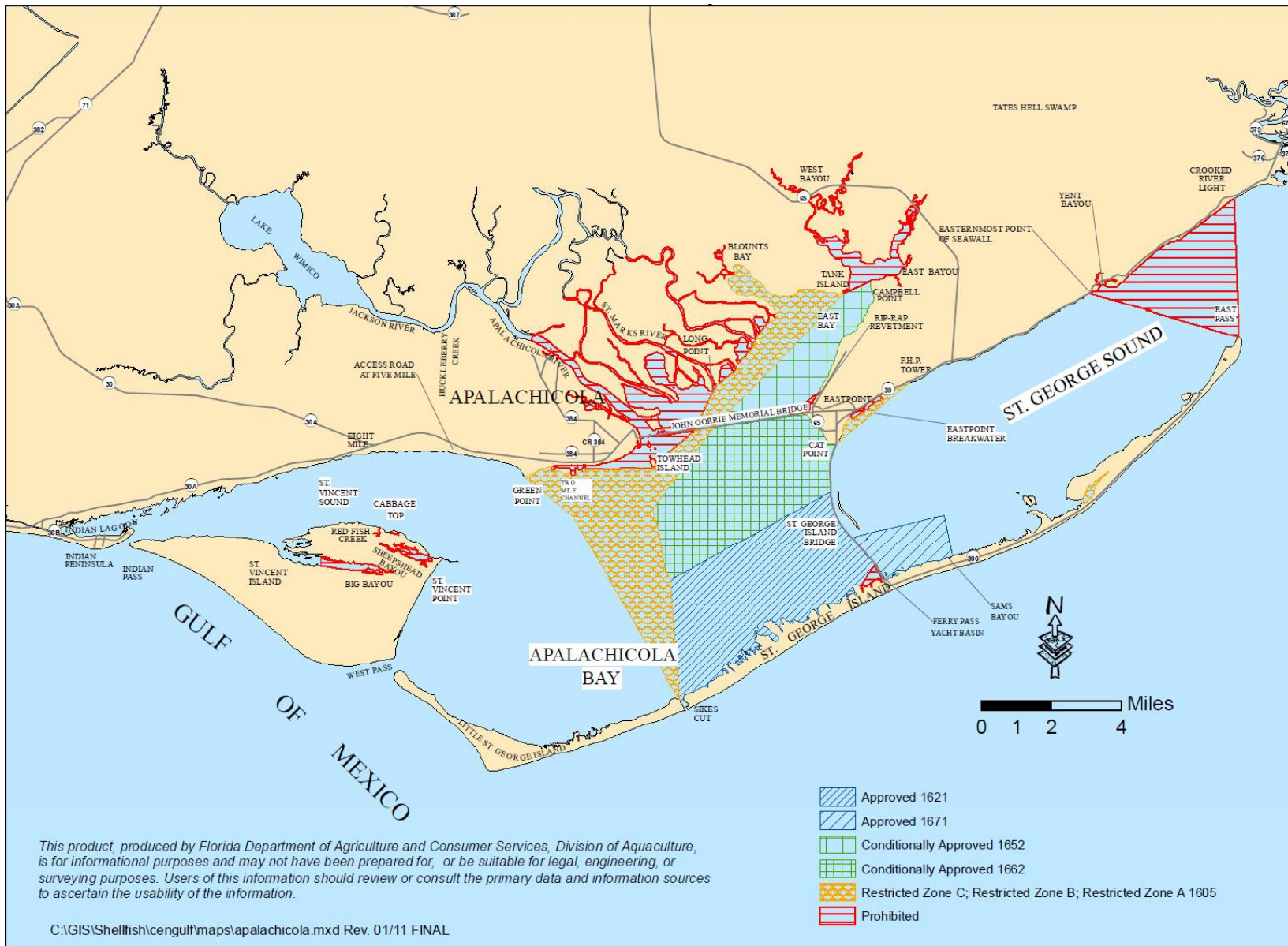
Figure 5. Summer oyster reefs in Apalachicola Bay. Source: Florida Department of Agriculture and Consumer Services.
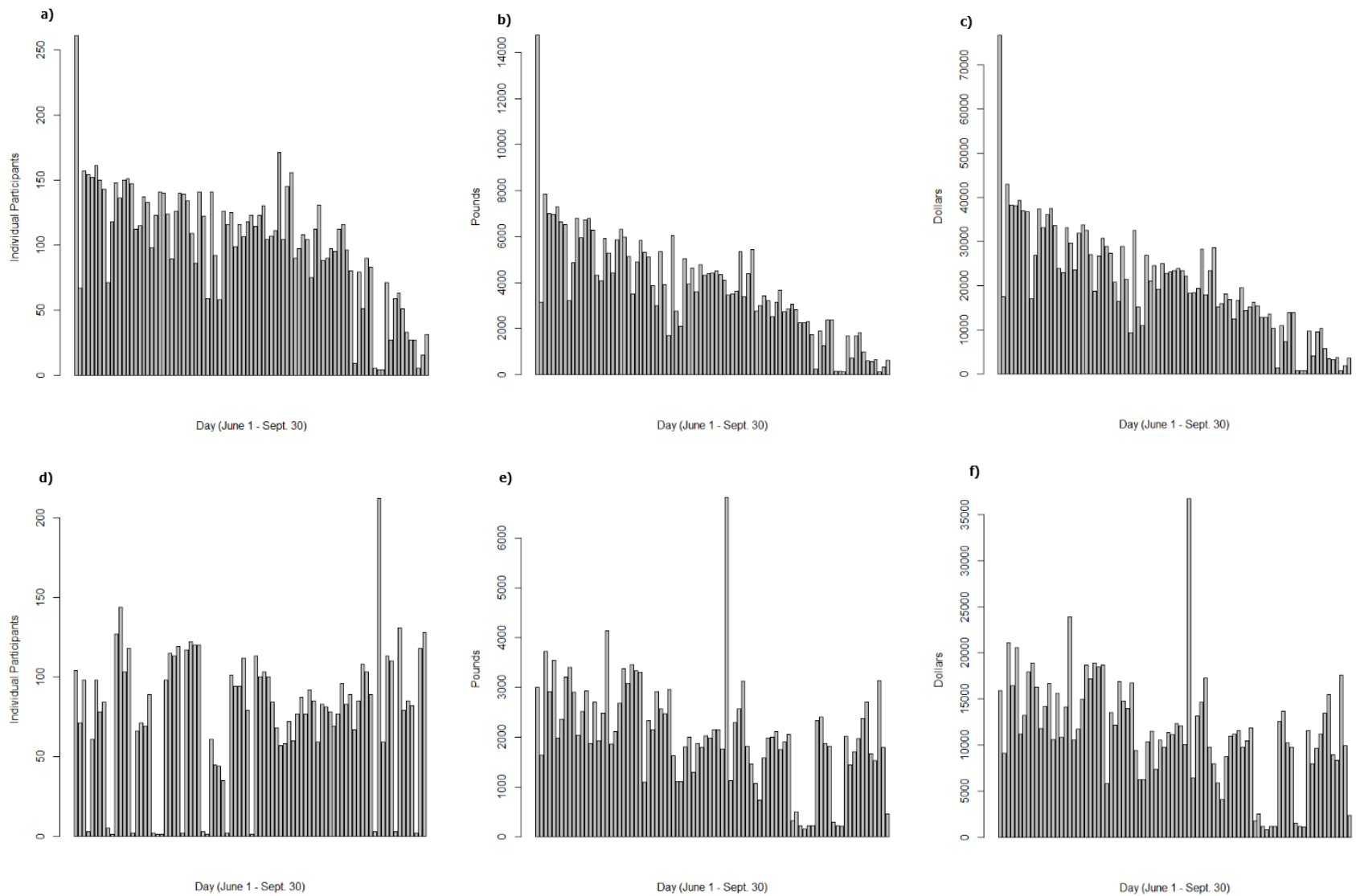
Figure 6. Winter oyster reefs in Apalachicola Bay. Source: Florida Department of Agriculture and Consumer Services.

Figure 7. Participation, landings, and dockside value of harvest for the Apalachicola Bay oyster Fishery in 2014 (top row) and 2015 (bottom row). a) Participation in 2014; b) Landings in 2014; c) Dockside value in 2014; d) Participation in 2015; e) Landings in 2015; and f) Dockside value in 2015.
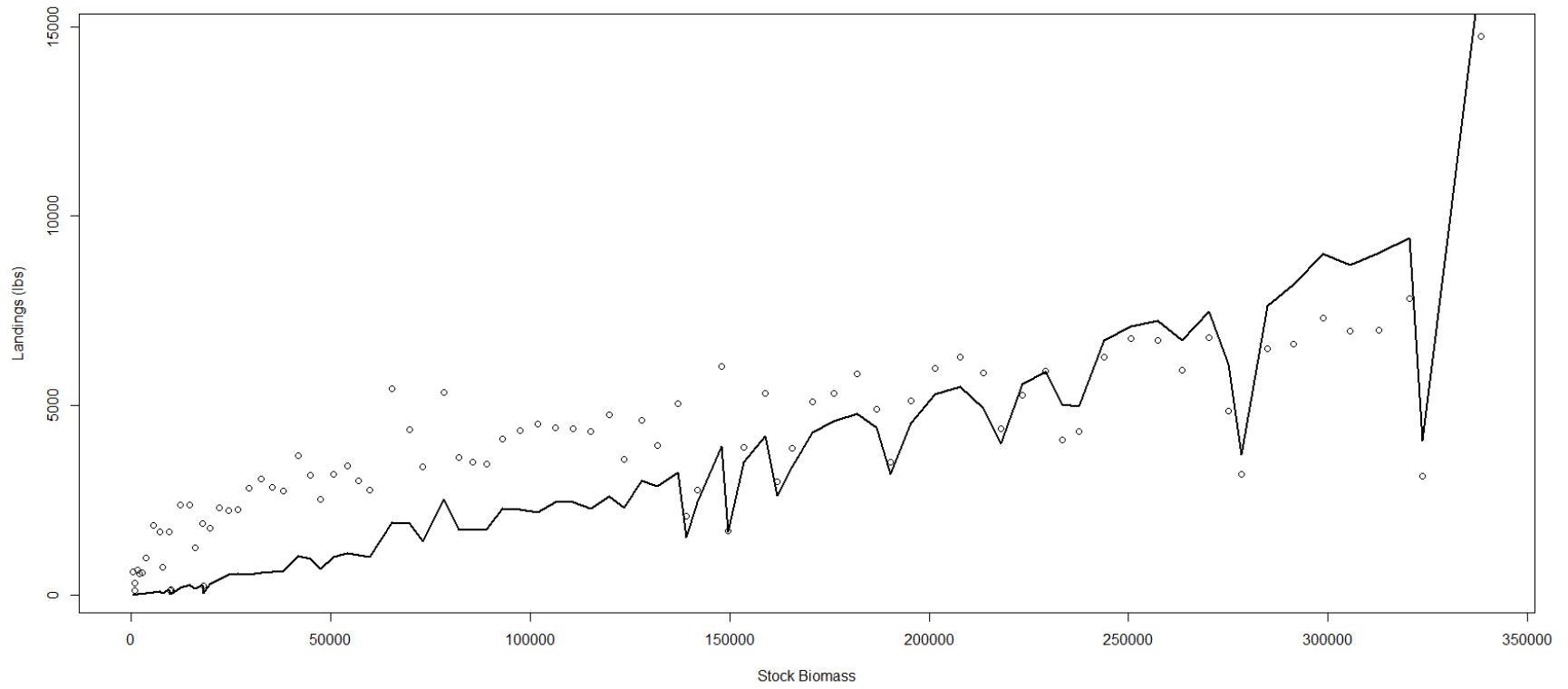
Fig 8. Observed and predicted landings at the observed levels of fishing effort. The circles represent observed values, and the solid line represents predicted values.
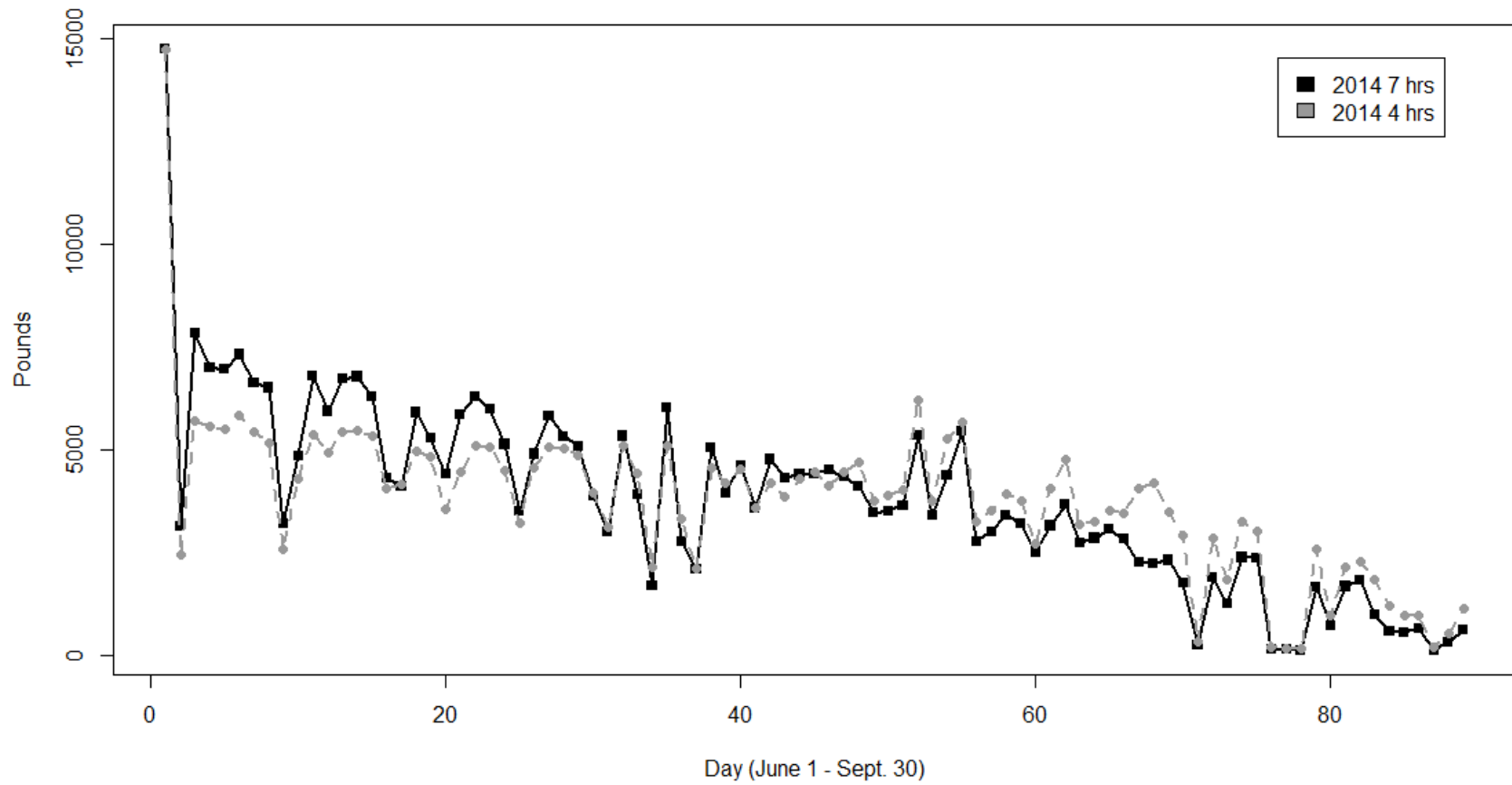
Figure 9. Observed and predicted daily landings in 2014. The solid black line shows the observed daily landings in 2014, when fishers are allowed 7 trip hours per day. The dashed grey line shows the predicted daily landings in 2014, when fishers are allowed 4 trip hours per day.