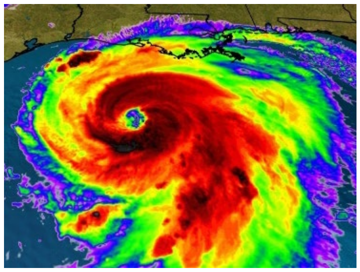
Projected Infrastructure, Revenue and Resource Losses to Louisiana Fisheries from the Hurricanes of 2020 and 2021



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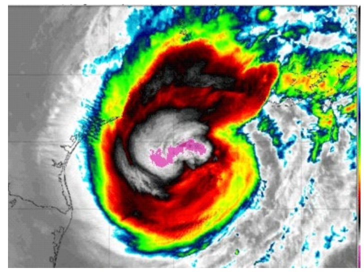

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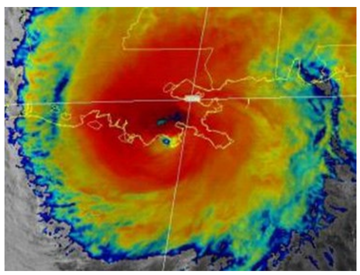

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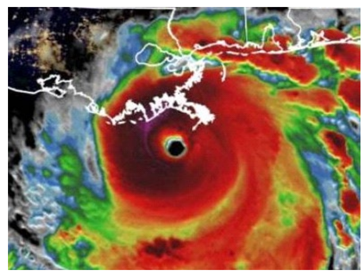

Ida

January 10, 2022

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SUMMARY

From August 27, 2020 to August 29, 2021, four Hurricanes (Laura, Delta, Zeta, and Ida) made landfall in coastal Louisiana, causing major destruction to a region of national importance for domestic fisheries and seafood production. In response to these storms, numerous efforts were initiated by public and private entities to provide humanitarian aid and basic commercial necessities. As part of an ongoing effort to assist the state in the documentation of economic impacts, this study was initiated to provide a detailed examination of the storms' impact on fisheries infrastructure, revenue, and biological resources. The analysis is based on an expansion of spatial impact assessment methods established in the wake of previous storms. Business addresses, obtained from state licensing and permitting records, were geocoded for 8,503 firms representing five marine sectors (commercial fishing vessels, seafood dealers, seafood processors, charter operations and coastal marinas). Economic valuation of individual businesses was based on firm- and industry-level revenue data within established methods of income capitalization and market-based appraisal. All business location and valuation data were integrated into a geographic information system, and combined with highly detailed estimates of maximum surge height and wind speeds for each storm at each firm location. Sixteen survey-derived damage functions were developed and applied to geocoded firm- and storm-data to produce geographically specific estimates of damage to coastal fisheries infrastructure and estimates of annual revenue loss. The following points contain select findings from the analysis.

- Total losses, estimated at **$579.9 million,** represent the midpoint of alternative damage estimation techniques based on linear and nonlinear damage models.
- In 2020, 99% of the maximum storm surge elevations and 83% of the maximum wind speeds in southwestern LA were attributed to Hurricane Laura, with the remainder from Hurricane Delta.
- From 2020-2021, 99% of maximum storm surge and 97% of the maximum wind speeds in southeastern LA were attributed to Hurricane Ida, the remainder were from Hurricane Zeta.
- Total damage to fisheries infrastructure, estimated at $304.9 million, equates to a 22% reduction to the $1.36 billion in appraised value of infrastructure for the five sectors of the analysis.
- Of the $304.9 million in infrastructure damages, Hurricanes Laura, Delta, and Zeta in 2020 accounted for 30%, and Hurricane Ida in 2021 accounted for 70%.
- Wind was the primary driver of impact for all four storms, accounting for 85% of the damage to vessels, 80% for dealers, 80% for processors, 89% for charters and 54% for marinas.
- Revenue losses for 22 coastal parishes totaled $155.3 million, with $48.1 million (31%) for 2020; $66.4 (43%) for 2021; and, $40.7 million (26%) in carry over losses expected for 2022.
- Annual revenue losses approaching or exceeding 35% were projected for one species (Brown Shrimp) and seven parishes (Cameron, Calcasieu, Jefferson, Lafourche, St. Charles, St. John and Terrebonne).
- Resource losses, estimated at $118.5 million for 2020-2021, are derived from field surveys by LDWF biologists and restitution values obtained from Natural Resource Damage Assessments.
- Survey data indicate ongoing challenges related to the availability and affordability of marine insurance, vessel evacuation options, and damages to residential dwellings.

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1. BACKGROUND

1.1 The Louisiana Hurricanes of 2020 and 2021

On August 27, 2020, Hurricane Laura made landfall in Cameron Parish, Louisiana with sustained winds of 150 mph and a maximum storm surge of 18 feet above sea level (Pasch et al. 2021). The storm maintained Category 4 strength 40 miles inland, causing widespread destruction of coastal fishing communities and severe damage to the Lake Charles metropolitan area. Hurricane Laura was the third and strongest of five named storms to make landfall in Louisiana during the record-breaking 2020 Atlantic storm season (NOAA 2021_a)[1]. Within days of landfall, Laura would be classified as the strongest[2] Louisiana hurricane on record, to date, since the "Last Island Storm" of 1856.

On October 9, two weeks after Laura's landfall, Louisiana was impacted by Hurricane Delta, a Category 2 storm. Hurricane Delta entered the coast at nearly the same location as Laura, and compounded damages to the heavily impacted southwest region. Later that month on October 28, Hurricane Zeta made landfall as a Category 3 storm. Zeta came ashore in southeastern Louisiana, causing substantial damages to coastal communities in Orleans, Plaquemines, and St. Bernard parishes.

Ten months later, a second Category 4 storm made landfall in Louisiana. Hurricane Ida came ashore at Port Fourchon on August 29, 2021, with sustained winds of 150 mph and substantially higher gusts (Erdman 2021). Equal in intensity to Hurricane Laura but larger in size, Hurricane Ida's path was a 40-mile-wide swath of impact from the Gulf of Mexico stretching 100 miles inland to the north shore parishes of Lake Pontchartrain. Ida destroyed major components of the power grid in the greater New Orleans region and inflicted its heaviest damages to the heart of Louisiana's seafood harvesting region - Terrebonne, Lafourche, and Jefferson Parishes.

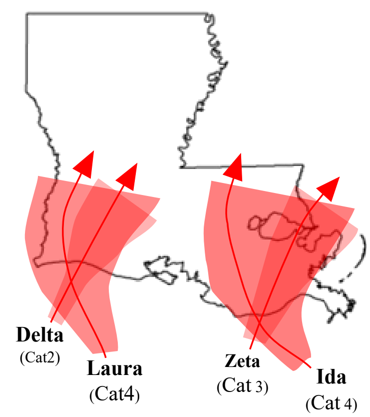

Figure 1. Tracks of Hurricanes Laura, Delta, Zeta, and Ida in 2020 and 2021

The landfall of four major Hurricanes in a single state in such a short time frame is unprecedented in the northern Gulf of Mexico region. In 12 months and 2 days, Hurricanes Laura, Delta, Zeta, and Ida crisscrossed the two regions of southwest and southeast Louisiana that have historically contained 80% of the state's commercial fishing population and fisheries infrastructure (Figure 1).

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[1] Tropical storm Cristobal made landfall on June 7, 2021. Tropical storm Marco made landfall on August 25, 2021

[2] Based on maximum sustained wind speed.

1.2 Challenges of Fisheries Response and Assessment

It is estimated the Louisiana hurricanes of 2020 and 2021 caused 174 fatalities nationwide and a total of $92 billion in economic losses to the U.S. economy (Aon 2021, NCEI 2021). While no detailed economic assessments have been released for fisheries, field-level assessments were initiated immediately following each of the four storms. Preliminary observations of impact were conducted by agents of the Louisiana Department of Wildlife and Fisheries (LDWF) and the Marine Extension Program (MEP) of Louisiana State University AgCenter and Louisiana Sea Grant. These ground-level assessments helped to direct the rapid response efforts of public and private organizations focused on vessel recovery, debris removal, and provision of the fuel, water, and generators needed for emergency ice production and cold storage. As learned with previous storms, getting basic commerce functions in place as soon as possible is critical for mitigating impacts to an industry that supports $2.47 billion annually in economic activity and 31,000 jobs related to the harvest, distribution, and processing of seafood ($NOAA_b$ 2021).

Beyond the rapid response phase, a more detailed assessment is necessary for measuring the scope of a storm's impact and for guiding additional resources for recovery. Ideally, such an assessment would address losses to fisheries infrastructure, revenue, and biological resources. Since 2011, however, revenue alone has been the sole criteria for determining whether a particular event constitutes a disaster warranting federal aid. Under guidance provided in Sections 312(a) and 315 of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), the declaration of an official "Federal Fisheries Disaster" hinges on a species-specific revenue reduction threshold of thirty-five percent of baseline activity for the previous five-year period. This threshold presents a number of challenges.

Under guidance from NOAA Fisheries, this reduction of revenue is to be measured at the "management level" for a given species. Yet Louisiana, like many states, manages most of its commercial fisheries on a coast-wide basis. Thus, any substantial impacts from a disaster on the harvesting of a species at the basin- or multi-basin level can be discounted by the NOAA mandated scale of a coast-wide revenue assessment. And because such determinations are made on an annual basis, the time required to document a disaster can be lengthy, up to 12 months post-impact. Moreover, the focus on revenue alone fails to measure the biophysical effects of a storm. This constraint is of particular concern in Louisiana, where hurricanes regularly result in substantial fish mortality and the loss of thousands of acres of subaerial marsh habitat. Finally, there is no direct accounting under the federal guidance for the loss of infrastructure - despite the fact that major hurricanes can cause considerable damage to the vessels, structures, and equipment necessary for fisheries operations. Such constraints, while frustrating for a single event, can be highly problematic in the wake of multiple disasters requiring more immediate attention.

1.3 Louisiana Fisheries Community Recovery Coalition

In response to the spate of recent storms, Louisiana's coastal fisheries leaders have resurrected an alliance of organizations that was initially formed in 2005 in the wake of Hurricanes Katrina (Caffey et al. 2006). The Louisiana Fisheries Community Recovery Coalition (LFCRC), as reconvened in September 2021, consists of 34 participating entities (Table 1). The primary purpose of the LFCRC is to coordinate the state's fisheries disaster communications by identifying short-term and long-term priorities for response and recovery.

Table 1. Representative Entities of the 2021 Louisiana Fishing Community Recovery Coalition

American Shrimp Processors' Association	Louisiana Oyster Task Force
Coastal Conservation Association	Louisiana Restaurant Association
Daybrook Fisheries	Louisiana Sea Grant
FEMA, Office of Community Planning & Capacity	Louisiana Seafood Exchange
Finfish Processor/Jensen Tuna	Louisiana Shrimp Association
Gulf Seafood Foundation	Louisiana Shrimp Task Force Chairman
Harlon's LA Fish and Seafood (LFCRC Chair)	LSU AgCenter Dept. of Agriculture Economics
LA Dept. of Natural Resources, Office of Conservation	NOAA Pascagoula Seafood Lab
LA Seafood Promotion and Marketing Board	Office of Lt Governor Billy Nungesser
Louisiana Bait Sector Representative	Omega Protein
Louisiana Charter Boat Association	Shell Oil
Louisiana Crab Processing Representative	US Dept. of Commerce, Economic Development
Louisiana Crab Task Force Chairman	US Dept. of Interior, Restoration & Damage Assessment
Louisiana Dept. of Wildlife and Fisheries	US Representative Garret Graves Office
Louisiana Finfish Task Force	US Representative Steve Scalise's Office
Louisiana Marina Representative	US Senator Bill Cassidy's Office
Louisiana Oyster Processing Representative	US Senator John Kennedy's Office

Concurrent with the Coalition's mission, an economic working group was established at LDWF to develop a comprehensive assessment of fisheries impacts resulting from the Hurricanes of 2020 and 2021. The group consists of economists, biologists, cartographers, and data managers employed by LDWF, Louisiana Sea Grant, and the Louisiana State University (LSU) AgCenter.

To conduct their analysis, the group is expanding on spatial assessment methods originally developed under contract with NOAA for the assessment of fisheries infrastructure damages resulting from Hurricanes Katrina and Rita in 2005. A similar approach was used for assessing fisheries infrastructure and revenue losses following Hurricanes Gustav and Ike in 2008 (Erlambang 2008, Caffey 2009).

2. OBJECTIVES AND METHODS

2.1 Objectives

This report focuses on the estimation of monetized losses resulting from the Louisiana hurricanes of 2020 and 2021. Specific objectives of the study include:

1. Mapping licensed and commercially active fisheries businesses in coastal Louisiana.
2. Mapping surge and wind data for each of the four storms at each business location.
3. Developing revenue- and market-based valuations for all mapped businesses.
4. Developing storm damage and loss functions through a fishing industry survey.
5. Producing aggregated estimates of infrastructure damage and revenue losses.

2.2 Methods

The analysis of fisheries-related businesses in the study was limited to those sectors for which primary data on a firm's location is available through state records and for which information on economic activity is available via primary and/or secondary sources.[3] For this reason, the effective definition of "fisheries infrastructure" in the report is limited to five commercial sectors that meet these two criteria: 1) commercially active fishing vessels[4]; 2) commercially active seafood dealers; 3) seafood processors; 4) charter boat operations; and 5) coastal marinas[5].

2.2.1 Mapping Fisheries Infrastructure

Objective 1 required the acquisition of confidential license records from LDWF and the Louisiana Department of Health (LDH). A non-disclosure agreement was signed by team members in the LSU AgCenter requiring data aggregation to protect the anonymity of individual businesses. To establish pre-impact baseline maps for fisheries infrastructure, LDWF and LDH databases were queried for the years 2018-2020. The addresses of all period-relevant license and permit-holders were converted into spatial coordinates (latitude and longitude) using geocoding procedures available in ArcMap software (ver. 10.8.1 ESRI Inc.). A total of 8,503 geocoded business operations were archived in a multi-layer project folder maintained in the Agricultural Economics Geographic Information System (GIS) laboratory on the LSU campus in Baton Rouge, Louisiana.

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[3] The word "firm" as used in this report refers to individual licensees, permit holders or otherwise documented businesses obtained from the commercial databases of LDWF or LDH.
[4] Active vessels and dealers were defined as any firms with trip ticket records submitted for the years 2018-2020.
[5] Although their customer base consists primarily of recreational anglers, charter boat operations and coastal marinas are classified as commercial entities in terms of their state and federal tax status.

2.2.2 Mapping Storm Data

Objective 2 required the acquisition of meteorological data from the Coastal Emergency Risk Assessment (CERA) program of the LSU Center for Computation and Technology (CCT). For the past 20 years, LSU has supported storm advisory projections based on the Advanced Coastal Circulation Model (ADCIRC). The model combines data from the National Weather Service (NWS) on storm trajectory and magnitude with data on coastal Louisiana bathymetry and elevation to generate predictions of storm surge and wind speed (ADG 2021). In October 2021, detailed contour data containing numerical estimates of maximum surge elevation (feet) and maximum wind speed (mph) were acquired from CERA for coastal Louisiana grid for Hurricanes Laura, Delta, Zeta and Ida.[6] These data were integrated into the project's GIS platform to produce estimates of maximum surge elevation and maximum sustained wind speed for each storm at each geocoded business location.

2.2.3 Valuation of Infrastructure

Objective 3 involved the valuation of all geocoded businesses using firm-specific economic data or sector level estimates from existing studies. These broad level valuations served as the baseline from which storm-related damages to fisheries infrastructure would be estimated. For the five commercial sectors[7] of this study, data on gross revenue and net revenue were obtained from primary and secondary sources and used to value that infrastructure using a form of income capitalization. This estimation derives from business appraisal methods in which a firm's value is expressed as a function of the gross revenue and net income generated by its assets (AIREA 1983). The basic valuation is given by:

$$V^i = \frac{GR^i \times NI^{ij}}{r^j} \qquad \text{Eq .1}$$

where V^i is the income-capitalized value of firm i based on: GR^i, the annual gross revenue of firm i (a baseline value derived from primary or secondary sources), NI^{ij} , the net income for firm i based on the average returns for a given sector j (derived from secondary sources and ranging from 5-25%), and r^j is an industry specific capitalization rate (derived from secondary sources and ranging from 5-15%). As used here, the capitalization rate is inversely related to a sector's profitability. More (less) profitable sectors with higher (lower) net incomes would be valued at lower (higher) capitalization rate. As such, the

[6] ADCIRC projections are developed across a coastal grid for Louisiana with computations at two million locations (i.e. simulation nodes). Final projections are hind-casted for consistency with post-storm observations.
[7] An additional, regression-based appraisal method for commercial vessels is described in Section 3.1.1 of this report.

income capitalization appraisal provides a more conservative valuation than replacement value, in that it accounts for the risk-adjusted market value of a firm's assets.

2.2.4 Estimating Damage Functions

Objective 4 required the refinement of previously established damage curves created after Hurricane Katrina and Rita and refined after Hurricanes Gustav and Ike. These curves allow for location-specific damage estimates of a storm's effect on fisheries infrastructure (Caffey et al. 2006). Adjusting equation 1 yields:

$$D^i = \frac{GR^i \times NI^{ij}}{r^j} \times Z^i \qquad \text{Eq .2}$$

where D^i is the total economic damage ($) to the value of firm *i* based on Z^i, a geographically specific damage factor (% loss of value) for firm *i* based on a functional relationship between observed and/or reported damages and observed/reported/modelled estimates of maximum surge elevation and maximum wind speed. For some Louisiana storms, like Hurricanes Katrina and Rita (2005) and Hurricane Ike (2008), a majority of the damages are caused by surge. For other storms, like Hurricanes Andrew (1992) and Gustav (2008), wind speed is the most critical factor. Moreover, within a given storm, the impacts on an individual firm can be dominated by either surge or wind, depending on a firm's location and other variables (i.e. site elevation, asset construction, evacuation of assets, etc.). A basic approach for parameterizing damage curves for these two meteorological drivers uses ordinary least squares (OLS) for estimating a simple regression line:

$$Z^i = b_0 + b_1 s \qquad \text{Eq .3}$$

or

$$Z^i = b_0 + b_1 w \qquad \text{Eq .4}$$

where Z^i is a geographically specific damage factor (% loss of value) for firm *i*. Variable b_o is the intercept, b_1 is the slope, *s* is a location-specific estimate of maximum storm surge elevation (eq. 3), and *w*, is a location-specific estimate of maximum wind speed (eq. 4).

While this simple linear model can effectively capture the positive relationship between a storm's magnitude and damage, it tends to overestimate economic damages at lower observations of surge elevation and wind speed.

Alternative methods for developing storm damage functions include a range of nonlinear models that have been used to describe how damages vary between the lower and upper bounds of 0-100% (Luino et al. 2006; Prahl et al. 2015). Nonlinear models can be used to depict changing rates of impact across different levels of surge elevation and wind speed.

For this analysis, a second approach for parameterizing Z^i was developed using a non-linear, sigmoidal function originally developed to model the rate of transformation of materials from one physical state to another (Avrami 1940):

$$\mathrm{Y_{fit}} = A * ((1 - \exp * (-k * t^n)) \qquad \text{Eq .5}$$

where $\mathrm{Y_{fit}}$ is an estimated dependent variable based on A, a constant representing the upper bound of the transformation process, *k* is a rate constant, *t* is the log of time and *n* is a power variable. When used to estimate hurricane damages, the equation can be rewritten as:

$$Z^i = A * ((1 - \exp * (-k * s^n)) \qquad \text{Eq .6}$$

or

$$Z^i = A * ((1 - \exp * (-k * w^n)) \qquad \text{Eq .7}$$

where *Zi* is the geographically-specific damage factor (% loss of value) for firm *i*, A is a constant representing the upper bound of the damages (set at 1.0, or 100%), *s* is a location-specific estimate of maximum surge elevation (eq. 6) and *w* is a location-specific estimate of maximum wind speed (eq. 7).

A spreadsheet-based routine for fitting this sigmoidal function is described by Sparks (2018) and involves the use of an optimization add-in package (Solver, ver. 2016). The iterative method yields values for *k* and *n* that minimize the sum of squared residuals between observed and predicted values of Z^i.

2.2.4.1 Fishing Industry Survey

Estimation of the linear and nonlinear models described above required an initial set of sample observations relating infrastructure damages to surge and wind. For this reason, a survey was developed to collect information from Louisiana fishing business owners and operators impacted by the 2020-2021 hurricanes. An electronic questionnaire was programmed using Qualtrics software (ver. 3.20) under a license held by Louisiana State University. The platform allows for conditional logic formatting,

prevention of duplicate responses, and survey conversion features that allow for participation on personal computers or smartphones. Links to Qualtrics surveys can be distributed via direct email or text, or posted online for open-access participation.[8]

Draft versions of the questionnaire were refined via panel testing with field agents of the MEP and LDWF in early October 2021, and the survey received LSU Institutional Review Board approval in late October 2021. The final survey instrument (Appendix A) included sixteen questions in seven sections: 1) cover letter and consent, 2) storm of record and business type, 3) location data, 4) infrastructure valuation, 5) storm-related losses, 6) revenue projections, and 7) comments (Appendix B). Respondents indicating any type of vessel damage were directed to six additional questions related to the primary vessel.[9]

Sections 2, 3, 4 and 5 of the survey were designed to collect the sample data required to estimate the infrastructure damage functions for maximum surge elevation and maximum wind as outlined in equations 3-7. Sections 2, 3 and 6 of the survey were used to estimate revenue loss functions through a similar process described in section 3.4 of this report.

The survey was implemented using two identical questionnaires. One version was sent by email to a sample of 639 industry contacts from all five sectors. A second, identical version of the survey, was made available via open access, and advertised through the social media accounts at LDWF and Louisiana Sea Grant, and distributed by members of the LFCRC to their various fisheries-related networks. The survey was active from November 10, 2021 to December 20, 2021.

2.2.5 Integration and Assessment

Objective 5 involved the integration of all geocoded firm data (objective 1), ADCIRC data (objective 2), and business appraisals (objective 3) into a spreadsheet model in Microsoft Excel (ver. 2016). These data were combined with damage functions created through the industry survey (objective 4) to assess storm losses for each of the 8,503 firms identified by LDWF and LDH records. Final asset and revenue losses are aggregated by sector and commodity, and combined with resource loss estimates developed by LDWF field biologists. Summary results are presented as the fisheries infrastructure, revenue, and resource losses resulting from the Louisiana hurricanes of 2020-2021

[8] Given the limited time available for the damage assessment, an electronic survey was the best option for data collection. Coastal extension agents of Louisiana Sea Grant provided assistance with data entry to survey respondents on an as-needed basis.

[9] Fisheries economic surveys often solicit data for the “primary vessel”, or the one most frequently used in a respondent’s commercial operations. This construct avoids the difficulties of discussing multiple vessels and is typically sufficient for characterization purposes when a sufficient number of observation is collected.

3. RESULTS AND DISCUSSION

3.1 Infrastructure Maps

Figure 2 depicts a statewide map derived from 56,485 license purchases downloaded from the LDWF commercial license database for the years 2018-2020. After parsing for redundancy, 16,849 individual commercial fishing license-holders were identified and geocoded. Consistent with the broader population of Louisiana, these individuals reside more prevalently in southern parishes of the state and tend to be more concentrated around the metropolitan areas of New Orleans, Baton Rouge, Houma, Lafayette, and Lake Charles. Individuals on this map residing in the 20 parishes of the Louisiana coastal zone[10] accounted for 83% of the dockside value of commercial fishery landings in Louisiana for this three-year period. Of this region, 16 "hurricane-impacted parishes" (experiencing winds of 75 mph or greater) accounted for 88% of the annual value of fisheries landings for this period. [11]

Figures 3 and 4 depict geocoded locations for 5,739 active commercial fishing vessels and 1,129 active seafood dealers identified in the LDWF database for the years 2018-2020. Given the marine-dependent nature of this infrastructure, these maps depict a substantial number of vessel and dealer business located along the coastal ridge communities extending southward towards the Gulf of Mexico. Hurricane-impacted parishes accounted for 87% of the active commercial vessels and 74% of active seafood dealers in coastal Louisiana.

Figure 5 shows the statewide location of 473 seafood processor businesses identified in the LDH database. Nearly three-fourths (74%) of these processors were located in the Louisiana coastal zone prior to the hurricanes of 2020-2021. Sixty percent of these firms were located in hurricane impacted parishes.

Figures 6 and 7 depict available location data for two types of recreational infrastructure: charter boat operations and coastal marinas. Charter businesses were mapped from a list of 1,031 state charter licenses identified by LDWF license records for the years 2018-2020. Of this number, 97% were located in the state's coastal zone with 90% residing in hurricane-impacted parishes. A total of 68 coastal marinas were identified from a list of 131 La CREEL sampling site coordinates located in the states' coastal zone. Marinas are one of the most southerly-located types of infrastructure, with 87% of these businesses located in hurricane-impacted parishes.

[10] As used here, "coastal zone" refers to the 20 Louisiana parishes with marine tidal waters.
[11] Cameron, Jefferson, Lafourche, Terrebonne, Calcasieu, St. Charles, St. James, St. John, Jefferson Davis, Orleans, Plaquemines, St. Tammany, and Tangipahoa, St. Bernard, Assumption and Ascension.

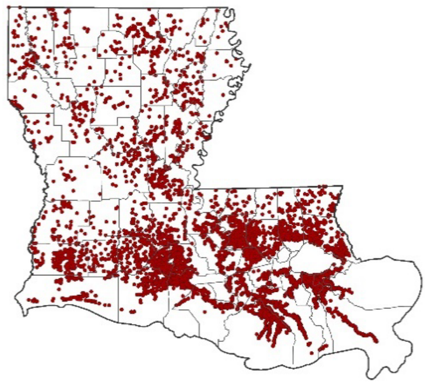

Figure 2. Location of commercial fishing license-holders from 2018-2020 (n=16,849)

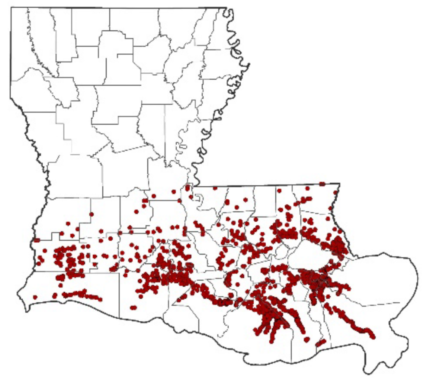

Figure 3. Location of commercial vessels with marine landings from 2018-2020 (n=5,739)

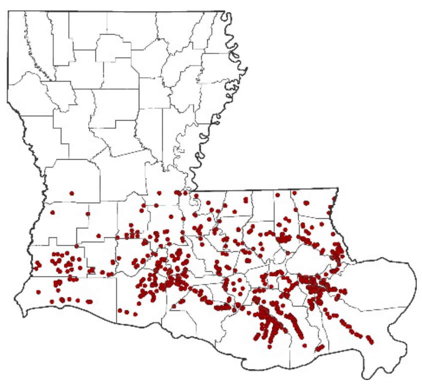

Figure 4. Location of commercial seafood dealers purchasing marine species from 2018-2020 (n=1,129)

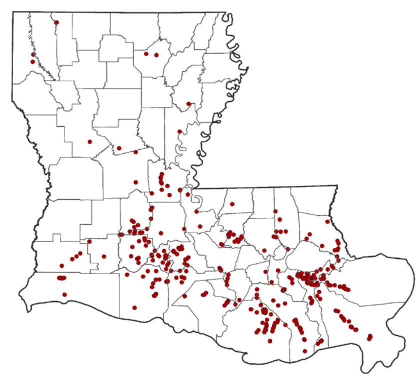

Figure 5. Locations of commercial seafood processors from 2018-2020 (n=473)

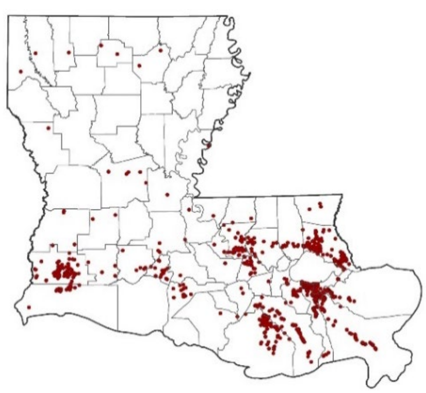

Figure 6. Location of Louisiana-licensed charter boat license holders from 2018-2020 (n=1,031)

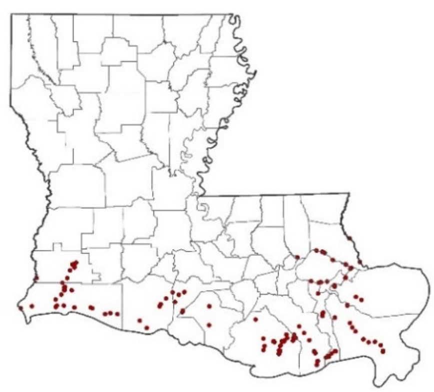

Figure 7. Location of coastal marinas, launches and other areas used in La Creel sampling in 2020 (n=131)

3.2 Surge and Wind Maps

Figure 8 depicts maximum surge elevations for Hurricane Laura as indicated by the final ADCIRC model hind cast obtained from LSU-CERA. Originally developed for storm surge advisory purposes, the ACRIC model performs well in regions with sufficiently mapped topography. For example, a survey team from the NWS in Lake Charles, Louisiana measured a high-water mark from Laura of 17.2 feet above ground level Rutherford Beach, Louisiana (NWS 2021). This measurement is consistent with range of ADCIRC predictions of 16-18 feet of surge for this general location of Cameron Parish.

Figure 9 depicts the maximum sustained wind speeds for Hurricane Laura as predicted by ADCIRC. These predictions track closely to observations from the NWS estimates; however, ADCRIC predictions are developed over spatial contours. Thus, the model is unable to account for embedded mesovortices that can spawn tornadoes in or near a storm's eye wall (Fox 2020). As a result, use of ADCIRC estimated wind speeds imbues a small measure of conservatism in damage modelling.

This characteristic is evident in Figures 10 and 11, which depict maximum surge and winds for Hurricane Ida. The ADCIRC model correctly predicted peak surge elevations ranging from 12 feet on Grand Isle, Louisiana to near 14 feet southeast of Cut off, Louisiana. And while the maximum sustained winds predicted by ADCIRC for Ida are similar to NWS estimates, the model fails to capture locally higher winds - like the 174 mph gust measured by a NOAA meteorological officer in Port Fourchon, LA (Erdman 2021). Despite these constraints, there is no other catalogue of surge elevations and wind speeds (observed or predicted) offering comparable detail for impact modeling. With more than 2 million simulation nodes in the coastal Louisiana grid, ADCIRC provides detailed surge and wind data for each of the 8,503 geocoded locations of fisheries infrastructure depicted in Figures 3-7.

Figure 12 shows the NWS track and ADCIRC surge contours for Hurricanes Delta. While there is contour (impact) overlap with Hurricane Laura, it is likely that most points of fisheries infrastructure in the southwestern region experienced their greatest impacts from Laura, a Category 4 storm versus Delta, a category 2 storm. Conversely, the wind field of Category 3 Hurricane Zeta (Figure 13) shows no overlap with other storms in 2020. While there is some overlap of Hurricane Zeta with Hurricane Ida in 2021, this intersection can be handled in various ways for impact modeling. Section 5 of this report addresses the merits of modeling storms individually or together, by year and region, or modelling all four storms as one event.

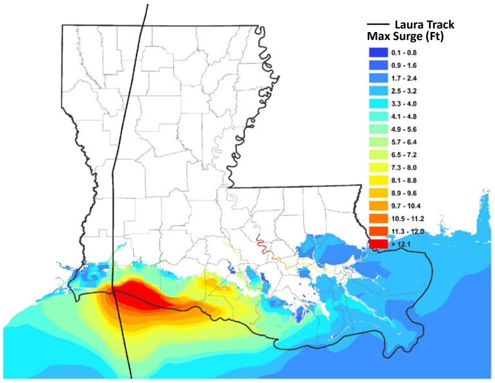

Figure 8. Maximum surge elevation (ft) for Hurricane Laura. ADCIRC hind cast data, LSU-CERA 2020

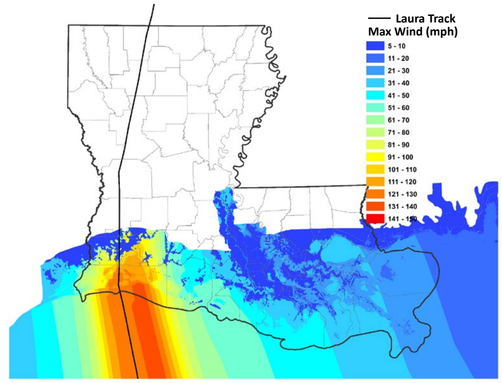

Figure 9. Maximum wind speed (mph) for Hurricane Laura. ADCIRC hind cast data, LSU-CERA 2020

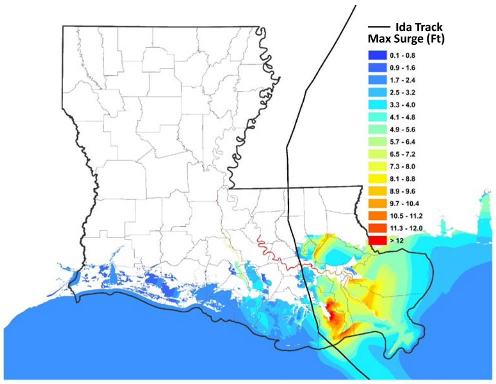

Figure 10. Maximum surge elevation (ft) for Hurricane Ida. ADCIRC hind cast data, LSU-CERA 2021

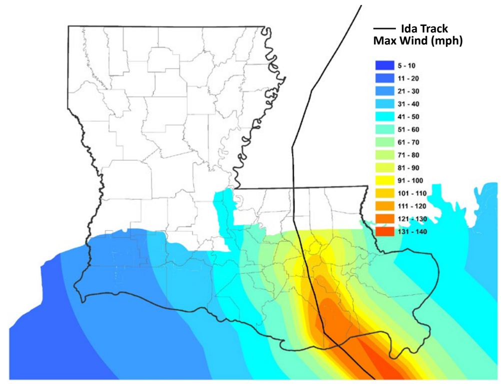

Figure 11. Maximum wind speed (mph) for Hurricane Ida. ADCIRC hind cast data, LSU-CERA 2021

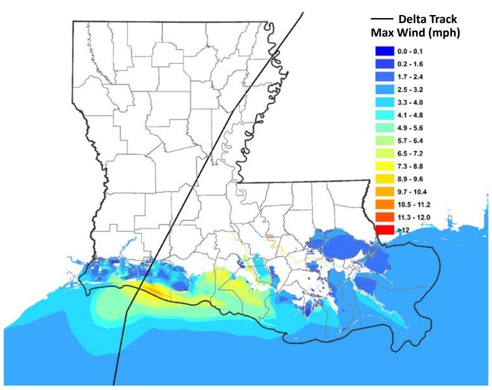

Figure 12. Maximum surge elevation (ft) for Hurricane Delta. ADCIRC hind cast data, LSU-CERA 2020[12]

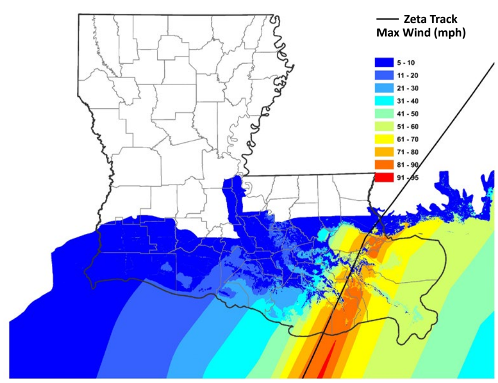

Figure 13. Maximum wind speed (mph) for Hurricane Zeta. ADCIRC hind cast data, LSU-CERA 2020

[12] Surge data for Hurricanes Delta and Zeta, though not shown, were used in all damage modeling.

3.3 Infrastructure Valuation

3.3.1 Vessels

Commercial vessels and seafood dealers identified in the study were limited to "active firms" that had submitted one or more trip ticket records during the baseline years 2018-2020 (LDWF 2021). With this criterion in place, more than two million transaction records were sorted by LDWF to produce individual estimates of average annual gross revenue for active vessels and dealers. Net income percentages of 5-10% and capitalization rates of 5-15% were applied based on published reports focused on the cost and earnings of Louisiana's inshore and offshore harvesting and seafood dealer operations (Miller and Isaacs 2014; Miller, Isaacs, and Bharadwaj 2014; Liese 2014; NMFS 2021).

Table 2 contains a list of revenues and sample valuations for 5,560 Louisiana commercial fishing vessels. Data are sorted by three categories of revenue to reflect the economic structure of the sector. Vessels categorized as "low" revenue had less than $25,000 per year in reported sales and an average length of 25 feet. Though smallest in revenue and size, these 3,250 vessels accounted for more than half (57%) of the active fleet, yet only 7% of the annual value of landings. An additional 2,044 vessels categorized as "medium" revenue had $25,000-$150,000 per year in reported sales and an average length of 30 feet. These vessels accounted for 36% of the active fleet and 39% of the annual value of landings. Finally, 366 vessels categorized as "high" revenue had more than $150,000 per year in reported sales and an average length of 40 feet. These vessels accounted for only 6% of the active fleet, but more than half (54%) of the annual value of landings. This high revenue category likely contains many of the vessels operating under the limited access permit for commercial shrimp harvesting. Three hundred and forty-three of these federally permitted vessels were located in Louisiana in 2020 (NMFS 2020).

The sample valuations of Table 2 include estimates from the income capitalization method (equation 1) and ranged from an average of $3,721 for low revenue vessels to an average of $476,822 for high revenue vessels. The low end of this appraisal range is a result of two factors: 1) the method's exclusive reliance on annual revenue for business appraisal[13]; and 2) the relatively low net incomes documented in the commercial fisheries harvesting sector[14]. For these reasons, an alternative valuation can be used based on the secondary market for commercial fishing vessels. Fair market value estimates for commercial vessels are regularly estimated using physical attributes such as a vessel's age, hull length, construction material, propulsion type and horsepower.

[13] Data from LDWF on active vessels included a large number of entries with five or less trip ticket transactions.
[14] Net income levels for Louisiana's largest fisheries harvesting sector by value (shrimp) have remained very low in the past three decades due to increasing input costs and declining dockside prices due to import competition.

Table 2. Revenues and approximated values of Louisiana commercial fishing vessels

	All	Low <$25K/year	Medium $25K-$150K/year	High >$150K/year
Number of active vessels (#)	5,660	3250	2044	366
Percent of active vessels (%)	100%	57%	36%	6%
Avg. length (feet)	27	25	30	40
Total revenue ($/year/category)	$324,019,196	$24,185,394	$125,316,802	$174,517,000
Percent of total revenue (%)	100%	7%	39%	54%
Revenue (avg. $/year/firm)	$57,247	$7,442	$61,310	$476,822
Revenue (max $/year/firm)	$7,288,505	$24,987	$149,921	$7,288,505
Income capitalization (avg.$/firm)*	$28,624	$3,721	$61,310	$476,822
Length-value method ($/firm)	$51,239	$39,269	$80,434	$134,110
Difference (%)	79%	955%	31%	-72%
Sector valuation (total $)	$344,925,623			

* Based on LDWF revenue data for 2018-2020, and an assumed 5% net income and 10% cap rate

In anticipation of the need for a supplemental valuation, these attributes were requested along with the vessel revenue data acquired from LDWF. Many of these attributes, however, were missing in the acquired data - likely because provision of such detail is voluntary during the vessel registration process. Fortunately, the one descriptor readily available, length, is a reliable determinate of market value.

Figure 14 depicts a power function in which a vessel's length is used to estimate its value. Data for this model were obtained from advertised prices for commercial vessels obtained from previous studies and surveys. All prices were adjusted to 2020 dollars {n=207, $y=16.082(\text{length})^{2.3779}$, R^2=.69}.

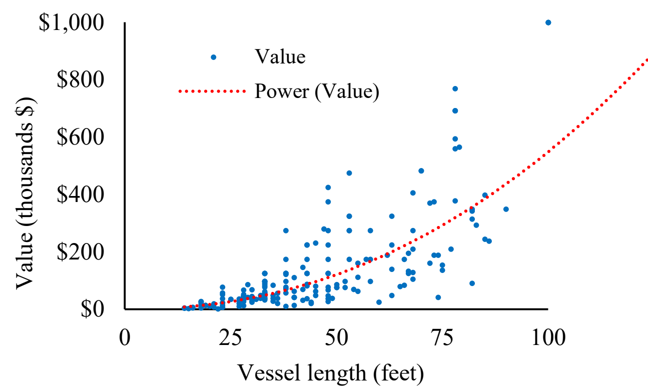

Figure 14. Value of Louisiana commercial fishing vessels as a function of length

Sample valuations of Table 2 based on this vessel market model ranged from an average of $39,269 for low revenue vessels to an average of $134,110 for vessels in the high revenue category. Compared to the income capitalization method, the length-value regression yields nearly 10x higher values for smaller vessels (955%), yet substantially lower appraisals for large sized vessels (-72%). For this reason, baseline values for a given vessel record are chosen as the maximum value of these two methods. Under this approach, the total business valuation of these commercial vessels is estimated to be $344.9 million.

3.3.2 Dealers

Table 3 contains average revenues and sample valuations for 1,042 seafood dealers. Seventy-seven percent of dealers (805) reported revenues less than $100,000 per year and accounted for 4% of sector income. These businesses are appraised at $10,046 (average) and $78,598 (maximum). An additional 106 are categorized as "medium" dealers, with sales of $100,000-$500,000 and accounting for 10% of sector revenues. Medium dealers had estimated values of $214,271 (average) and $391,232 (maximum). Only 12% (129) firms had sales exceeding $500,000 per year, but they accounted for 86% of sector revue. Income-based appraisals for these larger firms averaged $1.52 million and ranged to $9.3 million. Under this approach, the total business valuation of these commercial dealers is estimated to be $228.5 million.

Table 3. Revenue and approximated values of Louisiana commercial seafood dealers

	All	**Low** <$100K/year	**Medium** $100K-$500K/year	**High** >$500K/year
Number of active dealers (#)	1,042	805	106	129
Percent of active dealers (%)	100%	77%	10%	12%
Total revenue ($/year/category)	$285,649,241	$10,109,224	$28,443,889	$246,481,621
Percent of total revenue (%)	100%	4%	10%	86%
Revenue (avg. $/year/firm)	$274,136	$12,558	$268,339	$1,910,710
Revenue (max $/year/firm)	$11,639,994	$98,248	$489,040	$11,639,994
Income capitalization (avg. $/firm)*	$219,308	$10,046	$214,671	$1,528,568
Income capitalization (max $/firm)*	$9,311,995	$78,598	$391,232	$9,311,995
Sector valuation (total $)	$228,519,393			

* based on 8% net income and 10% cap rate

3.3.2.1 Bait Sales

A small portion of the revenues reported by seafood dealers consist of income from the sale of live fishing bait. Sale of live bait in Louisiana is managed under a special permit program managed by LDWF. Figure 15 shows the most common species sold under this permit. Live bait sales reported by 41 firms in the dealer data set averaged $942,580 for years 2018-2020. Developing separate valuations (and damage assessments) for bait sales at the firm level is not possible due to the nested aspect of the data. No detailed cost-return studies are available for this subsector, but given the mark-up on live bait, it is plausible that the aggregate value of bait businesses in the state ranges from $2-4 million annually.

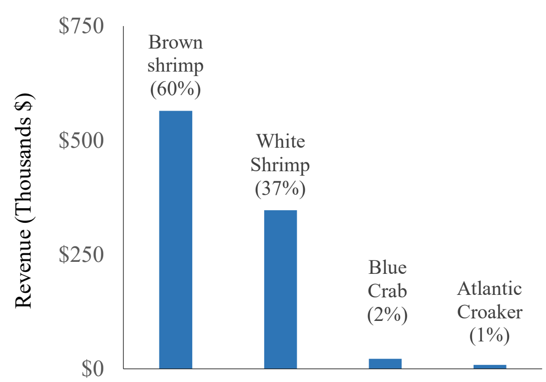

Figure 15. Values for Common bait species sold under live permits in coastal Louisiana

3.3.3 Processors

Commercial seafood processors were identified from a list of firms permitted by LDH in 2020. Gross revenues for each firm were extrapolated by taking the midpoint of annual revenue ranges associated with annual fees paid by each firm to LDH: $150 ($1,000,000 and under); $250 ($1,000,001 - $2,500,000); $350 ($2,500,001 - $5,000,000); and $500 (over $5,000,000). Net incomes were obtained from published and unpublished studies of seafood processor returns in Louisiana (NMFS 2021; Lively et al. 2020).

Table 4 contains permit-attributed revenues and sample valuations for 472 seafood processors. Data are sorted by three categories to reflect the economic structure of the sector. Seventy-three percent of the sector is comprised of firms with revenues under $1 million in annual sales. Processors with revenues greater than $1 million, but less than $5 million in annual is sales, make up another 17% of firms. The top 10% (48 processors) account for 39% of annual sector revue. Business valuations using these data range from $450,000 to $4.5 million annually. Under this approach, the total business valuation of these commercial processors is estimated to be $548.5 million.

Table 4. Approximate valuation of Louisiana commercial seafood processors

	All	**Low** <$1M/year	**Medium** $1 -4.99 M/year	**High** >$5M/year
Number of processors (#)	472	346	78	48
Percent of processors (%)	100%	73%	17%	10%
Total revenue ($/year/category)	$609,000,000	$173,000,000	$196,500,000	$240,000,000
Percent of total revenue (%)	100%	28%	32%	39%
Revenue (avg. $/year/firm)	$1,291,314	$500,000	$2,519,231	$5,000,000
Income capitalization (avg. $/firm)*	$1,163,691	$450,000	$2,267,308	$4,500,000
Sector valuation (total $)	$548,550,000			

* based on 9% net income and 10% cap rate

3.3.4 Charters

Charter fishing licenses were identified by LDWF license records for the years 2018-2020. Given no sales data are collected for this sector, vessel class structure, gross revenues, and net revenues were extrapolated from existing surveys of cost and earnings of the charter sector in Louisiana (Savolainen, Caffey and Kazmierczak 2011; Savolainen, Fannin and Caffey 2014; Caffey et al. 2019, Lively et al. 2020). Sample data from these studies were converted to 2020 dollars and extrapolated to the baseline population using a single, weighted revenue level created from the economic performance of three operating classes.

Table 5 contains survey-attributed revenues and sample valuations for 1003 licensed charter operators residing in coastal Louisiana parishes during the period 2018-2020. Consistent with cited research, the charter fleet for these individuals is assumed to continue being dominated by small charter boat operations (88%), averaging 23 feet and 3 passengers per trip. With 2020-adjusted gross revenues of $50,920, these 886 operators are assumed to account for 74% of total sector revenue. An additional 115 (12%) operations in the Louisiana fleet are assumed to be offshore-capable vessels averaging 32 feet, with an average trip featuring five customers and one deckhand. These medium-scale operations have a 2020-adjusted gross revenue of $129,601 and account for 25% of total sector revenue.

The largest and least numerous category of recreational-for-hire vessels in Louisiana is head boat operations. As many as six head boats have operated out of Louisiana ports in a given year, but only three were in service at the time these baseline data were collected. These vessels have a larger average size (57 feet) and average capacity (13 passengers), but account for only 1% of annual sector revenue. Taken together, the revenue ranges for these three classes translate to income-based business valuations of $127,300 to $722,970. For the purpose of this analysis, however, all 1003 operations are attributed the weighted income valuation of $151,191. While this weighted constant both underestimates and overestimates individual businesses, it is the only recourse for valuation given data limitations. Under this approach, the total business valuation of these charter operations is estimated at $151.6 million.

Table 5. Approximate valuation of Louisiana charter boat operations.

	All	Small Charter	Medium Charter	Head Boat
Number of charters (#)	1,003	886	114	3
Percent of charters (%)	100%	88%	11%	0.3%
Avg. length (feet)	*	23	32	57
Avg. passengers (# of angler/trip)	*	3	5	13
Avg. Deckhands (#/trip)	*	0	1	1.5
Total revenue ($/year/category)**	$60,657,842	$45,097,247	$14,948,827	$578,376
Percent of total revenue (%)	100%	74%	25%	1%
Revenue (avg. $/year/firm)	$60,476	$50,920	$129,601	$289,188
Income capitalization (avg. $/firm)*	$151,191	$127,300	$324,003	$722,970
Sector valuation (total $)	$151,644,606			

* all data based on Savolainen et al. 2014 (adjusted to 2020 dollars). Valuations based on 25% net income and 10% cap rate
** weighted revenue accounting for half, full and multi-day trips.

3.3.5 Marinas

Coastal Marinas in the study were identified by LDWF through its recreational landings data collection program (La CREEL). Given no annual sales data are collected for marinas, valuations were based

primarily on two surveys: a 2009 survey of cost and earnings of Louisiana's coastal marinas (Isaacs 2011), and a 2020 survey that collected quarterly marina revenues as part of a study of Covid-19 impacts on fishing-related businesses in Louisiana (Lively et al. 2020). Sample data from the 2009 survey were adjusted to 2020 dollars and compared with data from the 2020 survey. From these two sources, eight categories of marina revenue were identified ranging from $25,000 to $7,500,000 per year. Twenty-five percent of the revenue attribution for the La CREEL population was based on actual revenues reported in 2020 by survey participants. Revenue attribution for the remaining firms was categorized from descriptive information available of on commercial websites and site characteristics remotely observed via Google Earth Pro (version 7.3).

Table 6 contains attributed revenues and sample valuations for 69 marinas in coastal Louisiana. Based on survey-attributed revenues, 27 of these marina operations (39%) are assumed to have revenue less than $100,000 annually in sales. These small operations include private, fee-based launches, some with limited amenities (e.g. convenience food, ice, live bait, and light tackle). An additional 31 (45%) of coastal marinas have revenues ranging from 100,000 to $2.5 million in annual revenues. These mid-tier facilities offer a range of additional amenities including fee-based dockage, restaurants, and limited lodging.

The largest operations include 11 multi-service marinas generating $2.5 to $7.5 million in annual sales. These marinas offer a wide range of services including short- and long-term mooring, vessel storage, retail, restaurants and multi-unit lodging. Taken together, these marina revenue ranges translate to income-based business valuations of $87,500 to $11.25 million. Valuations below or above these bounds are not possible to show because of the attribution of revenues from categorical survey data. Under this approach, the total business valuation of these marinas is estimated at $91.7 million.

Table 6. Approximate valuation of Louisiana coastal marinas

	All	**Low** <$100K/year	**Medium** $100K - $2.5M/year	**High** >$2.5 M/year
Number of marinas (#)	69	27	31	11
Percent of marinas (%)	100%	39%	45%	16%
Total revenue ($/year)	$61,175,000	$1,575,000	$22,100,000	$37,500,000
Percent of total (%)	100%	3%	36%	61%
Revenue (avg. $/year)	$886,594	$58,333	$712,903	$3,409,091
Revenue (max $/year)	$7,500,000	$87,500	$1,250,000	$7,500,000
Income capitalization (avg. $)*	$1,329,891	$87,500	$1,069,355	$5,113,636
Income capitalization (max $)*	$11,250,000	$131,250	$1,875,000	$11,250,000
Sector valuation (total $)	$91,762,500			

* based on 15% net income and 10% cap rate

3.4 Industry Surveying

3.4.1 General Responses

Responses to the electronic survey of Louisiana fishing businesses included 15% returns from email and 85% from web respondents. Of the original 639 email solicitations, 112 were returned for a response rate of 17.5 percent. An additional 656 responses were obtained from the web-based survey. After parsing for non-consent, panel tests, aborted surveys[15] and duplicate responses, 516 useable surveys were obtained. Of these, 371 (72%) were fully completed[16]. Responses ranged from 508 (98%) to the first question regarding storm of record to 163 (21%) to the last question regarding final comments. Data from each survey was tagged by mode (web or email) and combined into a single database for analysis.

Respondents were asked to identify the one most damaging hurricane during the 2020 and 2021 seasons. This question allowed for subsequent parsing of storm-specific data (Figure 16). Given the timing of the survey and the higher population of the southeast coastal region, it is not surprising that a most respondents selected Hurricane Ida (88%), followed by Laura (8%), Zeta (3%) and Delta (1%). Distribution of business categories (Figure 17) appeared to be in line with the actual population, with harvesters accounting for a plurality of responses (48%), followed by charters (22%), dealers (14%), processors (6%) and marinas (2%). An "other" category was chosen by 10% of respondents, but no details were collected on other business types. Distribution of primary commodities for respondents with seafood-oriented business (Figure 18), included shrimp (54%), crab (25%), oyster (14%) and marine finfish (4%).

When asked about the effects of the storms on their personal residences (Figure 19), 34% indicated that they had not been displaced, but their homes had received some level of damage. Other respondents indicated being displaced one week (7%), 2-4 weeks (33%) and up to 12 months (6%). A fifth of respondents (20%) indicated they were still displaced from their homes. Nearly half (49%) indicated that their home was less than 5 miles from their business[17] (Figure 20), with others indicating they lived 6-20 miles (19%), 21-50 miles (19%) or more than 50 miles away (13%). To gauge impacts to their business infrastructure, respondents were asked to indicate the types of assets affected by the storms (Figure 21). Equipment was the most frequently listed asset damaged by the storms (73%), followed by supplies (58%), buildings (57%), vessels (50%), inventory (41%), other assets (35%) and motor vehicles (23%).

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[15] A large number of surveys were initiated but aborted after viewing the cover letter - which indicated that the survey was only for commercial owners and operators of fishing related businesses. It is likely that many of these individuals were private anglers or other non-commercial interests.

[16] Given that none of the questions were mandatory, response rates varied by question.

[17] Of this group, 68% indicated their business and residence were the same location.

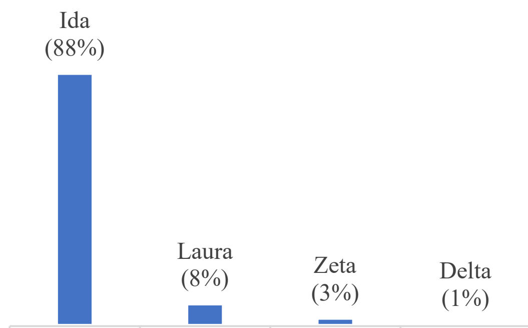

Figure 16. Primary storm of impact
(% of respondents)

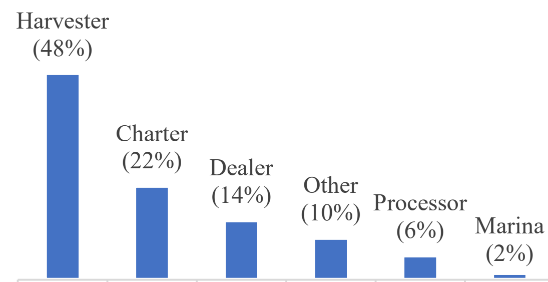

Figure 17. Primary business category
(% of respondents)

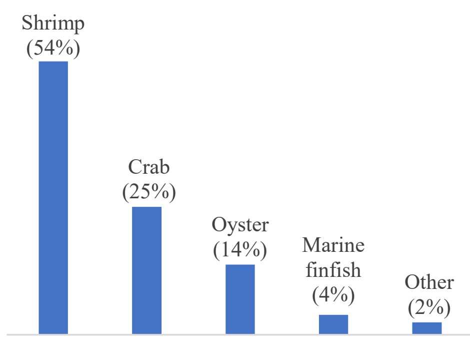

Figure 18. Primary seafood commodities
(% of respondents)

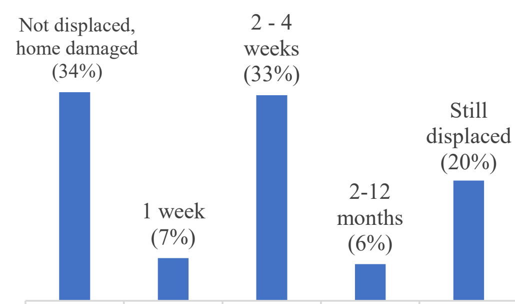

Figure 19. Time displaced from personal residence due to the 2020-2021 Hurricanes (% of respondents)

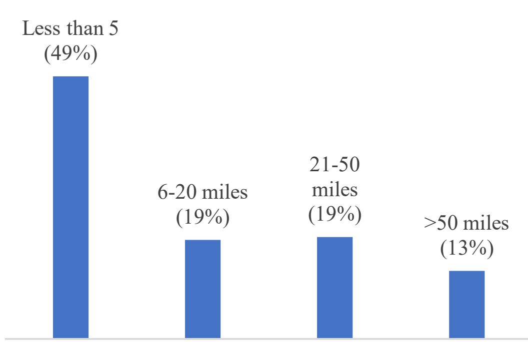

Figure 20. Estimated distance from personal residence to business (% of respondents)

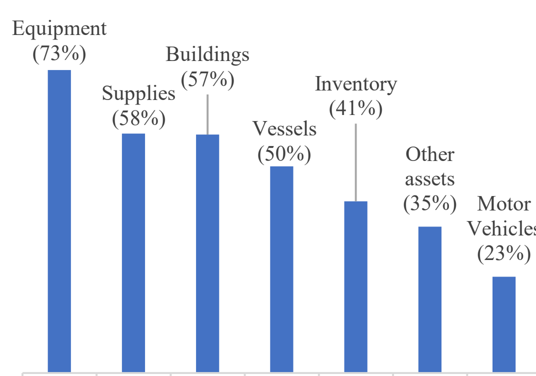

Figure 21. Business assets affected by the 2020-2021 Hurricanes (% listed by respondents)

Figure 22 depicts the results of a follow-up question to the 50% of respondents listing “vessels’ as part of their storm-impacted assets. Recognizing that many firms have more than one vessel, participants were asked to estimate the fair market value of their “primary vessel”, or the one responsible for the largest portion of their business activities. Offshore shrimp harvesting vessels had the highest average value at $375,011, followed by offshore charter vessels ($130,625), inshore shrimp vessels ($102,591), inshore charter vessels ($76,974), oyster vessels ($73,472), bait vessels ($55,000) and crab vessels ($50,658).

These vessels vary in size from 18 to 100 feet, presenting a range of opportunities and constraints in terms of pre-storm evacuation (Figure 23). More than a third (36%) were not moved prior to the storm while 58% were moved distances ranging from 1-50 miles. A small portion (6%) were moved more than 50 miles. Three size classes of vessels were examined to determine which ones were most likely to stay or evacuate. No clear differences in the tendency to stay or evacuate were found between small vessels (up to 25 feet), medium vessels (26-40 feet) and large vessels (greater than 40 feet).

Figure 24 provides average values of business types prior to the storm of record. In question 20, participants were asked to provide fair-market value estimates of their business, including the combined value of all vessels, vehicles, buildings, equipment, supplies and inventory. At $1,282,082, the average survey-derived estimate for processors is within 10% of the income-capitalized appraisal of processors (Table 4). At $413,182 and $816,875 the average respondent value for charters and marinas (respectively) is similar to mid-tier appraisals for these business (Table 5 and 6). The average dealer valuation from the survey ($786,474) is between the medium- to high-valued dealer appraisals (Table 3). The average harvester business from the survey is valued at $232,093, which is below the highest income capitalized values for harvesters (Table 2), but above the value for an appraised vessel length at 40 feet. [18]

In question 21, participants were asked to indicate total dollar damages to their firms from the storm of record.[19] Dividing these damages by a firm’s value generates a percentage loss (Figure 25). Imputed losses ranged from an average of 44% for dealers to 31% for charter operations. When asked if they had sufficient insurance to cover these losses (Figure 26), a large majority (75%) had none, and only 10% said that 50% or more of their losses were covered. In terms of lost work (Figure 27), 63% indicated they had lost anywhere from 2 weeks (20%) to 1-2 months of work (43%). Twenty-three percent indicated they had lost 3-4 months of work. Six percent indicated they had lost, or expected to lose, 5-6 months and 5% indicated they had lost, or expected to lose more than 6 months of work.

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[18] The length of the primary vessel by those harvester respondents providing a firm-level valuation was 38 feet.
[19] Questions 20 and 21 used drop-down menus with 30 ranges of firm market value and 40 ranges of asset loss.

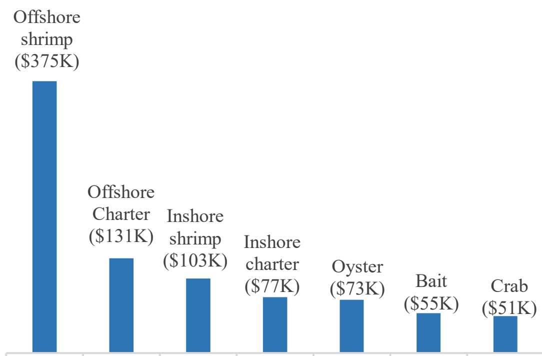

Figure 22. Average value of primary vessels as estimated by respondents ($ thousands)

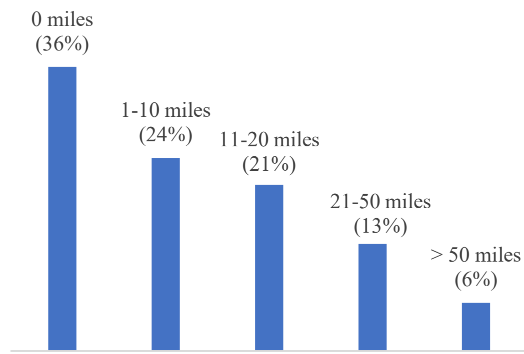

Figure 23. Evacuation distances for all types of primary vessels (% of all respondents)

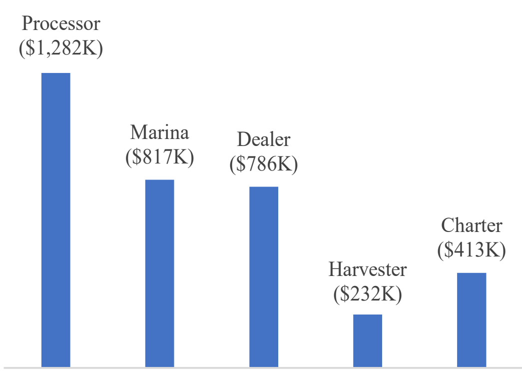

Figure 24. Average business values estimated by respondents ($ thousands)

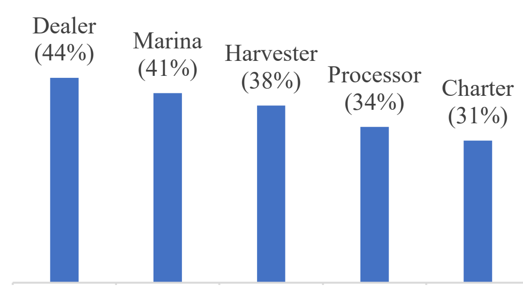

Figure 25. Average business damages estimated By respondents (% of value loss)

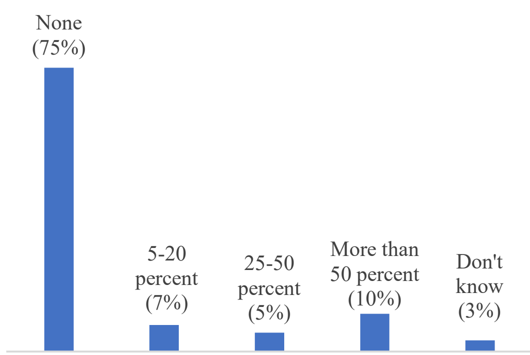

Figure 26. Estimated coverage of hurricane damage to business (% of respondents)

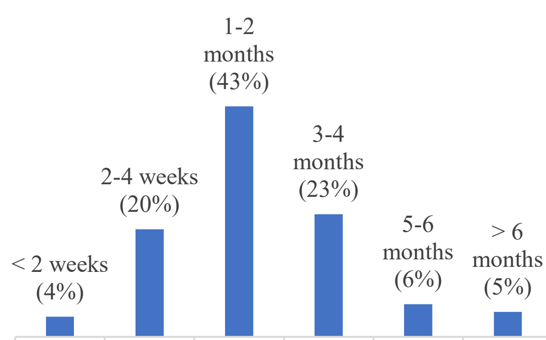

Figure 27. Days of work lost due to the 2020-2021 Hurricanes (% of respondents)

3.4.2 Damage Curves: Infrastructure

As indicated in equations 2-7, the primary purpose of the industry survey was to obtain the sample data needed to develop functional relationships (damage curves) between loss estimates and meteorological data. Figures 28 and 29 contain simple regression lines fit to respondent generated estimates of asset loss, maximum surge elevation, and maximum wind speed.[20] While the raw data appear to lack structure, an increasing trend is evident when the data are averaged for every 1-foot of elevation (Figure 30) and every 25 mph of wind (Figure 31). With intercepts set to zero, two equations emerge for estimating linear damage coefficients:

$$Z^i = 0.0419s \qquad \text{Eq .8}$$

and

$$Z^i = 0.0027w \qquad \text{Eq .9}$$

where Z^i is the geographically specific damage factor (% loss of value) for firm *i*, and *s* is the maximum surge elevation at a given firm location derived from the ADCIRC model for a given storm, and *w* is the maximum wind speed at a given firm location derived from ADCIRC model for a given storm.

Figures 31 and 32 depict the results of nonlinear, sigmoidal models relating asset damage to different levels of surge elevation and wind speed.

$$Z^i = 1 * ((1 - \exp * (-0.010 * s^{2.08})) \qquad \text{Eq .10}$$

and

$$Z^i = 1 * ((1 - \exp * (-0.35\text{E-}11 * w^{5.0})) \qquad \text{Eq .11}$$

where Z^i is the geographically specific damage factor (% loss of value) for firm *i*, and *s* and *w* are maximum surge and wind (respectively) as estimated by the ADCIRC model for a given storm.

[20] Additional analysis is required to compare survey-generated estimates of surge and wind to those generated by the ADCIRC model for a given location. While there is potential for respondent exaggeration of surge and wind, such overestimation would imbue a measure of conservatism in the estimation of damages. If ADIRC-generated estimates of surge and wind are lower (for a given location and estimate of loss) any resulting rectification would serve to increase the level of damages expected at lower surge elevations or lower wind speeds, thereby increasing economic loss. For this reason, and due to time constraints, the damage functions developed in this section are based on respondent-estimated levels of maximum surge and wind at their location for a given storm.

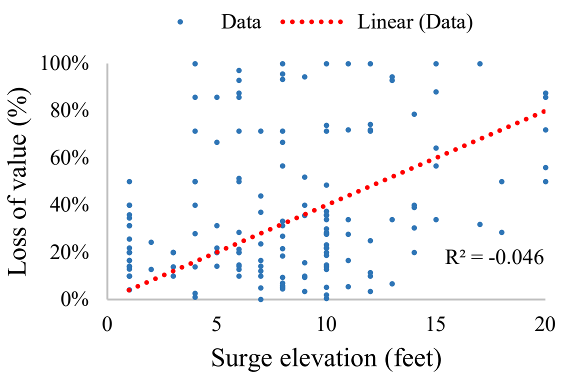

Figure 28. Individual business damages at maximum surge depths indicated by survey respondents

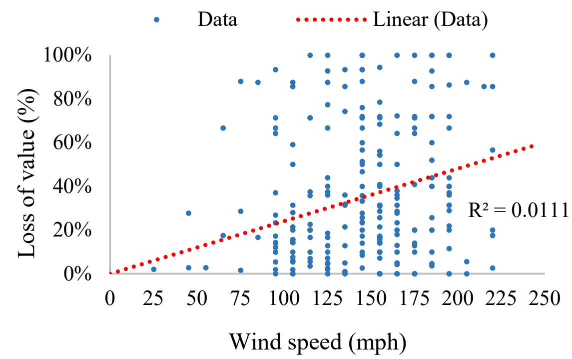

Figure 29. Individual business damages and maximum wind speeds indicated by survey respondents

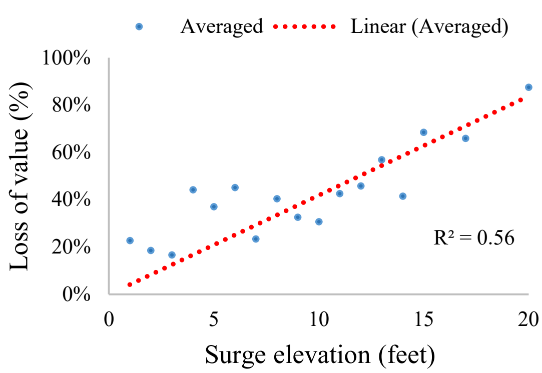

Figure 30. Average linear asset losses per one foot increment of surge indicated by survey respondents

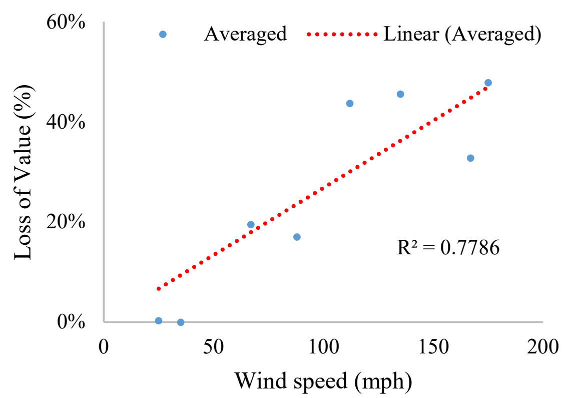

Figure 31. Average linear asset losses per 25 mph increment of wind speed indicated by respondents

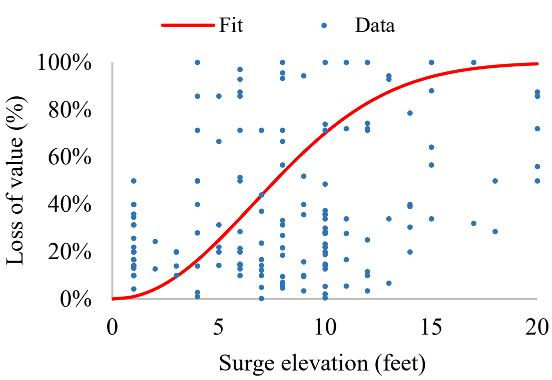

Figure 32. Non-linear damage curve fit to maximum surge depths indicated by survey respondents

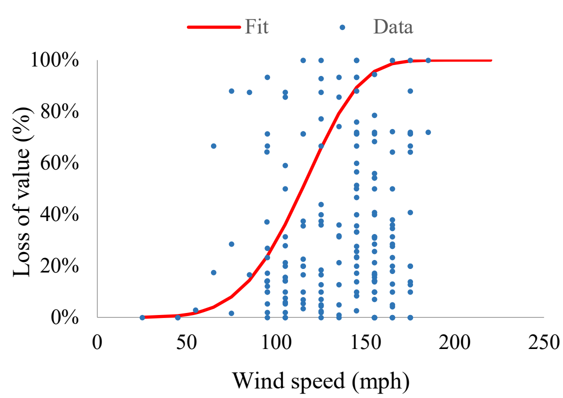

Figure 33. Non-linear damage curve fit to maximum wind speeds indicated by survey respondents

3.4.3 Loss Curves: Revenue

Questions 24, 25, and 26 asked participants to estimate revenue losses for their business. Selections were provided through a drop-down menu with 22 options in 5% increments of loss ranging from 0 to 100%. Depending on the storm of record, a respondent was either asked to estimate revenue losses for the two years 2020 and 2021 (for Hurricanes Laura, Delta or Zeta), or for the two years 2021 and 2022 (for Hurricane Ida). Modifying equation 2, storm-related revenue losses are given by:

$$R^{it} = GR \times Z^{i} \quad \text{Eq .12}$$

Where R^{it} is the revenue loss for firm i in year t, and Z^{i} is a geographically specific revenue loss factor. Figure 34 depicts linear functions for each of these years based on respondent estimates of maximum wind speed at their business location. With intercepts set to zero, linear equations for revenue losses are estimated for each year:

2020 $Z^{i} = 0.0035w$ Eq .13

2021 $Z^{i} = 0.0034w$ Eq .14

2022 $Z^{i} = 0.0020w$ Eq .15

Where Z^{t} is the revenue loss and w is the maximum wind speed at a given firm location derived from ADCIRC model for a given storm. Likewise, Figure 35 depicts nonlinear, sigmoidal models in which revenue losses in each of the three years are given by:

2020 $Z^{i} = 1 * ((1 - \exp * (-0.35\text{E-}11 * w^{4.8}))$ Eq .16

2021 $Z^{i} = 1 * ((1 - \exp * (-0.35\text{E-}11 * w^{4.77})))$ Eq .17

2022 $Z^{i} = 1 * ((1 - \exp * (-0.35\text{E-}11 * w^{4.6}))$ Eq .18

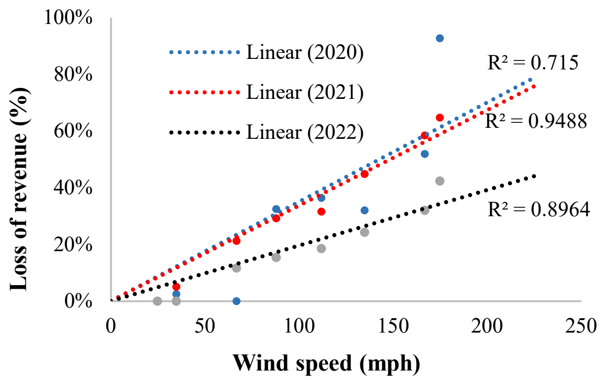

Figure 34. Average revenue losses per 25 mph increment of maximum wind indicated by respondents

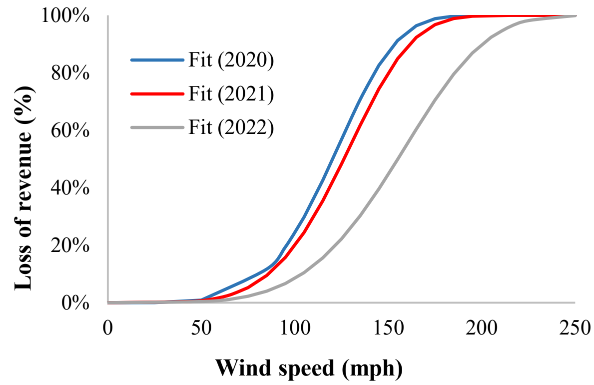

Figure 35. Nonlinear revenue losses for maximum wind speeds as indicated by survey respondents

These six revenue loss curves were applied to data provided from LDWF on the average value of commercial landings by parish and by species group for the years 2018-2020. This baseline data allowed for the aggregation of revenue loss projections for major commodity groups. As the final section of this report will show, wind was the primary causal factor in damages to fishing related business from the Hurricanes of 2020-2021. For this reason, a set of corresponding revenue loss curves was not estimated for maximum surge levels.

3.5 Biological Surveying

In the wake of Hurricane Ida, field biologists in the marine fisheries section of LDWF conducted a variety of sampling measures in an effort to estimate natural resource losses from Hurricane Ida. Tables 7 and 8 include a summary of those findings for oyster and finfish losses, respectively. Additional details regarding the resource loss methodology for finfish are contained in Appendix C.

Table 7. Estimated Oyster Resource Losses from Hurricane Ida

Sector	Estimated % Mortality	Estimated Value of Loss
Public Grounds	80%	$6,376,698
Private Leases	80%	$44,469,843
Total		$50,846,541

Table 8. Estimated Finfish Resource Losses from Hurricane Ida

Species	Total Number	Restitution Value	Total
Sunfish	4,448,178.00	$0.91	$4,047,842
Largemouth Bass	2,310,294.00	$13.43	$31,027,248
Suckers	137,928.00	$0.62	$85,515
Gars	620,676.00	$1.74	$1,079,976
Catfishes	482,748.00	$0.97	$468,266
Red Drum	241,374.00	$26.47	$6,389,170
FW Drum	34,482.00	$0.32	$11,034
Bowfin	137,928.00	$2.01	$277,235
Black Crappie	448,266.00	$5.37	$2,407,188
Mullet	1,310,316.00	$1.00	$1,310,316
Shads	1,275,834.00	$0.40	$510,334
Spotted Seatrout	34,482.00	$28.97	$998,944
Carps	137,928.00	$0.25	$34,482
Shiners	172,410.00	$0.62	$106,894
Silversides	68,964.00	$0.62	$42,758
Anchovies	34,482.00	$0.62	$21,379
Total			**$48,818,581**

3.5 Integration and Assessment

3.5.1 Model variables

Results from sections 3.1-3.4 were integrated into a single spreadsheet with 46 attributes, and were collected or generated for each of the 8,503 fisheries-related businesses identified by LDWF and LDH records (Table 9). The integrated file contains more than 300,000 original or attributed data points.

A master worksheet (Table 10) with all control variables and model coefficients is used to actuate more than 600,000 firm-level calculations across 24 integrated worksheets.[21] Net income and capitalization rates are combined with firm-specific or sector-attributed revenues to assign a baseline valuation for all geocoded firms. Ten linear and nonlinear damage curves influence the degree to which the asset values of firms and the annual revenues of commodities are affected by different levels of surge and wind.[22] Two final control variables added to the model provide a range of minimum observations below which no damages are allowed to accrue.[23] The minimum depth range for storm surge is set at 0.5 - 2 feet. The minimum speed for wind ranged from 40-75 mph.

[21] For each category of business, the infrastructure damage model was replicated for three periods: 2020, 2021 and 2020-21 combined.
[22] Estimating damage and loss curves separately for each sector was beyond the scope of this assessment.
[23] Minimum controls prevent damage calculations below inconsequential levels of surge or wind.

Table 9. Variables used for estimating damage to fisheries businesses from the Hurricanes of 2020-2021

#	Variable	Description	Source
1	Category1	Type of infrastructure	LDWF, LDH
2	Category1	Subtype	LDWF, LDH
3	Address1	Street	LDWF, LDH
4	Address2	City	LDWF, LDH
5	Address3	State	LDWF, LDH
6	Address4	Zip	LDWF, LDH
7	Latitude	Geocoded coordinate	Study-generated
8	Longitude	Geocoded coordinate	Study-generated
9	Parish	GIS referenced	Study-generated
10	Model Year	Vessel constant	LDWF, for vessels only
11	Length (inches)	Vessel constant	LDWF, for vessels only
12	Length (ft)	Vessel Formula	Study-generated
13	Propulsion	Vessel constant	LDWF, for vessels only
14	Laura Max Surge (ft)	ADCIRC estimate	LSU CERA
15	Delta Max Surge (ft)	ADCIRC estimate	LSU CERA
16	Zeta Max Surge (ft)	ADCIRC estimate	LSU CERA
17	Ida Max Surge (ft)	ADCIRC estimate	LSU CERA
18	Max Surge1 (ft)	Formula	Study-generated
19	Max Surge2 (ft)	Formula	Study-generated (minimum 0.5-2.0 feet)
20	Laura Max Wind (mph)	ADCIRC estimate	LSU CERA
21	Delta Max Wind (mph)	ADCIRC estimate	LSU CERA
22	Zeta Max Wind (mph)	ADCIRC estimate	LSU CERA
23	Ida Max Wind (mph)	ADCIRC estimate	LSU CERA
24	Max Wind1 (mph)	Formula	Study-generated
25	Max Wind2 (mph)	Formula	Study-generated (minimum 40-75 mph)
26	Vessel revenue (avg. $/yr)	Primary data	LDWF, 2018-2020
27	Dealer revenue (avg. $/yr)	Primary data	LDWF
28	Dealer bait revenue (avg. $/yr)	Primary data	LDWF, for dealers only (shrimp, crab, croakers)
29	Processor revenue (avg. $/yr)	Fee attributed	LDH permit fees and operational classes
30	Charter revenue (avg. $/yr)	Weighted constant	Published studies and surveys
31	Marina revenue (avg. $/yr)	Survey attributed	Published studies and surveys
32	Net income (%)	Rate	Published studies and surveys
33	Cap rate (%)	Rate	Published studies and surveys
34	Cap value ($)	Rate	Study-generated
35	Vessel value ($)	Function	Study-generated
36	Vessel evacuation rate (%)	Rate	Study-generated (from industry survey) (10-30%)
37	Linear surge loss (%)	Equation 8	Study-generated (from industry survey)
38	Linear wind loss (%)	Equation 9	Study-generated (from industry survey)
39	Linear surge loss ($)	Formula	Study-generated
40	Linear wind loss ($)	Formula	Study-generated
41	Linear max loss($)	Formula	Study-generated
42	Nonlinear surge loss (%)	Equation 10	Study-generated (from industry survey)
43	Nonlinear wind loss (%)	Equation 11	Study-generated (from industry survey)
44	Nonlinear surge loss ($)	Formula	Study-generated
45	Nonlinear wind loss ($)	Formula	Study-generated
46	Nonlinear max loss ($)	Formula	Study-generated

Table 10. Model control variables and coefficients

Sector	Net income rate (%)	Income cap rate (%)	Assets: Linear damage slope (b_1)*	Assets: Nonlinear damage slope (*n*)	Revenues: Linear damage slope (b_1)	Revenues: Nonlinear damage Slope (*n*)	Min. surge height for damage (feet)	Min. wind speed for damage (mph)
Commercial Vessels†	5-10%	10-15%	0.0419(s) 0.0027(w)	1.9-2.2 (s) 4.8-5.0 (w)	0.0034(w) 0.0034(w) 0.002(w)	4.8-4.5(w) 4.8-4.5 (w) 4.5-4.7 (w)	0.5-2.0	40-75
Seafood Dealers	5-12%	5-15%	0.0419(s) 0.0027(w)	1.9-2.2 (s) 4.8-5.0 (w)	0.0034(w) 0.0034(w) 0.002(w)	4.8-4.5(w) 4.8-4.5 (w) 4.5-4.7 (w)	0.5-2.0	40-75
Seafood Processors	5-15%	5-15%	0.0419(s) 0.0027(w)	1.9-2.2 (s) 4.8-5.0 (w)	0.0034(w) 0.0034(w) 0.002(w)	4.8-4.5(w) 4.8-4.5 (w) 4.5-4.7 (w)	0.5-2.0	40-75
Charter Operations	15-25%	5-10%	0.0419(s) 0.0027(w)	1.9-2.2 (s) 4.8-5.0 (w)	0.0034(w) 0.0034(w) 0.002(w)	4.8-4.5(w) 4.8-4.5 (w) 4.5-4.7 (w)	0.5-2.0	40-75
Coastal Marinas	10-20%	5-10%	0.0419(s) 0.0027(w)	1.9-2.2 (s) 4.8-5.0 (w)	0.0034(w) 0.0034(w) 0.002(w)	4.8-4.5(w) 4.8-4.5 (w) 4.5-4.7 (w)	0.5-2.0	40-75

** s=maximum surge elevation, w=maximum wind speed*

†A supplemental valuation for commercial vessels is given by $16.082(l)^{2.3779}$, where l=vessel length

3.5.2 Infrastructure Losses

Table 11 provides a summary of the estimated damages to fisheries infrastructure from hurricanes in 2020 and 2021. For each of the five sectors, the *lower bound* estimate is generated by aggregating the maximum losses generated by nonlinear models (surge and wind) at a given business location (Table 9, line #45). The *upper bound* estimate is generated by aggregating the maximum losses of linear models (surge and wind) at a given business location (Table 9, line #40). A numerical average of the lower and upper bounds is provided for each category. From a modelling perspective, Hurricanes Laura, Delta, and Zeta are treated as single-storm event for the year 2020. Damages for these storms are driven by the maximum surge and wind levels at a given business location (Table 9, lines #19&25). Hurricanes Ida is the only storm event modelled for the year 2021. Results indicate that in 2020, Hurricanes Laura, Delta, and Zeta produced \$80.6 to \$120.9 million in damages to the five categories of fisheries infrastructure, for an average estimate of \$100.7 million. This amount was more than doubled by Hurricane Ida alone, with 2021 damages ranging from \$218.7 to \$240.9 million with an average impact of \$229.8 million. For 2020 processors and dealers are estimated to have had the highest amount of damage. In 2021, the highest damages were to seafood processors and commercial vessels. A 20% evacuation rate is assumed for commercial vessels and charter operations based on results from the industry survey.

Table 11. Estimated damages to fisheries infrastructure from hurricanes in 2020 and 2021

Sector	**2020** Hurricanes Laura, Delta and Zeta			**2021** Hurricane Ida		
	Lower bound	Upper bound	Average	Lower bound	Upper bound	Average
Commercial Vessels	11,286,414	25,825,064	18,555,739	58,659,696	59,230,692	58,945,194
Seafood Dealers	21,741,436	26,068,481	23,904,959	48,257,116	58,858,164	53,557,640
Seafood Processors	24,574,017	39,469,356	32,021,686	66,849,217	68,604,975	67,727,096
Charter Operations	5,868,518	11,282,127	8,575,322	22,212,948	23,061,280	22,637,114
Coastal Marinas	17,151,730	18,277,712	17,714,721	22,797,084	31,158,045	26,977,564
Total	**$80,622,115**	**$120,922,739**	**$100,772,427**	**$218,776,060**	**$240,913,156**	**$229,844,608**

[*] based on a minimum damage estimation floor of 1 foot for surge and 50 mph for wind and a 20% vessel evacuation rate for commercial vessels and charter operations

Table 12 depicts an alternative approach in which all four storms are modeled as a single event. The $292.8 million in total infrastructure damage from this "one-event" model is 18% lower than the sum of damages ($357.7 million) obtained when 2020 storms and 2021 storms are modelled separately. While this alternative method removes any potential double-counting of damages, it also removes the value of any repairs made between the two seasons. Indeed, several survey participants commented how they had repaired their businesses from one storm, only to be impacted again by another storm the following year. This scenario was more prominent for firms initially damaged by Hurricane Zeta in 2020 and then again in 2021 by Hurricane Ida.

Table 12. Estimated damages to fisheries infrastructure from the 2020-2021 storms modeled as one event

Sector	**2020-2021** All four storms modelled as one event		
	Lower bound	Upper bound	Average
Commercial Vessels	61,812,156	63,751,677	62,781,917
Seafood Dealers	56,438,737	71,636,087	64,037,412
Seafood Processors	86,285,327	90,008,563	88,146,945
Charter Operations	25,390,614	25,824,929	25,607,771
Coastal Marinas	25,153,352	35,143,176	30,148,264
Total	**$255,080,185**	**$286,364,432**	**$270,722,308**

The losses reflected in Tables 11 and 12 were mostly driven by wind damage compared to surge damage. Although the ratio of wind to surge damage varied by location and by minimum damage assumptions[24], the percentage of damage ratios (*wind:surge*) are: commercial vessels (85:15), dealers (80:20), processors (80:20), and charters (89:11). Given their exposed coastal locations, the damages to marinas - though still dominated by wind (54%) – was almost equally (46%) dominated by storm surge. Finally, all infrastructure losses reflect uninsured losses, derived by reducing all baseline estimates by 8%, the weighted average coverage identified in the industry survey.

3.5.3 Revenue Losses

Estimating revenue losses from the Hurricanes of 2020 and 2021 required a related, but slightly different process than the method used for measuring infrastructure damage. The firm-level revenue data obtained from trip ticket records (for 5,739 commercial vessels and 1,139 dealers) were not disaggregated by seafood commodity. Such a disaggregation - though possible - would have increased the size of the analysis by a minimum of seven-fold. As an alternative approach, projected changes to revenue were derived using baseline values available from LDWF for 22 coastal parishes and 8 major seafood commodities.

Table 13 contains a listing of 20 variables used for estimating revenue losses from the four storms. Recall that questions 24, 25, and 26 of the industry survey inquired about actual and expected revenue losses in the years 2020, 2021 and 2022. Combined with respondent estimates of maximum wind speed at their business location, these data provided a basis for six equations for estimating revenue losses by wind speed: eq. 13-15 (linear) and eq. 16-18 (nonlinear). To apply these revenue loss functions at the parish level, parish-level winds would be needed. For that calculation, average estimates of maximum sustained wind were derived using the ADCIRC wind estimates linked to 5,739 vessel locations.[25] [26]

Table 14 contains the resulting parish-level estimates of revenue loss for the years 2020, 2021 and 2022. In most cases, the lower bound estimates are from the non-linear models and the higher estimates are derived from the linear models. Wind damages are limited to speeds of 50 mph or greater. For the year 2020, revenue losses range from an estimated $14.0 million to $58.8 million, with the highest percentage

[24] In Tables 11 and 12, the minimum controls for damage estimation were 1 feet for surge and 50 mph for wind.
[25] Using the vessel locations ensured that the largest amount of point-based wind observations (5,739) would be available to develop wind estimates for each of the 22 coastal parishes.
[26] An additional 6 functions relating revenue loss to surge were developed, but not used given that all revenue losses were all dominated by wind when estimated at the parish level.

losses in Cameron and Calcasieu parishes (due to Hurricane Laura) and the highest dollar losses in Plaquemines Parish (due to Hurricane Zeta).

Table 13. Variables used for estimating revenue losses from the Hurricanes of 2020 and 2021

#	Variable	Description	Source
1	Parish landings (avg. $)	Aggregated value	LDWF, 22 coastal parishes, 2018-2020
2	Commodity value (avg. $)	Aggregated value	LDWF, 8 commodities, 2018-2020
3	Laura Max Wind (mph)	ADCIRC estimate	LSU CERA, at 5,739 vessel locations
4	Delta Max Wind (mph)	ADCIRC estimate	LSU CERA, at 5,739 vessel locations
5	Zeta Max Wind (mph)	ADCIRC estimate	LSU CERA, at 5,739 vessel locations
6	Ida Max Wind (mph)	ADCIRC estimate	LSU CERA, at 5,739 vessel locations
7	Mean, Median, Max Wind – All storms (mph)	Formula	Study-generated
8	Max Wind (mph)	Formula	Study-generated (minimum 40-75 mph)
9	Linear Wind 2020 Loss (%)	Equation 13	Study-generated (from survey)
10	Linear Wind 2021 Loss (%)	Equation 14	Study-generated (from survey)
11	Linear Wind 2022 Loss (%)	Equation 15	Study-generated (from survey)
12	Linear Wind 2020 Loss ($)	Formula	Study-generated
13	Linear Wind 2021 Loss ($)	Formula	Study-generated
14	Linear Wind 2022 Loss ($)	Formula	Study-generated
15	Nonlinear Wind 2020 Loss (%)	Equation 16	Study-generated (from survey)
16	Nonlinear Wind 2021 Loss (%)	Equation 17	Study-generated (from survey)
17	Nonlinear Wind 2022 Loss (%)	Equation 18	Study-generated (from survey)
18	Nonlinear Wind 2020 Loss ($)	Formula	Study-generated
19	Nonlinear Wind 2021 Loss ($)	Formula	Study-generated
20	Nonlinear Wind 2022 Loss ($)	Formula	Study-generated

Projections of revenue loss in 2021 (due to Hurricane Ida and carry-over from the 2020 storms) range from $21.2 to $81.9 million, with the greatest percentage losses in Jefferson, Lafourche, St. Charles, St. John, and Terrebonne parishes and the greatest single dollar loss in Plaquemines Parish. Carry-over losses in 2022 revenue (from Hurricane Ida) were projected to be from $10.1 to $48.0 million and highest in Lafourche, Plaquemines, Jefferson, and Terrebonne parishes.

Revenue losses in seven parishes (Cameron, Calcasieu, Jefferson, Lafourche, St. Charles, St. John and Terrebonne) were projected by one or both models to exceed their 35% baseline revenue thresholds during either 2020 or 2021. Projected threshold exceedances in these instances ranged from Cameron Parish at 44.5% in 2020 to Terrebonne Parish at 35.1% in 2021. While losses at the parish level alone may not be considered “management level” losses for a given species under MSA, these numbers reflect the substantial revenue impacts to these parish economies in addition to infrastructure damages.

Table 14. Parish-level revenue losses projected from the Hurricanes of 2020 and 2021

Parish	2020 Revenue Loss (%)		2021 Revenue Loss (%)		2022† Revenue Loss (%)	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Acadia	$13,598	$246,354	$1,812	$160,761	$0	$0
Ascension	$0	$40	$1,876	$12,235	$900	$7,197
Assumption	$0	$3,369	$57,908	$825,971	$28,588	$485,865
Calcasieu	$356,847	$429,759	$0	$0	$0	$0
Cameron	$1,831,719	$1,965,479	$0	$0	$0	$0
Iberia	$0	$29,858	$0	$0	$0	$0
Jefferson	$1,227,539	$4,624,207	$1,665,385	$6,301,258	$788,265	$3,706,622
Jefferson Davis	$1,271	$2,694	$0	$0	$0	$0
Lafayette	$1,858	$41,410	$0	$0	$0	$0
Lafourche	$2,020,452	$5,603,629	$6,614,958	$10,349,573	$3,176,385	$6,087,984
Orleans	$457,958	$1,399,280	$138,286	$1,382,995	$67,330	$813,527
Plaquemines	$5,713,321	$25,378,125	$4,425,541	$32,441,638	$2,131,092	$19,083,317
St. Bernard	$1,121,203	$7,604,827	$683,658	$7,683,719	$334,346	$4,519,835
St. Charles	$0	$21,082	$800,268	$1,611,646	$379,551	$948,027
St. James	$0	$0	$0	$0	$0	$0
St. John	$0	$65	$10,167	$25,559	$4,802	$15,035
St. Martin	$0	$16,324	$0	$0	$0	$0
St. Mary	$53,693	$1,233,403	$52,521	$1,301,957	$26,533	$765,857
St. Tammany	$0	$886,032	$194,107	$2,499,879	$95,436	$1,470,517
Tangipahoa	$0	$0	$0	$0	$0	$0
Terrebonne	$1,224,659	$8,912,605	$6,533,360	$17,329,879	$3,084,867	$10,194,047
Vermilion	$0	$464,907	$0	$0	$0	$0
Total	$14,024,118	$58,863,449	$21,179,847	$81,927,072	$10,118,094	$48,097,830

* Shaded areas indicate projected losses that exceed 35% of the baseline revenue of that parish.
† Revenue loss projections for 2022 are carry-over losses expected from Hurricane Ida.

Table 15 contains commodity-level[27] estimates of revenue loss for the years 2020, 20021 and 2022. For 2020, projected revenue losses range from an estimated $22.9 to $73.3 million, with the highest dollar losses projected for white Shrimp and Saltwater fish. Projected revenue losses increase in 2021 due to carry-over effects of 2020 and the substantial impacts of Hurricane Ida – which affected the heart of the state's coastal fishing industry. Projected commodity losses for 2021 range from $27.5.2 to $105.3 million, with more than half the losses occurring in White shrimp, Saltwater fish, and Crab fishing. Carry-over losses in 2022 revenue (from Hurricane Ida) were projected to be from $14.8 to $66.5 million with the greatest losses in White shrimp, Saltwater fish and Charter fishing. At a projected 32% reduction in

[27] Commodity-level revenue losses are intended to capture the dockside losses to primary species of commercial seafood harvesters, dealers and processors. Revenue losses for charters and marinas are included here and reflect weighted losses from equations 13-18 at the state level.

Table 15. Commodity-level revenue losses projected from the Hurricanes of 2020 and 2021

Commodity	2020		2021		2022	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Crabs	3,690,089	10,159,992	4,664,069	15,309,250	2,228,505	8,992,929
Oysters	2,076,308	9,605,131	2,275,521	12,625,309	1,087,906	7,357,308
Brown Shrimp	1,232,267	4,708,273	2,780,643	7,398,769	1,327,033	4,352,127
White Shrimp	4,114,599	15,422,575	7,632,995	23,493,721	3,639,304	13,816,254
Wild Crawfish	97,641	706,580	135,783	1,532,809	66,120	900,587
Freshwater Fish	51,713	250,772	100,200	422,114	47,685	240,332
Saltwater Fish	4,292,472	16,362,533	3,557,445	21,019,519	1,705,832	12,364,423
Charters	3,670,804	8,054,328	3,184,922	11,729,248	3,212,076	11,829,249
Marinas	3,702,101	8,122,998	3,212,076	11,829,249	1,528,842	6,735,927
Total	**$22,927,995**	**$73,393,180**	**$27,543,654**	**$105,359,989**	**$14,843,302**	**$66,589,135**

* Shaded area indicates an estimate approaching the 35% baseline revenue estimate for a coastal parish.
† Revenue loss projections for 2022 are carry-over losses expected from Hurricane Ida.

2021 revenue, Brown shrimp in 2021 is the only state-managed fishery approaching the 35% threshold required by NOAA for a fisheries disaster declaration at the management level. At the time of Hurricane Ida's landfall; however, most of the brown shrimp season had concluded. Thus, it is possible that the actual reduction in state brown shrimp landings could be substantially lower than projected here. Conversely, the hurricanes of 2020 and 2021 heavily affected White shrimp during the peak of their harvesting season. White shrimp accounts for a plurality of the value of state landings (~ 30%) and the state season for harvesting begins in August and runs through the fall months.

3.5.4 Total Estimated Losses

Table 15 depicts a summary of the results presented in tables 7-14. When the effects of Hurricanes Laura, Delta, and Zeta in 2020 are estimated separately from Hurricane Ida in 2021, the combined average projections for infrastructure, revenue, and resource losses are estimated at $161 million in 2020 (E) and $378.1 million for 2021 (F). With the additional, carry-over loss of $40.7 million in revenue projected for 2022 (G), the total projected losses for the three years (2020+2021+2022) is $579.9 million (H). If all four storms are modeled as a single event, the total loss estimate is $524.6 million (I). The losses reflected in Table 15 represent an 8%

Table 16. Estimated infrastructure, revenue and resource losses to Louisiana fishing-related businesses resulting from the Louisiana hurricanes of 2020-2021

	Lower bound	Upper bound	Average
A. Infrastructure[1]			
2020 (Laura, Delta, and Zeta)	$74,373,901.25	$111,551,227	$92,962,564
2021 (Ida)	$201,820,915	$222,242,386	$212,031,651
Total	$276,194,817	$333,793,613	$304,994,215
B. Revenue[2]			
2020	$22,927,995	$73,393,180	$48,160,587
2021	$27,543,654	$105,359,989	$66,451,821
2022	$14,843,302	$66,589,135	$40,716,219
Total	$65,314,952	$245,342,304	$155,328,628
C. Infrastructure and Revenue			
2020	$97,301,896	$184,944,407	$141,123,152
2021	$229,364,570	$327,602,375	$278,483,472
2022	$14,843,302	$66,589,135	$40,716,219
Total	$341,509,768	$579,135,917	$460,322,843
D. Resource Loss[3]			
2020			
Oysters (Laura, Delta, Zeta)	$10,169,308	$10,169,308	$10,169,308
Finfish (Laura, Delta, Zeta)	$9,763,716	$9,763,716	$9,763,716
2021*			
Oysters (Ida)	$50,846,541	$50,846,541	$50,846,541
Finfish (Ida)	$48,818,581	$48,818,581	$48,818,581
Total	$119,598,146	$119,598,146	$119,598,146
E. Total Impacts 2020	$117,234,920	$204,877,431	**$161,056,176**
F. Total Impacts 2021	$329,029,692	$427,267,497	**$378,148,594**
G. Total Impacts 2022	$14,843,302	$66,589,135	**$40,716,219**
H. Total Impacts 2020+2021+2022	$461,107,914	$698,734,064	**$579,920,989**
I. Total Impacts 2020-2022†	$434,654,427.22	$614,681,779.66	**$524,668,103**

1 Loss of business value to vessels, dealers, processors, charters and marinas. Assumes 8% of asset losses are covered by insurance

2 Revenue losses for crab, oysters, shrimp, wild crawfish, freshwater fish, marine fish, charters and marinas.

3 LDWF-based field mortality estimates monetized with restitution values

** Estimated at 20% of 2021*

† Models the impacts (on infrastructure) of all four storms as a single event

4. SUMMARY AND CONCLUSIONS

4.1 Rationale Recap

The landfall of four large storms over a 12-month period caused widespread economic losses to fishing- and seafood-related businesses in coastal Louisiana. From August 27, 2020 to August 29, 2021, Hurricanes Laura (Cat 4), Delta (Cat 2), Zeta (Cat 3), and Ida (Cat 4) transected the state's southwest and southeast regions. These regions contain a majority of the state's commercial fishing infrastructure and are part of a coastal zone that has historically led the coterminous U.S. in annual fisheries landings. Taken together, the 22 parishes of coastal Louisiana provide an estimated $2.47 billion annually in economic activity and support 31,000 jobs related to the harvest, distribution, and processing of seafood.

In response to these storms, numerous organizations mounted humanitarian response efforts focused on the provision of food, water, shelter, fuel, and ice to the state's seafood industry. To maintain and expand these efforts, a long-standing alliance of fisheries leaders was reconvened in September 2021. The Louisiana Fisheries Community Recovery Coalition (LFCRC) consists of 34 private and public sector organizations that have agreed to coordinate the state's fisheries disaster communications and to identify short- and long-term priorities for response and recovery.

Concurrent to reemergence of the LFCRC, a small working group was organized by LDWF to develop economic assessments of the storms' impact on fisheries infrastructure, revenue, and resources. In conducting their analysis, the group expanded on a spatial method originally developed in the wake of Hurricane Katrina in 2005. The GIS-based method combines information on the location and value of individual firms with site-specific meteorological data. Combined with survey derived damage functions, this approach can be used to examine key questions at the firm-level for a given storm, including: *Where was the business located prior to the storm?*; *What was the maximum surge height and maximum wind speed at the business location?*; *What was the approximate, pre-storm value of the business?*; and, *How did that business value change as result of the storm?*

Answering these questions for entire sectors requires two types of firm-level information: 1) primary data on a firm's location (obtained from license and permit records); and 2) primary data on a firm's revenue (obtained from trip tickets) or secondary data obtained from economic studies. For this reason, the definition of "fisheries infrastructure" in the report was limited to five marine sectors that meet these two criteria: 1) commercially active fishing vessels; 2) commercially active seafood dealers; 3) seafood processors; 4) charter boat operations; and 5) coastal marinas.

4.2 Primary Findings

The mapping of fisheries infrastructure involved the creation of latitude and longitude coordinates from address data for 8,503 commercial firms in the license and permit databases of LDWF and the Louisiana Department of Health (LDH). This total included 5,739 commercially active fishing vessels; 1,129 seafood dealers; 473 seafood processors; 1031 charter boat operators; and 131 coastal marinas and launches. For each of the 8,503 geocoded locations, a maximum surge height and a maximum wind speed were obtained for each of the four Hurricanes (Laura, Delta, Zeta and Ida). In total, 68,024 meteorological projections of the Advanced Circulation (ADCIRC) model were obtained from the Coastal Emergency Risk Assessment (CERA) laboratory at Louisiana State University.

Approximate valuations for each of these 8,503 operations were based on income capitalization appraisal methods, with assumed net incomes ranging from 5-25% and capitalization rates of 5-15%. A supplemental method for valuing vessel-based operations utilized a regression derived estimate of fair market value based on vessel length. Total valuation from these appraisal methods yields an estimated $1.36 billion in infrastructure value for commercial vessels ($344.9 million), seafood dealers ($228.5 million), seafood processors ($548.5 million), charter boat operations ($151.6 million) and coastal marinas ($91.7 million).

Understanding the degree to which these values were impacted by a given storm required the collection of sample observations from individual firms. For this reason, an electronic survey (email and web) was developed to collect information from Louisiana fishing businesses impacted by the 2020-2021 hurricanes. The survey ran from November 10, 2021 to December 20, 2021 and generated 516 useable responses. A series of initial questions was used to characterize respondents in terms of two categories: primary storm of impact and primary sector. Answers to these questions allowed parsing and comparison of a range of responses pertaining to business assets, insurance, residential displacement, and specific characteristics of primary vessels.

The main purpose of the survey was to generate a series of damage and loss curves that could be applied to the broader populations of mapped firms. Questions regarding business value, storm damage and expected revenue loss were combined with meteorological observations to create 16 asset-damage and revenue-loss functions (curves). For each year of infrastructure impact (2020 and 2021), two damage curves were developed to show how a firm's market value was impacted - one based on storm surge, and one based on wind speed. For each year of revenue impact (2020, 2021, and 2022) an additional set of curves was estimated to show expected revenue reductions for various levels of surge and wind.

For every loss estimation, two functional forms were used. A basic linear model was developed by regressing average losses at incremental levels of surge height and wind speed. A second, nonlinear model, was developed by fitting the raw data (estimated losses for surge and wind) with a sigmoidal curve bounded by 0 and 100%. Even with intercepts set to zero, the linear models typically yielded substantially larger losses, especially at lower values of surge and wind. For this reason, a minimum condition for damage estimation was applied to both models and set as 1 foot for storm surge and 50 mph for wind. Used together, the two models produce a wide range of damage and loss estimates for the same meteorological conditions at a given location. The more conservative, nonlinear models constitutes a lower bound, and the more liberal, linear models yield an upper bound for all loss projections.

4.2.1 Infrastructure damages

Infrastructure damage from the four storms was estimated at $304.9 million (average of lower bound and upper bound estimates). Taken together, these damages equate to a 22% reduction in the $1.36 billion in appraised infrastructure value for the five sectors of this analysis. While this is a considerable reduction in value, it is important to reiterate that this is an aggregate estimate resulting from four storms. Of the total amount of damages, $92.9 million (30%) accrue from the impact of the 2020 hurricanes (Laura, Delta, and Zeta). The remaining $212 million (70%), derives from the impacts of Hurricane Ida in 2021. The higher losses for Ida reflect the larger size of the storm and the more heavily populated impact zone.

It is noteworthy that most of the damage from these storms was driven by wind damage. This finding is consistent with wind-dominated storms of the past like Hurricane Gustav (2008) but stands in contrast to storms like Hurricane Katrina (2005) in which storm surge accounted for the majority of damage. The dominance of wind as a primary driver of damage varied by location, but averaged 85% for vessels, 80% for dealers, 80% for processors and 89% for charters. Given their more exposed coastal locations, marinas had a higher fraction of surge-related damage, but losses remain slightly dominated by wind (54%).

4.2.2 Revenue losses

Revenue impacts from the four storms were estimated using loss curves based on parish-averaged wind speeds. The total projected revenue losses for 22 coastal parishes over the 3-year period was $155.3 million. Of this amount, $48.1 million (31%) in revenue losses is estimated for 2020; $66.4 (43%) for 2021; and, an additional $40.7 million (26%) in carry over losses to revenue expected for 2022. All revenue loss projections were solicited from the industry survey separately for two years (i.e. 2020 and 2021 revenue loss estimates for Hurricanes Laura, Delta and Zeta; and 2021 and 2022 revenue loss

estimates for Hurricane Ida). As result of this carry-over, revenue impacts are more evenly spread across the 3-year period.

At the commodity level, only one species (brown shrimp) had annual losses approaching the 35% revenue reduction threshold required for a federal disaster declaration under NOAA Fisheries guidance. Projected revenue losses of 35% and above; however, were estimated by one or both models for seven parishes (Cameron, Calcasieu, Jefferson, Lafourche, St. Charles, St. John, and Terrebonne) for the years 2020 and 2021. The submission and verification of additional landings data overtime may cause changes to the above revenue loss figures.

4.2.2 Total Damages and Losses

The uninsured losses to infrastructure, revenue and biological resources from Hurricanes Laura, Delta, Zeta, and Ida range from $434.6 million to $698.7 million. The spread of these estimates reflects the large variation in output produced by the linear and nonlinear damage models used in this study. The authors suggest that the average of this range, $579.9 million, is the best available estimate at this time.

4.2 Study Limitations

Estimates produced by this study are subject to a number of limitations that should be clearly stated. First and foremost, the effective definition of commercial infrastructure is constrained to only those five sectors for which sufficient data on firm location and firm revenue are available. While these five sectors represent the majority of fishing- and seafood-related businesses in coastal Louisiana, there are numerous unlicensed, ancillary sectors that were not included in the analysis. Such businesses include, but are not limited to commercial ice houses, marine fabrication and supply shops, non-marina-based retail, grocery, and lodging for commercial and recreational fishing.

Aquaculture is large sector that was not included due to data limitations, yet it accounts for substantial economic activity in the state’s coastal parishes. The LSU AgCenter estimates that in 2019, there was $201 million in annual revenue generated from farm-raised crawfish, $86.1 million from farm-raised alligators, and an additional $1.3 million from the pet turtle production (Guidry and Blanchard 2020). Coastal bait sales are another sector that confounded by a lack of economic data. Although this study identified 44 seafood dealers with records of bait sales, the value of these transactions is not easily disaggregated from total revenue of seafood dealers. Moreover, bait sales tracked under the LDWF special permits do not include the value of interstate commerce or farm-raised bait species.

Additional questions pertain to the tracks of the four storms and the potential for the over-counting or under-counting of damages. While there was sufficient geographic separation for the two major storms (Laura and Ida), each of their impact zones were partially overlapped by the two smaller storms (Delta and Zeta). In 2020, Hurricanes Laura and Delta both made landfall in Cameron Parish. Yet, the intensity of Laura (Cat 4) was much stronger than that of Delta (Cat 2). A review of the ADCIRC data shows that Delta's maximum storm surge exceeded Laura's surge in 1% of locations and Delta's maximum wind speed exceeded Laura's wind in 13% of locations[28]. Likewise, the impact zone of Hurricanes Zeta in 2020 was heavily overlapped by Hurricane Ida in 2021. Yet, Zeta's maximum storm surge exceeded Ida in only 1% of locations and Zeta's maximum wind speed exceeded Ida in only 3.2% of locations.

Modeling all four storms as one-event yields an average infrastructure damage estimate that is 18% lower than the sum of damages obtained separately for 2020 and 2021. While this alternative approach removes any potential double-counting of damages, it also removes the value of any repairs made between the two seasons. Hurricane Zeta for example, made landfall in late October 2020, nearly a year prior to Hurricane Ida in late August 2021. Modeling the two storms together serves to discount the value of any repairs made during the 10-month interval between these two storms.

An analysis external to this study conducted by LDWF biologists estimated natural resource losses for oysters and a selection of finfish species identified in fish kill reports. Monetization of these resource losses was based on species-specific restitution values obtained from the Natural Resource Damage Assessment (NRDA) process. Species included in the analysis, however, were selected based on their accessibility from sampling and from areal extrapolation of visible fish kills. Mortalities of economically important species like shrimp and crab are not included in the analysis. These species account for a large portion of commercially-relevant biomass, but typically sink rather than float when they die, making visual surveying impossible.

Although 16 separate damage curves were generated for this analysis, this number of curves is the result of having separate functions (linear and nonlinear) for both surge and wind. Applying these curves to infrastructure damage yields 4 models. Applying similar curves for three years of revenue loss yields an additional 12 models. Despite this level of modeling, sector-specific curves were not developed individually for each category of infrastructure. And while previous studies have shown differences in the resiliency of various business structures to surge and wind, the development of category-specific

[28] Based on maximum surge heights and wind speeds for all storms at 5,660 geocoded license locations of commercial vessel.

curves would have required dozens of additional functions. Such detail, while possible in future refinements, is beyond the available time and resources of this study.

The validity of spatially-based storm impact models hinges on the accuracy of business asset mapping. There are often differences between the address of an individual license- or permit-holder and the location of their business assets. To address the potential error from such differences, the industry survey inquired about the distance between a respondent's work and home. Nearly half of respondents (49%) indicated living within five miles of their fisheries- or seafood-related business, and 68% of these indicated that their business location was the same location as their personal residence. While these findings help to partially document home-to-business proximities, they lack sufficient detail on the direction and magnitude of these differences. Additional research is required to improve the identification and minimization of this source of error on storm damage projections within specific sectors.

The effects of the storms on residential structures was not captured in the economic analysis, though partial insight can be obtained from the industry survey. All respondents indicated having some level of residential damage, and 20% indicated that they were still displaced from their homes. The home-to-business proximity is of particular interest in lower Lafourche and Terrebonne parishes, where Hurricane Ida was the strongest hurricane to make landfall in a lifetime for many residents. The owners and employees of fisheries businesses in this region typically reside in houses located along coastal bayous where they moor their vessels. Many of these houses were constructed prior to the construction regulations implemented in early 21st century. Anecdotal accounts describe entire families riding out the storm on commercial fishing vessels, as their older homes were heavily damaged or completely destroyed. Some of these families remain dependent on remnant vessels as their primary shelter. The long-term effects of this housing crisis are largely unknown for a region that has traditionally accounted for a large portion of the state's seafood commerce.

As with any analysis of disaster impact, there are various assumptions that can serve to inflate or deflate final estimates. In this analysis, there are a number of instances in which the construction and execution of the integrated model imbued levels of conservatism in damage estimation. As previously mentioned, there are several categories of infrastructure, resource, and residential loss for which no data are readily available for this analysis. This factor alone suggests that the estimates of this report could be viewed as a lower bound projection of the storms' impact. Moreover, for the 8,503 mapped firms, damages are primarily driven by ADCIRC hind casts of maximum sustained wind speed. While these model-generated wind speeds are consistent with NWS projections, they are contour-based. As such, they fail to capture

locally-higher gusts that can result in higher than average impacts. Finally, the projections of damage and loss in this study are dampened by assumptions related to insurance coverage and vessel evacuation. Currently assumed at 8% and 20%, respectively, these assumptions are somewhat elementary in their application. Additional research is required to determine to refine how insurance coverage and vessel evacuation are accounted for in future hurricane damage assessments.

4.3 Future Assessment Needs

A list of short-term and long-term recovery priorities for the storms of 2020 and 2021 is currently in development by the LFCRC. While those needs will ultimately be the focus of a separate report, the suggestions outlined below address how the methods used in this study can be refined through improved planning, response, and assessment.

In the wake of any disaster, one of the most pressing and ongoing challenges is the need for direct communication. After a major hurricane, it is understandably difficult to coordinate rapid response efforts due to power outages and communications failures. Yet even after power and communications are restored, very little contact data are currently available from state agency records beyond names and addresses. In the wake of the 2020 and 2021 storms, public and private agencies had no formal directory available for coordinating response efforts with coastal leaders and for quickly communicating with large numbers of businesses. Even after the rapid response phase, the lack of direct contact information remains problematic. For example, in this study only 600 email addresses were available for 16,849 commercial license-holders.

In the wake of the 2020-2021 storms, numerous state and local partnerships have emerged which seek to solve this communication problem through the establishment of disaster planning and response teams. While such initiatives are laudable, they are not necessarily new. Similar networks have been established after previous storms, only to lose momentum due to changes in leadership and the loss of contact information during the intervals between storms. Whether it be for the provision of rapid response aid or to conduct damage surveying, direct contact information will always be needed. There is likely no better method for the voluntary provision of direct contact information (emails and cell numbers) than through the annual purchase and renewal of commercial license and permits. [29]

[29] Recent changes in the LDWF computer systems will allow commercial entities to purchase or renew licenses and permits online. This process should improve the collection and annual updating of email and cell phone contact information.

Another idea receiving increased attention is that of mapping. The assertion is that, with recent improvements in technology, commercial infrastructure maps can and should be used more effectively to guide storm response and inform impact assessment. This is yet another area that has been pursued in years past, only to wane due to various factors. For example, the spatial assessment method used in this study dates back more than 16 years to the wake of Hurricanes Katrina and Rita. While the spatial impact methodology took more than two years to finalize after those storms, once in place, it produced detailed damage estimates in only two weeks after Hurricanes Gustav and Ike in 2008. The success of this approach led to interagency agreements that would be activated for any major storm slated for Louisiana landfall. Unfortunately, these agreements were discontinued in the wake of the Deepwater Horizon oil spill - primarily because of legal constraints on data transfer during the NRDA process.

Redevelopment of this 15-year-old spatial model has required several months of effort by the economic working group. Some of the overhead portions of this work could be easily carried over and replicated in the coming months and years (e.g. renewing memorandums of understanding and non-disclosure agreements of data transfer). Other aspects could be refined annually with moderate amounts of collaboration during the 6-month interval between the end (November 30th) and beginning (June 1st) of the Atlantic Hurricane season. During this period, pre-mapping and valuation of baseline data could be completed for all fisheries- and seafood-related infrastructure, along with refinements to storm damage and loss models. Pre-staging these elements would help in directing rapid response and communication efforts and would greatly reduce the time needed to produce more rapid and reliable economic impact assessments after the passage of future storms.

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