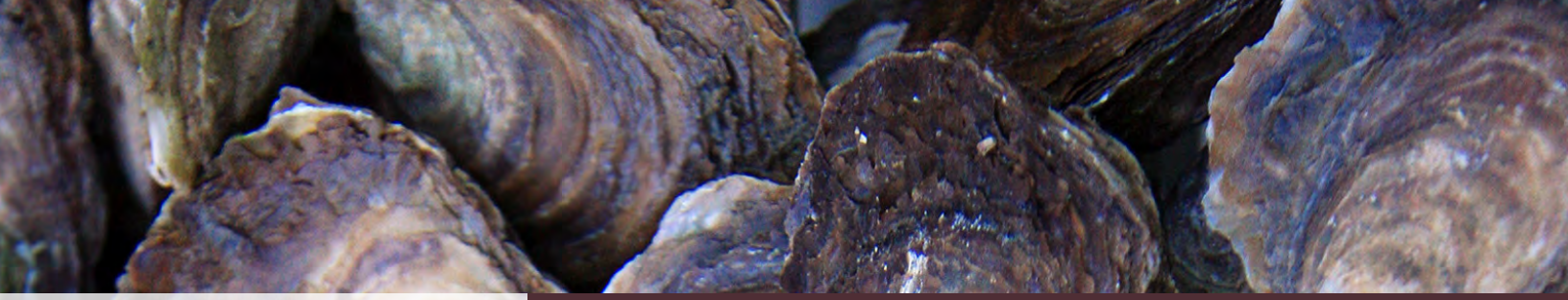

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Economic Impacts of the Opening of the Bonnet Carré Spillway on the Mississippi Oyster Fishery

Economic Impacts of the Opening of the Bonnet Carré Spillway on the Mississippi Oyster Fishery

Abstract

We evaluated the negative economic impacts on the Mississippi oyster fishery of the prolonged opening of the Bonnet Carré Spillway in 2011 using two assessment methods: (1) a preliminary assessment conducted before data on landings after 2010 were available and (2) an updated assessment conducted when landings data after 2010 became available. We prepared the preliminary assessment in late 2011 to support the state's application for a federal fisheries disaster declaration. Recently, a more rigorous assessment of the impacts of the freshwater flooding was part of an overall assessment of the individual and joint impacts of natural and technological disasters to the Mississippi oyster fishery since 2005. The preliminary assessment model used the pre-Hurricane Katrina years 2002–04 as the baseline period. With disaster funding, the state of Mississippi was in the process of restoring the oyster reefs after Hurricane Katrina in 2005 and the Deepwater Horizon oil spill in 2010, when the prolonged Bonnet Carré Spillway opening in 2011 resulted to 86 percent oyster mortalities. These massive mortalities halted the recovery of the fishery to its baseline levels in 2002–04. Prolonged exposure to fresh water required restoration projects to enable the oyster fishery to recover to its baseline status. Restoration efforts included, but were not limited to, dredging nonaffected oyster seed stock and relaying it to affected reefs between 2006 and 2008. Cultch materials consisting of oyster shells and limestone were planted at affected public oyster reefs between 2006 and 2011. These restoration efforts were expected to replenish the damaged oyster populations and provide adequate shellfish for harvest when they reached market size. Direct losses in oyster harvesting associated with the prolonged Bonnet Carré Spillway opening ranged from 80–100 percent of the baseline average annual commercial landings from 2002–04. The cumulative foregone landing values of commercial oyster harvesting were estimated to range from $21.8 million to $46 million. The negative output impacts reached $9.6 million in 2011, $19.6 million in 2012, $19.9 million in 2013, and $8.9 million in 2014. As a resulting of the downturn in oyster harvesting, the state lost between 145 and 324 jobs per year during the period. Labor income lost ranged from $1.8 million to $8 million per year.

Introduction

Heavy rainfall in the Mississippi Valley and rising Mississippi River water levels prompted the New Orleans District of the U.S. Army Corps of Engineers to operate both the Bonnet Carré Spillway and the Morganza Floodway in May 2011 (U.S. Geological Survey 2012). Bonnet Carré was partially opened on May 9, 2011, to keep the volume of the Mississippi River flow at New Orleans from exceeding 1.25 million cubic feet per second. It was fully closed 43 days later on June 20, 2011 (U.S. Army Corps of Engineers 2012).

Prolonged exposure of Mississippi oyster-growing areas to fresh-water intrusion due to the Bonnet Carré opening during the Mississippi River flood in spring 2011 caused massive oyster mortalities (86 percent) (MDMR 2011a). These mortalities created economic hardships in the state's oyster harvesting industry and other input- and output-linked sectors. Rapid economic recovery of the oyster sector required immediate restoration efforts to replenish the damaged resources and allow the resumption of oyster harvesting, processing, distribution, and consumption of oyster products.

These massive mortalities were similar to the devastation of the state's oyster resources after Hurricane Katrina. Sampling conducted by the Mississippi Department of Marine Resources (MDMR 2007) after Hurricane Katrina showed losses of 90–95 percent in

Table 1. Mississippi oyster-growing areas.

Area	Location	Acreage
I	St. Joseph Reef	250
II	Telegraph Reef	1,273
II	Pass Marianne Reef	2,420
II	Pass Christian Reef	3,641
II	Waveland Reef	16
II	St. Stanislaus Reef	20
III	Long Beach Reef	89
II	Private Oyster Leases	623
	Total	8,332

Source of raw data: MDMR (2011a).

oyster populations. To replenish the oyster reefs damaged by Hurricane Katrina, MDMR (2007) relayed almost 94,000 sacks of oysters between November 2006 and March 2008. Eighty-two Mississippi oyster boats helped harvest oysters from Biloxi Bay and Graveline Bayou for relay to the damaged reefs in the western Mississippi Sound. In addition, MDMR planted public oyster reefs with more than 375,000 cubic yards of cultch materials consisting of oyster shells and limestone between November 2006 and September 2011.

The overall goal of this publication is to provide an updated assessment of the negative economic impacts of the prolonged spillway opening on the Mississippi oyster fishery. Specifically, it aims to estimate the foregone commercial oyster landings and the associated negative economic impacts on the fishery. An initial version of this publication was hurriedly prepared (Posadas 2011) in support of the state request for a federal determination of a commercial fishery failure due to a fishery resource disaster. The fresh-water flooding from the Mississippi River waterway system that necessitated the spillway opening on May 9, 2011, met the conditions required by the Magnuson-Stevens Fishery Conservation and Management Act of 1976 (MSA).

In a letter to the Mississippi governor dated September 12, 2012, the U.S. secretary of commerce stated that "a commercial fishery failure due to a fishery resource disaster exists for the oyster fishery from 2011–2013 and the blue crab fishery in 2011 under Section 308(b) of the Interjurisdictional Fisheries Act of 1986 (IFA) and Section 312(a) of the MSA." It further stated that "natural causes are an allowable cause under the IFA and the MSA, and the resulting damage caused a significant loss of access to fishery resources with revenue declines that have greatly affected these commercial fisheries. This determination provided a basis for Congress to appropriate disaster relief funding under the IFA and the MSA. After Congress appropriated disaster relief funding, the National Oceanic and Atmospheric Administration (NOAA) worked with Mississippi to develop appropriate economic spending plans."

NOAA Fisheries (2014) reported that "as part of the fiscal year 2014 federal budget, Congress approved $75 million in fishery disaster relief funds. Mississippi received $10,941,828 from the allocation that came after the Department of Commerce declared six fishery disasters in 2012 and 2013. Funds can be used for activities that will restore the fishery or prevent a similar failure in the future, and to assist a fishing community affected by such failure."

The economic recovery of the oyster fishery has been the primary goal of the Oyster Restoration and Resiliency Council convened by the Mississippi Office of the Governor in 2015 (MDMR 2016). The council has developed and organized recommendations, projects, and programs for the restoration and resiliency of the Mississippi oyster resource and industry. This updated assessment of the negative economic impacts of the prolonged opening of the Bonnet Carré Spillway in 2011 was prepared in support of the goals of the council.

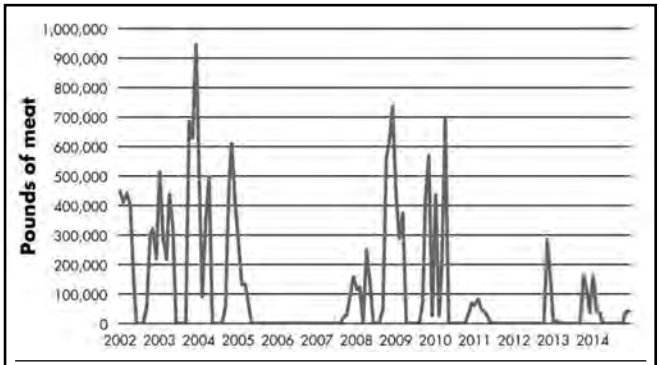

Figure 1. Monthly Mississippi commercial oyster landings in pounds of meat. Source of raw data: NOAA Fisheries (2016).

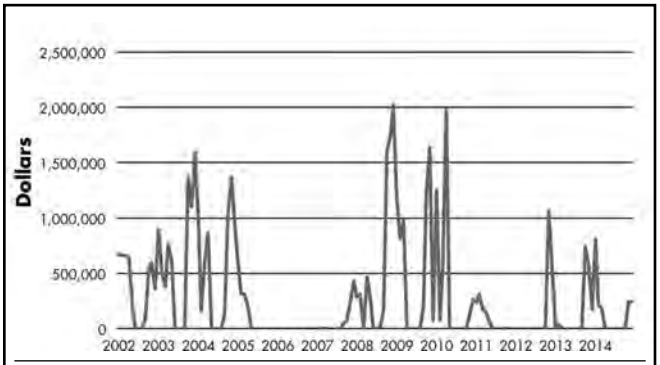

Figure 2. Monthly Mississippi commercial oyster landing values in dollars. Source of raw data: NOAA Fisheries (2016).

Public Oyster Reefs and Private Leases

State oyster fisheries cover public oyster reefs and private oyster leases. Normally, most commercial oyster harvesting occurred in state public oyster reefs from October to April. There are several oyster-growing areas managed by MDMR (2011a). These growing areas are open to harvesting by licensed oyster fishermen with either tonging or dredging licenses during open seasons. The state oyster-growing areas are shown in Table 1.

Commercial Oyster Landings

The natural and technological disasters since 2005 adversely impacted the oyster fisheries in Mississippi. Figures 1 and 2 show the available monthly data on Mississippi commercial oyster landings covering the 4 years before and the 5 years after Hurricane Katrina, as well as 5 years after the Deepwater Horizon oil spill. Observe the rapid decline in oyster landings after Hurricane Katrina in August 2005, the oil spill in April 2010, and the years after the prolonged spillway opening in May 2011. The state's public oyster reefs are generally closed to harvest during May, June, July, August, and September. Oyster landings made up 1.53 percent of the total commercial landings by Mississippi commercial fisheries during the 4 years before Hurricane Katrina. The share of oyster landings fell to 0.55 percent during the 5 years after Hurricane Katrina. During the 5 years after the oil spill, the share of oyster landings further declined to 0.38 percent of total commercial landings.

Preliminary Assessment Using Katrina Model

We evaluated the negative economic impacts of the spillway opening in 2011 using the preliminary assessment method when landings data after 2010 were not yet available (Posadas 2011). An updated, more rigorous assessment followed when landings data after 2010 became available. The overall assessment examined individual and joint impacts of natural and technological disasters to the state oyster fishery since 2005.

This section describes the modified version of the initial assessment hastily conducted to support the state request for a federal determination of a commercial fishery failure after the spillway opening. Changes in the initial assessment models include updated landings and price data. The preliminary assessment model used the pre-Hurricane Katrina years 2002–04 as the baseline period.

With disaster funding, the state of Mississippi was in the process of restoring oyster reefs after Hurricane Katrina and Deepwater Horizon oil spill when the spillway opening in 2011 caused 86 percent oyster mortalities. These massive mortalities halted the recovery of the fishery to its 2002–04 baseline levels.

Monthly Baseline Harvesting Model

We developed a monthly baseline harvesting model to examine the detrimental economic impacts of the protracted spillway opening on the Mississippi commercial oyster harvesting. The critical step in

Table 2. Monthly and baseline Mississippi oyster landings in pounds of meat from 2002–04.

Month	2002	2003	2004	Mean 2002–04	Deviation 2002–04
January	446,225	511,256	557,680	505,054	55,986
February	410,775	287,816	90,496	263,029	161,572
March	439,151	216,632	342,824	332,869	111,593
April	397,592	437,840	494,920	443,451	48,906
May	146,136	330,840	0	158,992	165,794
June	0	0	0	0	0
July	0	0	0	0	0
August	0	0	0	0	0
September	57,112	0	57,824	38,312	33,181
October	302,200	684,448	464,039	483,562	191,870
November	319,344	627,872	608,752	518,656	172,874
December	219,304	945,432	412,856	525,864	376,023
Total	2,737,839	4,042,136	3,029,391	3,269,789	684,574

Source of raw data: NOAA Fisheries (2016).

Table 3. Baseline and monthly Mississippi oyster landings in pounds of meat from 2005–10.

Month	Mean 2002–04	2005	2006	2007	2008	2009	2010
January	505,054	271,736	0	0	114,296	445,240	436,227
February	263,029	132,152	0	0	123,997	289,128	27,344
March	332,869	130,344	0	1,496	0	373,560	195,680
April	443,451	76,152	0	88	249,496	0	691,581
May	158,992	0	0	0	140,856	0	0
June	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0
August	0	0	0	0	3,864	0	0
September	38,312	0	0	19,152	53,152	71,088	0
October	483,562	0	0	29,520	561,768	416,776	0
November	518,656	0	0	91,792	628,128	570,548	33,176
December	525,864	0	0	157,040	734,792	25,384	68,704
Total	3,269,789	610,384	0	299,088	2,610,349	2,191,724	1,452,712
Percent of baseline	100%	19%	0%	9%	80%	67%	44%

Source of raw data: NOAA Fisheries (2016).

developing the model was determining the appropriate mean and standard deviation of the monthly oyster landings before the natural disaster. The baseline period selected was the pre-Hurricane Katrina period. Using the monthly oyster landings from 2002–04, we developed this model for the commercial oyster harvesting sector. These monthly data came from the NOAA Fisheries website (Table 2). The mean and standard deviation of the baseline monthly landings enabled us to develop a simple or randomized forecasting model. For the purpose at hand, we considered it sufficient to use a simple forecasting model. We used the simple monthly forecasting model to generate projections of the monthly landings from 2011–14.

Monthly Landings Data

The next step was compiling monthly oyster landings data following the natural disaster. Post-Katrina monthly landings relative to pre-Katrina monthly landings were selected as the basis for estimating the monthly landings after the prolonged fresh-water intrusion due to the spillway opening. We made this choice for two main reasons. First, the scope and magnitude of the damages to the oyster reefs after the 2011 spillway opening were similar to those reported after Hurricane Katrina. Second, oyster restoration efforts planned after the spillway opening were similar to restoration efforts conducted after the hurricane. Post-Katrina monthly landings showed how the oyster fish-

Table 4. Ratio of Mississippi oyster landings to baseline period mean monthly landings from 2005–10.

Month	Mean 2002–04	2005	2006	2007	2008	2009	2010
January	505,054	0.54	0.00	0.00	0.23	0.88	0.86
February	263,029	0.50	0.00	0.00	0.47	1.10	0.10
March	332,869	0.39	0.00	0.00	0.00	1.12	0.59
April	443,451	0.17	0.00	0.00	0.56	0.00	1.56
May	158,992	0.00	0.00	0.00	0.89	0.00	0.00
June	0	0.00	0.00	0.00	0.00	0.00	0.00
July	0	0.00	0.00	0.00	0.00	0.00	0.00
August	0	0.00	0.00	0.00	0.00	0.00	0.00
September	38,312	0.00	0.00	0.50	1.39	1.86	0.00
October	483,562	0.00	0.00	0.06	1.16	0.86	0.00
November	518,656	0.00	0.00	0.18	1.21	1.10	0.06
December	525,864	0.00	0.00	0.30	1.40	0.05	0.13
Total	3,269,789	0.19	0.00	0.09	0.80	0.67	0.44

Monthly ratio = monthly landings in 2005-2010 ÷ baseline monthly landings in 2002–04.

Table 5. Monthly Mississippi oyster landings in pounds of meat from 2011–14.

Month	2011	2012	2013	2014
January	62,480	0	9,280	42,648
February	82,704	0	0	35,432
March	46,792	0	0	0
April	38,728	0	0	0
May	16,160	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	696	0
September	0	0	160,744	0
October	520	0	124,744	41,408
November	0	142,048	38,992	39,952
December	0	1,736	161,312	0
Total	247,384	143,784	495,768	159,440

Source of raw data: NOAA Fisheries (2016).

ery responded to a natural disaster that wiped out about 90–96 percent of the oyster population. Monthly oyster landings data from 2005–10 were retrieved from the NOAA Fisheries (2016) website (Table 3).

Monthly Landings Forecasting Model

The next step was to develop the monthly-landings-forecasting model of oyster harvesting. This model was formulated from monthly landings following a natural disaster (Table 3) relative to the baseline monthly landings before a natural disaster (Table 2). Post-Katrina monthly landings were expressed as a ratio of pre-Katrina baseline monthly landings (Table 4). We used the model to forecast monthly oyster landings following the spillway opening in 2011. This model can be tweaked—but it would be difficult—to account for changes in the actual mortality rates, harvesting guidelines, sack limits, number of harvesting days, amount of cultch, shells, seed stock, and other factors. Using an economic-recovery model, we added adjustments to include more rigorous assessment of the damaging impacts of the disaster. The results of the economic-recovery model are presented in a later section.

Foregone Monthly Landings

After estimating the projected monthly oyster landings that followed the prolonged fresh-water intrusion, we compared the forecasted values to the baseline monthly landings. The foregone monthly oyster landings in 2011–14 were measured by examining the differences between the projected monthly landings after the spillway opening and the baseline

Table 6. Projected monthly Mississippi oyster landings in pounds of meat using Hurricane Katrina model from 2011–14.

Month	2011	2012	2013	2014
January	271,736	0	0	114,296
February	132,152	0	0	123,997
March	130,344	0	1,496	0
April	76,152	0	88	249,496
May	0	0	0	140,856
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	19,152	53,152
October	0	0	29,520	561,768
November	0	0	91,792	628,128
December	0	0	157,040	734,792
Total	610,384	0	299,088	2,606,485
Percent of baseline	0.19	0.00	0.09	0.80

Predicted Landings = Monthly baseline Mississippi oyster landings in 2002–04 X Ratio of Mississippi oyster landings to baseline period in 2005–10.

monthly landings in 2002–04. These projected foregone monthly oyster landings illustrate the direct losses associated with the spillway opening.

Monthly Ex-Vessel Prices

The next step was to estimate the ex-vessel prices of foregone monthly oyster landings in 2011–14 following the prolonged fresh-water intrusion. These prices were based on the landings value and landings in 2011–14 reported by NOAA Fisheries (Figure 3). Ex-vessel prices were used to convert the predicted foregone annual landings to the foregone annual landings values starting in January 2011. In the original report (Posadas 2011), data in 2011–14 were not available. Instead, the average ($2.86 per pound) and standard deviation ($0.29 per pound) of ex-vessel prices in 2005–10 were used.

Hurricane Katrina Model Results

Table 5 shows the actual NOAA monthly commercial landings in 2011–14. Since these data were not yet available in 2011, the Hurricane Katrina forecasting model was used to estimate the monthly landings following the prolonged spillway opening (Table 6). Normally, oyster harvesting would have been expected to recover about 3 years from the implementation of reef-restoration projects. Projected landings in 2011 were expected to be about 19 percent of the baseline average for 2002–04. No oyster landings were expected in 2012. Only about 10 percent of the 2002–04 baseline period was expected in 2013. By the fourth year, annual oyster landings were projected to reach 80 percent of the 2002–04 baseline period average landings.

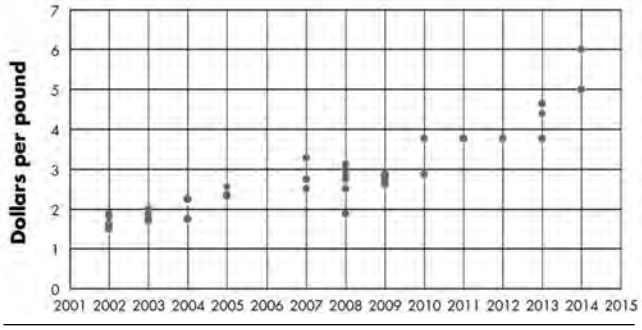

Figure 3. Monthly Mississippi commercial oyster ex-vessel prices. Source of raw data: NOAA Fisheries (2016).

Economic Recovery Model of the Oyster Fishery

With federal disaster funding, the state of Mississippi was in the process of restoring oyster reefs after Hurricane Katrina in 2005 and the Deepwater Horizon oil spill in 2010 when the Bonnet Carré Spillway opening in 2011 resulted in 86 percent oyster mortalities. This damage required restoration projects to enable the fishery to recover to its baseline status. Restoration efforts included dredging oyster seed stock and relaying it to designated public reefs, among other actions. Cultch materials consisting of oyster shells and limestone were purchased and planted in designated public reefs. These efforts enabled the reefs to replenish the damaged oyster populations and make them available for harvest when the shellfish reached market size. Restoration allowed reefs to reproduce more oysters for future seasons.

Oyster restoration is part of the social cost of the prolonged spillway opening. Mississippi's oyster fishery will not recover without the implementation of appropriate and timely restoration projects. MDMR has frequently used both oyster relaying and planting of cultch materials to manage the state's public oyster reefs. Oyster relaying after Hurricane Katrina enabled the state oyster fishery to slowly recover from the storm's devastation. After Katrina, MDMR (2007) replenished the damaged reefs with about 19 cubic yards of relayed seed stock per acre of public oyster reef. In addition, the agency planted about 54 cubic yards of cultch materials per acre to 4,818 acres of oyster reefs. Restoration costs include the cost of dredging, transporting, and planting seed stock from nonaffected areas to damaged reefs. Additional costs include purchasing, transporting, storing, and planting the cultch materials in the affected areas. These expenses are part of the social cost of reversing damage caused by the spillway opening.

The economic recovery model (ERM) attempts to measure the effects of economic, biological, technical, and environmental factors on commercial oyster landings during the past two decades. Following are the specifications of the economic recovery model using the regression function of Stata 12 for Windows (StataCorp LP, College Station, Texas):

```
regress pounds time i.code diesel2 gulfevp2 shrimpevp2 urate i.open totdolag12 totdolag13 totdolag14 totdolag15 totdolag16 totdolag17 totdolag24 totdolag25 totdolag26 totdolag27 totdolag28 totdolag29 katrina05 katrina06 katrina07 gomos10 opening11 opening12 opening13, vce (robust)
```

Equation 1

where pounds = commercial oyster landings (pounds per month); code = dummy variables representing month (base month is January); diesel2 = deflated Gulf diesel retail price (dollars per gallon); gulfevp2 = deflated oysters ex-vessel price (dollars per pound); shrimpevp2 = deflated white shrimp ex-vessel price (dollars per pound); urate = unemployment rate (percent); open = dummy variable representing open season; $totdolag_t$ = lagged deflated total cost of cultch planting and oyster relaying (dollars per month); katrina = dummy variables representing Hurricane Katrina; gomos = dummy variable representing the Deepwater Horizon oil spill; opening = dummy variable representing the Bonnet Carré Spillway opening.

The oyster fishery economic recovery model defined by Equation 1 was estimated using available monthly data on commercial oyster landings from January 2002 to December 2014. The choice of explanatory variables was guided by those demand and supply determinants that have available monthly data since 2002. The time variable was expected to capture the long-term trend in commercial landings from 2002–14. Commercial oyster harvesting normally occurred from September–May in 2002–04 but shifted to October–April after Hurricane Katrina. The dummy variables representing months were designed to reflect the seasonal nature of oyster harvesting in the state. Diesel retail price was used to reflect possible shifts in the supply of oysters over time. The oyster ex-vessel price influenced both quantity of oysters demanded and supplied over time. The white shrimp ex-vessel price was assumed to influence quantity of oysters demanded by consumers either as a complementary or substitute product. The dummy variable representing whether the season was opened or closed was used as a proxy variable for water quality in the oyster growing areas. Total costs of oyster relaying and cultch planting reflected the restoration activities conducted by state regulatory agencies. The total cost of cultch planting and oyster relaying was lagged to determine optimal harvesting time. The dummy variables representing Hurricane Katrina, the oil spill, and the spillway opening were added to measure their effects on landings. Some dummy variables representing the oil spill were removed to eliminate collinearity problems in estimation.

The estimated coefficients of Equation 1 explained 70 percent of the variations in commercial landings. The coefficients of the explanatory variables have the expected signs, and some are significantly different from zero (Appendix A). The estimated equation was used to estimate monthly commercial landings from October 2005 to December 2014.

Estimates of Mississippi monthly commercial oyster landings were made on the assumption that none of the natural and technological disasters since 2005 took place. The predicted value of the ERM model was forced to be zero when oyster season closed normally from May to September. The differences between these estimates and the actual monthly oyster landing and landing values measured the direct economic losses associated with the recent natural and technological disasters.

Economic Impacts Model

After computing the foregone annual landing values of the direct losses in oyster harvesting associated with the prolonged Bonnet Carré Spillway opening, we estimated the negative economic impacts using IMPLAN (2016) models for Mississippi. The income, value-added, and sales impacts are expressed in dollars for the year specified. Output or sales is the gross sales by businesses within the economic region affected by an activity. Labor income includes personal income, such as wages and salaries, proprietors' income, or income from self-employment. Employment impacts are expressed in terms of a mix of both full-time and part-time jobs (Kirkley 2009, 2011).

The total economic impacts of an economic sector consist of direct, indirect, and induced effects. Direct impacts express the economic impacts in the sector in which the expenditure was initially made. Indirect impacts result from changes in economic activity of industrial sectors that supply goods or services to the sector being evaluated. Induced impacts are the result of personal consumption expenditures by industry employees.

Oyster harvesting corresponds to economic sector 114112 or "shellfish fishing" in the North American Industrial Classification System (NAICS 2011). The shellfish fishing industry includes establishments primarily engaged in the commercial catching or taking of shellfish (clams, crabs, lobsters, mussels, oysters, sea urchins, and shrimp) from their natural habitat.

The total negative sales impact of the prolonged spillway opening in 2011 was computed as follows:

$$TSI(p) = FLV(p) \times K, \qquad \text{Equation 2}$$

where TSI(p) = stochastic total sales lost by an economic sector in year t; FLV(p) = stochastic foregone landings value by an economic sector in year t; and K = sales multiplier of an economic sector at year t.

The stochastic variables were computed by using the Simetar (2011) software as an add-in to Excel. For this publication, only the means are used in the estimation of negative impacts. Output or sales impacts were estimated using IMPLAN (2016). Labor income, jobs, and value-added impacts of the commercial landing values lost due to the spillway opening were also estimated using IMPLAN (2016).

Results and Discussion

The oyster industry suffered economic hardships due to the closure of state public oyster reefs to harvesting due to the prolonged Bonnet Carré Spillway opening. The absence of access to the public reefs caused the shutdown of oyster-harvesting activities and associated economic activities in the region. The state oyster-harvesting industry then suffered tremendous economic downturns during the 4 years after the spillway opening in 2011 (Figure 4).

Foregone landings were estimated from the difference between the baseline pre-Hurricane Katrina landings and actual monthly landings. When actual landings data were not yet available, the predicted values using the Hurricane Katrina model were used. Direct economic losses associated with the disastrous opening of the spillway were reported when predicted values were greater than actual values. There were no direct economic losses reported when predicted values were less than actual values.

The monthly oyster landing values foregone after the spillway opening were computed from the annual mean of the imputed ex-vessel prices of the monthly oyster landings and the foregone annual landings after the prolonged spillway opening. The foregone monthly oyster landings from May 2011 to December 2014 were measured by the difference between the projected landings and the 2002–04 baseline monthly landings.

This publication presents three different estimates of the direct losses associated with the prolonged spillway opening in 2011 to Mississippi commercial oyster landings. The preliminary approach used the Hurricane Katrina model with predicted data since no data in 2011–14 were available at that time. Under this method, direct losses equaled "predicted monthly landings using Hurricane Katrina model less monthly baseline oyster landings in 2002–04." The cumulative direct losses under this method reached $37.6 million (Figure 5).

With 2011–14 data available, the preliminary Hurricane Katrina model was modified by estimating the direct losses associated with the prolonged spillway opening as equal to "actual monthly landings minus monthly baseline oyster landings in 2002–04." With this approach, the cumulative direct loss to Mississippi commercial oyster landings was $46 million (Figure 5).

With the oyster-relaying and cutch-planting economic recovery model (Appendix A), the effects of the prolonged spillway opening on commercial oyster landings were calculated. Under this method, direct losses were equal to "actual monthly landings – monthly landings without disaster." Cumulative direct losses amounted to $21.9 million (Figure 5).

Direct losses in oyster harvesting associated with the prolonged spillway opening ranged from 80 percent to 100 percent of the baseline average annual com-

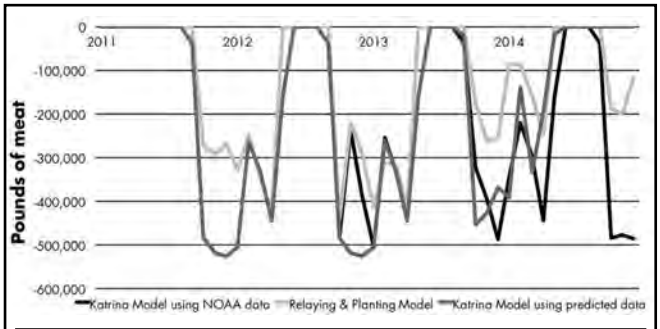

Figure 4. Comparative foregone annual oyster landings in Mississippi since 2011 using economic recovery and Hurricane Katrina models.

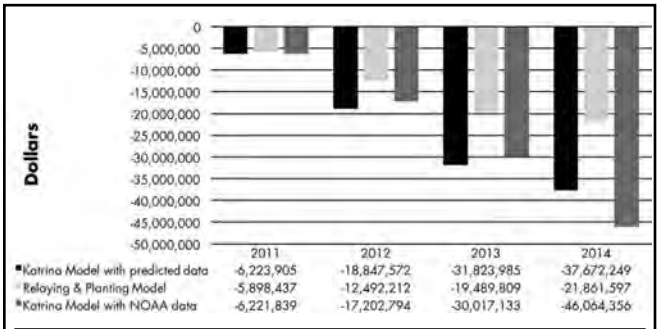

Figure 5. Comparative foregone annual oyster landing values in Mississippi since 2001 using economic recovery and Hurricane Katrina models.

Table 7. Estimated negative economic impacts of the spillway opening to the Mississippi oyster harvesting industry from 2011–14 using Hurricane Katrina model predictions.

Year	Employment impacts (jobs)	Labor income impacts ($)	Value-added impacts ($)	Output impacts ($)
2011	-238	-1,758,557	-3,618,312	-9,620,179
2012	-318	-7,855,340	-10,581,350	-19,574,876
2013	-324	-7,994,211	-10,768,414	-19,920,932
2014	-145	-3,566,886	-4,804,690	-8,888,394
Total	NA	-21,174,995	-29,772,766	-58,004,380

NA = not applicable since the number of jobs pertains to the same pool of commercial oyster fishermen and workers in related industries.

mercial landings. The cumulative foregone landing values of commercial oyster harvesting ranged from $21.8 million to $46.0 million in 2011–14, depending on the estimation method used (Figure 5).

The total direct losses estimated by the preliminary Hurricane Katrina model were applied in calculating the negative economic impacts of the 2011 spillway opening. Using the IMPLAN (2016) economic impact program and 2014 Mississippi data, the negative economic impacts of the spillway opening in 2011–14 were calculated. The negative output impacts reached $9.6 million in 2011, $19.6 million in 2012, $19.9 million in 2013, and $8.9 million in 2014. Resulting from the downturn in oyster harvesting, the state lost between 145 and 324 jobs per year during the period. Labor income lost ranged from $1.8 to $8 million per year (Table 7).

Summary and Implications

The Mississippi oyster industry underwent severe economic hardships due to the massive destruction and frequent closures of the state public reefs associated with natural and technological disasters since 2005. The absence of access to public reefs caused the shutdown of oyster-harvesting activities and associated processing and distribution activities. The direct losses in oyster harvesting associated with the prolonged Bonnet Carré Spillway opening in 2011 ranged from 80 percent to 100 percent of the baseline average commercial annual landings in 2002–04. The cumulative values of commercial oyster landings lost in 2011–14 reached up to $46 million. Negative economic impacts of the spillway opening consisted of the reduction in economic output by $58 million, the loss of 145–324 jobs lost per year, and a decline in labor income by more than $21 million in 2011–14.

The damage estimation methodologies developed included both rapid assessment and robust economic models. Application of these models can be used to estimate direct economic losses or damages and total negative economic impacts to the state oyster fishery. There are several areas for improvement, however, that will make these models better tools to evaluate the economic performance of the state oyster fishery. In order to increase the efficiency of the models, additional long-term monthly variables are useful to the model, such as water quality, restoration efforts, oyster relaying, and cultch planting. It is anticipated that these adjustments in the models will improve their predictive and explanatory properties.

The federal disaster assistance and oil spill restore funds allocated to the restoration of the state public oyster reefs are massive. However, the postdisaster economic recovery of the state's oyster fishery depend on the immediate and timely implementation of appropriate restoration efforts and disaster assistance to oystermen. The long-term economic recovery of the oyster fishery requires the immediate implementation of the recommendations, projects and programs outlined by the Governor's Oyster Restoration and Resiliency Council.

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Appendix A

Multiple linear regression results of the oyster relaying and cultch planting economic recovery model with monthly Mississippi commercial landings as the dependent variable, January 2002 to December 2014.

Variable	Coefficients	Robust Standard Error	t-value	P>|t|
time	42,851.79 **	17,080.58	2.51	0.01
Feb	-112,739.80 *	49,108.22	-2.30	0.02
Mar	-63,189.10 ns	48,968.15	-1.29	0.20
Apr	18,014.89 ns	60,343.85	0.30	0.77
May	-75,370.56 ns	56,872.00	-1.33	0.19
Jun	-69,265.09 ns	63,599.03	-1.09	0.28
Jul	-83,183.04 ns	59,198.61	-1.41	0.16
Aug	-96,529.88 ns	52,361.37	-1.84	0.07
Sep	-150,557.40 ***	51,335.54	-2.93	0.00
Oct	42,548.47 ns	57,387.90	0.74	0.46
Nov	104,638.30 ns	57,652.83	1.81	0.07
Dec	74,608.94 ns	74,571.41	1.00	0.32
diesel2	-42,613.38 ns	43,622.60	-0.98	0.33
gulfevp2	-236,986.60 ***	65,330.81	-3.63	0.00
shrimpevp2	-19,990.99 ns	27,993.84	-0.71	0.48
urate	-39,239.57 ns	24,128.12	-1.63	0.11
open	125,215.50 ***	27,205.16	4.60	0.00
totdolag12	0.02 ns	0.02	1.53	0.13
totdolag13	0.01 ns	0.01	0.55	0.58
totdolag14	0.04 ***	0.01	3.59	0.00
totdolag15	0.01 ns	0.02	0.71	0.48
totdolag16	-0.01 ns	0.02	-0.34	0.74
totdolag17	0.03 ns	0.02	1.16	0.25
totdolag24	0.02 ns	0.02	1.17	0.24
totdolag25	0.01 ns	0.02	0.39	0.70
totdolag26	0.00 ns	0.02	0.03	0.98
totdolag27	-0.02 ns	0.02	-1.38	0.17
totdolag28	-0.04 ns	0.02	-2.39	0.02
totdolag29	-0.02 ns	0.02	-1.00	0.32
katrina05	-28,140.74 ns	42,711.87	-0.66	0.51
katrina06	-131,811.70 ***	43,865.43	-3.00	0.00
katrina07	-302,854.90 ***	77,305.83	-3.92	0.00
gomos10	-109,787.10 ns	69,504.06	-1.58	0.12
opening11	-111,109.10 ns	80,601.89	-1.38	0.17
opening12	-215,493.50 **	82,292.02	-2.62	0.01
opening13	-123,960.00 ns	69,302.55	-1.79	0.08
Constant	1,217,282.00 ***	336,957.20	3.61	0.00
Number of months	156.00			
F (36, 119)	8.23			
Prob > F	0.00			
R-squared	0.70			
Root MSE	120,000.00			

*** = statistically significant at 0.001.
** = statistically significant at 0.01.
* = statistically significant at 0.05.
ns = not statistically significant at 0.05.

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