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Estimating the economic impacts of hurricane damage on coastal fishing infrastructure

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ESTIMATING THE ECONOMIC IMPACTS OF HURRICANE DAMAGE ON COASTAL FISHING INFRASTRUCTURE

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ABSTRACT

Two severe Hurricanes, Katrina and Rita, caused severe damage in the northern Gulf of Mexico during late summer and early fall 2005. Louisiana was the most heavily impacted state, where both storms made initial landfall. The storms caused billions of dollars in damages to public and private infrastructure, with particularly strong impacts to coastal fishing businesses. Numerous assessments of coastal fisheries infrastructure damage were developed by state and federal agencies following the storms. The range of estimates varied greatly (from $275 million to $3.5 billion), because of a wide range of methods and assumptions. This study describes two alternative damage assessment methods that utilize a combination of economic and biophysical data that can be used to produce rapid and geographically-specific estimates of commercial fisheries infrastructure damages.

Using a Geographic Information System (GIS) framework, location data was geo-coded for more than 100,000 addresses of commercial seafood infrastructures in 22 coastal parishes. Economic damage curves for seafood infrastructures were then fit using a combination of primary and secondary data. These damage curves were related to each location using data on maximum storm surge height simulated by the ADCIRC model via the LSU Hurricane Center. The first damage model, a form of partial income capitalization, estimated total damages to commercial seafood infrastructures at $269 million. The second model, in which revenue losses are discounted over a five-year period, produces a total of damage estimate of $455 million. As suspected, Plaquemines Parish received the highest overall economic damages, as this parish contained a high concentration of fisheries infrastructure and was the initial point of landfall for hurricane Katrina. Conversely, Cameron Parish, the initial point of landfall for Hurricane Rita, had only the 6th highest level of economic damage. This outcome reflects the ability of the

models to account for the geographic concentration of fisheries infrastructure, as well as the trajectory and intensity of a particular storm. The results of these applications can be used to guide damage assessments through more strategic allocation of recovery funding for short and long-term objectives.

CHAPTER 1: INTRODUCTION

Economic Assessment of Natural Disasters

The massive destruction caused by the Indian Ocean Tsunami of 2004 and the Gulf of Mexico hurricanes of 2005 has focused global attention on the economic impacts of natural disasters. Natural disasters, however, are not uncommon events, and typically occur every year worldwide. Some of the more notable disasters that have ravaged the United States in recent years include Hurricane Andrew in 1992, the Mississippi River flooding of 1993, the Northridge earthquake in 1994, severe drought in the Southern plains during 1996, Hurricane Floyd in 1999, Tropical Storm Allison in 2001, widespread drought over 30 states during 2002, and the four hurricanes (Charley, Frances, Ivan, and Jeanne) which made landfall in the state of Florida during 2004.

Concerning all weather and climate disasters in the US from the period of 1980 to 2005, Lott and Ross (2006) reported on those events in which at least one billion dollars or more in damages were recorded. There were 66 events included in this category, totaling more than $500 billion in inflation-adjusted damage costs. From these events, there were 23 tropical storms or hurricanes. These storms made up only 35 percent of the weather disasters in this category, but were responsible for 51 percent of the economic damages, with normalized costs around $250 billion dollars.

Extreme natural disasters cause death and injuries, property damages, economic disruptions, and political, social and cultural shocks. Coping with and mitigating these impacts has been a tremendous challenge for policy makers. Some efforts have been successful, while others have been constrained by several factors. One of the most problematic of these factors is the lack of consistent data and clear methods for rapid and precise assessment of the disaster losses. This problem was clearly stated in a report sponsored by the National Academies nearly a decade ago:

> "…the total economic losses that natural disasters cause the nation are not consistently calculated. Following a natural disaster, different agencies and organizations provide damage estimates, but these estimates usually vary widely, cover a range of costs, and change (usually increasing) through time." Committee on Assessing the Costs of Natural Disasters (CACND 1999)

Beyond the confusion and problems created by multiple, often conflicting methods of damage assessment, there is the simple issue of forgetfulness. While natural disasters do occur annually across the nation, they may occur very infrequently in one particular state or region. If several years and decades pass in between natural disaster events, local agencies may have lose the expertise required for proper assessment and mitigation of the disaster impacts. This problem is stated in a more recent report published by the Overseas Development Institute (ODI):

> "…A disaster raises public awareness of the importance of risk reduction but then interest rapidly wanes, overtaken by fresh, now more pressing concerns. To prevent (disasters) from being just another transient episode, considerable effort will be required to sustain awareness and understanding of the potential human, financial, and developmental costs posed by disasters." Aftershocks: Natural Disaster Risk and Economic Development Policy (ODI 2005)

Finally, even when preliminary damage assessments are conducted on a rapid and consistent basis over time, such assessments often lack the geographic detail required to target relief funding in the most efficient manner. Immediately following a major hurricane, initial damage assessments are usually reported on a highly aggregated basis (i.e. coast-wide or for an entire fishery). However, those initial assessments are not always refined after recovery funding is obtained from state and federal sources. Depending on the policy goals of a particular agency, there might be a need to target disaster mitigation funding on a more site-specific basis in order to direct funds to the most impacted areas. Conversely, other agencies may require site-specific damage assessments in order to redirect state and federal support funding towards more sustainable sectors or less vulnerable locations. Unfortunately, political pressures often carry more weight than efficiency and long-term management concerns when it comes to the allocation of disaster aid:

> "…This has been dubbed the CNN syndrome – where aid money follows public interest and media coverage. The outcome has been that large amounts of money are at times spent inefficiently in concentrated relief efforts that distort longer-term development and risk reduction efforts."
> The Macro-Economic Impact of Disasters (Pelling et al. 2002)

The challenges of data reliability, damage assessment consistency, institutional memory, and geographic specificity were all evident following the storms of the 2005 hurricane season in the Gulf of Mexico. That year included three of most powerful storms ever recorded in the Atlantic and Caribbean basin (NHC 2006).

The Hurricanes of 2005

There were 13 tropical storms, 2 sub-tropical storms and 15 hurricanes during 2005. The wind speed of the tropical storms ranged from 35 mph to 70 mph, while hurricane wind speeds ranged from 75 mph to 175 mph. Based on the Saffir-Simpson Hurricane Scale, there were three hurricanes, namely Katrina, Rita, and Wilma, that qualified as Category 5 storms. Measured at their peak intensity, these three hurricanes rank respectively as the sixth, fourth, and first most powerful hurricanes ever recorded (NHC 2006). The two most destructive of those storms (Katrina and Rita) made initial landfall in Louisiana.

On August 29, 2005, Hurricane Katrina made landfall along the central Gulf of Mexico and impacted five states directly including Louisiana, Mississippi, Alabama, Florida and Georgia. Two additional states, Kentucky and Ohio, were affected indirectly by flooding along the Mississippi River. The most severely impacted states were Louisiana, Mississippi, and

Alabama (Figure 1). Katrina was the most expensive and deadliest natural disaster since 1928. Levees constructed on all sides of New Orleans as well as its interior canals, not only function as flood control, but the area behind the levees also serve as magnet of economic development. The destruction of these levee, thus caused further costs of damage to society (Kefer *et al*, 2006)

On September 24, hurricane Rita made landfall on Louisiana-Texas borders (Figure 1). The hurricane caused major flooding in Port Author and Beaumont (Texas), and severe damages in Louisiana coastal and offshore areas, especially in Cameron and Calcasieu parishes (NCDC, 2005a and FEMA, 2005). Both Katrina and Rita's track and intensify were uncertain in forecasting thus causing massive evacuations. These evacuations led to major traffic jams, in which millions of evacuees were trapped in roadways, blocking to access public facilities, facing with frustration and exhausted, and shortage of fuel, food and water.

The storms also wreaked havoc on the vital portion of US domestic energy infrastructure. Bernanke (2005) reported that significant damage from the two storms caused a range of economic shocks to US economy. Destruction of important pipelines and refineries together with factors of declining of production and import difficulties induced high energy prices for several months after the hurricanes. These interruptions caused initial supply shortages of around one million barrels per day of crude oil and 5.2 billion cubic feet per day of natural gas due to hurricane Katrina

Hurricane Rita reduced oil production around 4.8 million barrel per day, and 75 percent of natural gas production were shut down. These hurricanes briefly surged the price of oil in New York Mercantile Exchange (NYME) around 38 percent and pump price around 11 percent (Bamberger and Kumins 2005a and 2005b).

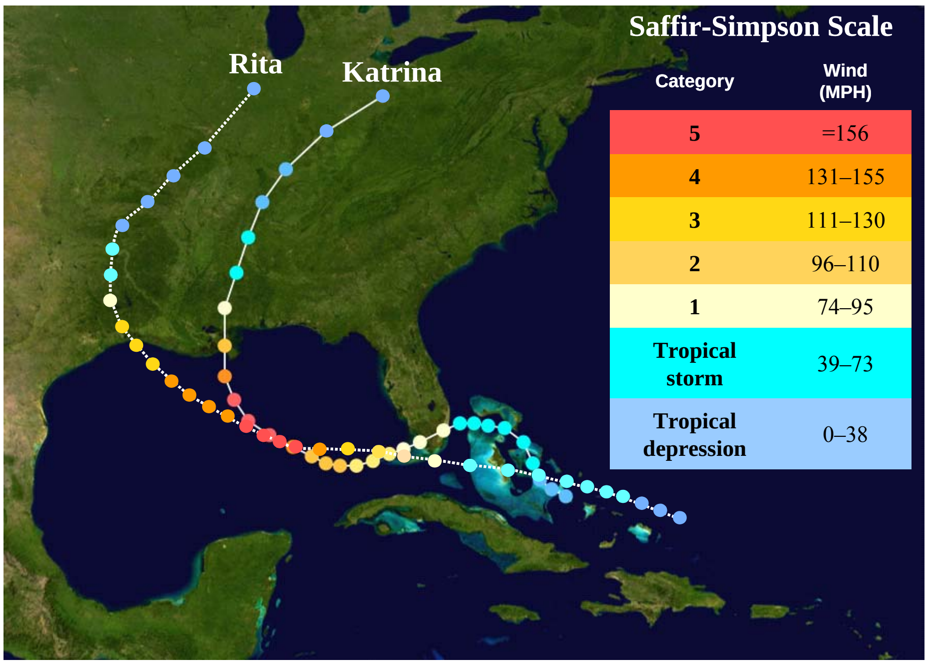

Figure 1.1 Intensity Levels and Trajectories of Hurricanes Katrina and Rita

Although Hurricane Katrina is primarily known for the destruction and loss of life it caused in New Orleans, Louisiana and the Mississippi Gulf Coast, the initial point of landfall for Hurricane Katrina was the fishing port of Empire, Louisiana in lower Plaquemines Parish. In 2004, Empire was in the number one fishing port by volume in the continental United States (NMFS 2005).

Hurricane Rita destroyed the coastal fishing port of Cameron, which in 2004 was the number four fishing port (by volume) in continental US (NMFS 2005). Together, these hurricanes caused direct and indirect damages to the commercial and recreational fisheries sectors in these ports and all along the northern Gulf of Mexico.

Initial Damage Assessments

Fisheries infrastructures (fishing vessels, docks, ice houses, processing facilities, warehouses and marinas) were directly damaged by both storms. However, indirect impacts from the storms came through destruction of coastal wetland habitat which provides multiple functions. According to the United States Geological Survey more than 219 square miles of coastal wetlands were destroyed (converted to open water) by hurricanes (USGS 2006). The exact amount of damages and its environmental consequences might not be known for several years.

As described by Polasky (2002), Lupi *et al* (2002), and Boyd and Wainger (2002); wetlands provide many different ecosystem functions, which generate a range of environmental services including flood control, nutrient cycling, water purification, wildlife habitat, recreation, and aesthetic values. In coastal ecosystems, wetland areas provide nursery, feeding and breeding grounds for fish and wildlife biota. Thus, the destruction of coastal wetlands means the lost of their valuable ecosystem functions. In Louisiana, wetlands associated with economic activities, aesthetic values and culture identifications of local communities.

Following the hurricanes of 2005, preliminary economic assessments of fisheries damages were developed by numerous researchers and institutions. Data and methods used for these assessments were inconsistent, and preliminary estimates released immediately following the storms varied greatly, in some case by more than one order of magnitude. Reliable assessments of damage to specific sectors were even more difficult to obtain. For example, preliminary damage estimates to Louisiana fisheries developed separately by the LSU Agricultural Center (Guidry 2005) and the Louisiana Department of Wildlife and Fisheries (LDWF 2005) ranged from $275 million to $3.5 billion, respectively. These reports have provided the basis for numerous funding requests. To date, the state has obtained more than $100 million in federal dollars for fisheries recovery program (Caffey et al. 2007).

The large difference in these preliminary estimates suggests there may be some merit in standardizing, or at least clarifying the methods in which post-disaster economic assessments are conducted. This variation is also indicative of the range of impacts that can be considered in a given damage study. For example, the initial reports released from the LSU AgCenter in late 2005 were based solely on estimated revenue losses, whereas the LDWF reports included estimated losses to revenue, infrastructure, and fisheries habitat.

Furthermore, numerous techniques that have emerged in the more than 13 years since Louisiana had landfall of a major hurricane (Category 3 or greater). Since the landfall of Hurricane Andrew in St. Mary Parish in 1992, several methods have emerged for assessing the economic impacts of coastal storms and hurricanes. Some of these methods rely of new data sources, such as revenue tracking systems and vessel registration databases. Others utilize technological advancements in computing (storm surge simulations) and spatial assessment (geographic information systems) to provide site-specific assessments of hurricane and tropical storm impacts.

Problem Statement

Assessment of damages due to natural disasters is typically complicated by the fact that there are a number of different estimation results that can be derived from rapid assessment models and methods to calculate the impacts. Decision-makers are often confronted with a wide range of estimates, which produces ambiguity in designating policies. Furthermore, preliminary damage estimates often lack the geographic-specificity required to efficiently target recovery funding in a manner that meets the short term and long term goals of a particular recovery program. Although no single framework or formula is widely accepted for estimating the damages, and no individual or agency is responsible for providing such estimates, there is some merit in describing alternative approaches that will allow for more specific and precise estimation of post-storm impacts.

Objectives

This study will review and characterize the various available assessment methods, and draw from these methods to develop an alternative advance method for estimating economic losses to coastal fisheries infrastructure from hurricanes. The proposed method is both rapid and more precise, while providing an additional level of geographic-specificity. The specific objectives of the study are:

1) To review the natural resource damage assessment and disaster recovery literature and describe the different methods used for assessing economic damages to northern Gulf of Mexico fisheries caused by the hurricanes of 2005;

2) To demonstrate alternative methods for producing a more rapid and spatially precise estimates of the post-hurricane impacts to fisheries infrastructure; and

3) To compare and contrast the damage assessment methods currently available and make recommendations for application of these methods for future storm events.

Data and Methods

Data for the first objective will be derived from extent published literature on common property resources and fisheries management and from draft reports and written documents that contain preliminary and final damage estimates and economic impacts of natural disasters. A review of fisheries damage estimation methods from the 2005 storm will include, where possible, a description of each technique, model assumptions, required data, mathematical approaches, and range of results.

For objective two, two types of data (biophysical and economic) will be utilized. Simulated storm surge data from the LSU Hurricane Center will be combined with commercial fisheries revenue and market data to produce a location-specific estimate of coastal fisheries infrastructure damages. Damage functions will be fitted using pre-existing studies and ground truth observations that document the relationship between storm surge height and economic damage. Damage curves will be incorporated into two revenue-based models (income capitalization and discounted losses) and one market-based model (hedonic regression) in order to estimate economic losses for commercial fisheries infrastructure; seafood processors, dealers and commercial fishing vessels.

Revenue and vessel license data required for the study will be obtained from the Trip Ticket Information System of the LDWF. To protect anonymity, only aggregated data from 2002 to 2004 will be used into developed alternative models. The outputs from the alternative models wills be analyzed descriptively and statistically using computer programs such as Microsoft Excel (Version 2003) and Statistical Analysis System (SAS) version 9.1.3 (released by SAS Institute, Inc in 2005). Spatial data will be geo-coded and analyzed using three integrated computer software that are ArcMap, ArcCatalog and ArcView version 9.0 (produced by ESRI Inc.). Based on the results of objectives two and three, recommendations will be made to ensure adequate data and methods are available for the assessment of coastal fisheries infrastructure damages following future disaster events.

CHAPTER 2: LITERATURE REVIEW

Economic Recovery from Natural Disasters

Disasters are different in terms of frequency, consequence, extent and predictability when compared to more normal events. Disasters occur when hazards hit a vulnerable area and cause chaotic situations both to society and environment, and thus have different economic impacts compared to changes in economic activities in normal conditions either naturally or due to human decisions such as public policies and regulations. There are two important period of disasters, short period of recuperation and the long-term recovery.

Okuyama (2005) described that immediately after a natural disaster, there is recuperation period of emergency response and restoration damages. In this phase, we require quick, accurate and reliable data, and effective information in order to formulate efficient decisions, particularly in terms of scare resource allocation. While, long-term recovery defined as rebuilding process that bring back the economic activities to the level of pre-disaster as soon as possible. This period is influenced by many factors, some of them are macroeconomic condition of the nation, and business cycle at national and regional level.

Natural disasters usually negatively impact economic activity (reduction in income generation, investment, production, consumption, and employment, and transportation and distribution implications) in the short run. In the longer term, a disaster may disturb economic growth and development, wealth improvement and poverty alleviation. But, as reported by Overseas Development Institute (ODI 2005), the construction development and infrastructure upgrades can result in positive economic activity after extreme disasters. However, economists suggest that the specific outcome of natural disasters on economic activity depend on sequencing of impacts, the type of hazard experienced, the vulnerability to a particular hazard, and other concurrence on economic performance.

In some cases, natural disasters are localized events, and are less likely to indirectly impact national markets though changes in output and prices. Horwich (2000) described that disasters could reduce capital stock, though not always outputs in some cases. He then explained that gross domestic product (as a measure of output) might increase due to the replacement of capital and other disaster related expenditures (such as rescue and clean up costs). In examination of the earthquake which struck Kobe, Japan in 1995, the quake, the worst to hit this modern city of around 4 million people, ruptured ports, buildings, roads, rail lines, water, sewer, electrical and gas systems. Many economists predicted that full recovery of the city would require a decade. However, the destruction of physical assets opened the way for innovations in human capital expertise. Through rapid rebuilding and the use of substitutes, much of the damage infrastructure was repaired relatively quickly. The primary economic activities of Kobe (e.g. manufacturing and imports) were back to 98 percent of their pre-disaster conditions within 18 only months, much quicker than previously estimated

In rural areas and developing countries, disasters not only affect on economic activities, but also may culminate in hunger and poverty if severe damage is caused to the agriculture and natural resource sectors (e.g. fisheries and mining). Long (1978) argues that agriculture is the most crucial single sector in many developing countries and accounts for the greatest source of employment, the most important national value-added, and a majority of foreign currency receipts. Agriculture and natural resources are fundamental sectors of national economics in term of capital formation, economic transactions, and social well being. Unfortunately, without appropriate infrastructures – as characteristic of many developing nations – such resource are susceptible to the destructive effects of natural disasters. It is therefore essential to explore available information on economic data and analysis as it pertains to mitigating the adverse effects of natural disasters on agriculture and natural resources.

Concerning hurricanes, Kelly and Zeng (1999) analyzed effects of intense hurricanes in regards to economic losses, while Burrus *et al* (2002) studied the impacts on low-intensity of hurricanes on regional economic activities. Based on Saffir-Simpson scale, low-intensity hurricanes are included in category 1–2. The category of 3-5 are called higher-intensity hurricanes. These intense hurricanes usually cause severe damages, and the potential losses are often several times greater than predicted. On average, the stronger the wind, the greater the costs of damage. A 15% increase in wind speed could cause a doubling in economic damages. Higher intensity hurricanes such as Andrew were found to cause $25 - $70 billion direct damages. Historical records; however, show that lower intensity hurricanes could cause less structural damages, but impacts on regional economic activities through business interruption were around $10 billion in potential damages. Because lower intensity hurricanes usually occur with more frequency, the cumulative impact can be significant.

The study of three low-intensity hurricanes, namely Bertha, Fran and Bonnie in region of the Wilmington, NC showed that the average per-hurricane impact on business interruptions (direct, indirect and induced impact) is equivalent to a high-intensity hurricane. In monetary terms, the costs of damages are approximately $3.7 billion during 1996 to 1998 observations. Hence, the exposure to both lower and higher intensify hurricanes are important for regulators, planners and insurance companies in order to formulate proper actions in the coming events

Resource Recovery vs. Resource Management

One purpose of social welfare program is to provide public goods. Public goods are not traded in the market, no price mechanism and no clearly ownership, thus public goods are non-excludable and non rivalry in consumptions. Kaul (2000) mentioned that once public goods exist, all may enjoy them. The dilemma that one, mainly profit oriented institutions will have rational strategic by waiting others, including competitors to provide public goods without own contributions. Some of public goods are health program, education, roads, airports, parks, security and a clean environment. Public goods may face with pollution, noise, street crimes, and even natural disasters without some sort of collective action mechanism. At national and international levels, public goods damages may require cooperation, policy harmonization and management to reach agreement on coordinated actions cross the borders, nations, generations and population groups.

Cowen (2002) described externalities in public goods. When person performs activity that affects on another individual well-being, but the relevant costs and benefits are not reflected in market prices, then externalities occur. A positive externality implies that a person's action may benefit other individuals. Negative externality is opposite to positive externality, in which one action may cause damage to other people. Externalities produce free rider problems that can be solved by business institutions in many ways, among them are excluding non-payers from enjoying the benefit of goods or service. Some of examples are fee basis for cable TV, toll for highway, charge for fire services and license fee for fishing (either commercial or recreational fishing). Another way to solve free-rider is by defining individual property rights in the appropriate economic resources such as lake. By lake ownership, the cost of cleaning and maintaining could be charged to the users (fishermen, boaters and other recreational users).

Agriculture has both positive and negative externalities. Spreading fertilizers on farms can cause nitrogen and phosphorus run off in local waters. On the other hand, farmers generate public goods in forms of traditional rural landscapes and a habitat for wildlife. Hanley *et al* (1998) suggested applying the Polluter Pay Principle (PPP) for producers of negative externality, and Provider Get Principle (PGP) for positive externality suppliers. How much farmers should pay or get pay depends on several criteria guided by government policies. However, in the almost 30 countries of Organization for Economic Co-operation and Development (OECD[1]), including USA, farmers were subsidized to reduce emission of Nitrogen from fertilizers, because farmers have political power.

In fisheries with common property ownership, the resource is open for access to all fishermen. In the open access concept, fisheries are a public resource and too much the fish will be harvested from social perspective without regulation. The fishermen will harvest the resources until the costs to catch an additional fish (marginal costs) equal to the price of the fish (marginal benefit). Continuing of exploitation open access resource may lead to severe stock depletion, by decreasing the stocks available for catching, the individual efforts cause the increase of marginal costs to all other fishermen. (Welmer and Vining, 1999).

Free and open access absent of management restrictions often leads to overcapacity, and can result in over-fishing in domestic and global fisheries. Overcapacity can't be corrected by itself and if not addressed properly, the problem would extend indefinitely. The Food Agriculture Organization (FAO, 2007) suggested that before any decision is made, assessment of the existing and desirable level of fishing capacity should be conducted through knowing the amount of fish that can be harvested in certain period by a fishing boat at given resource conditions. Then, excessive levels of fishing effort would be reduced by restriction of fishing access (limit the

[1] Names of OECD countries and date of their entrance to organizations are Australia (7 June 1971), Austria (29 September 1961), Belgium (13 September 1961), Canada (10 April 1961), Czech Republic (21 December 1995), Denmark (30 May 1961), Finland (28 January 1969), France (7 August 1961), Germany (27 September 1961), Greece (27 September 1961), Hungary (7 May 1996), Iceland (5 June 1961), Ireland (17 August 1961), Italy (29 March 1962), Japan (28 April 1964), Korea (12 December 1996), Luxemburg (7 December 1961), Mexico (18 May 1994), Netherlands (13 November 1961), New Zealand (29 May 1973), Norway (4 July 1961), Poland (22 November 1996), Portugal (4 August 1961), Slovak Republic (14 December 2000), Spain (3 August 1961), Sweden (28 September 1961), Switzerland (28 September 1961), Turkey (2 August 1961), United Kingdom (2 May 1961), and United States of America (12 April 1961)

number of fishermen entry, fishing net size, and fishing fleet size) and by inducing property rights. Reductions in capacity level would, in theory, lead to increased efficiency of fisheries harvesting and improve fish stocks.

Each fisherman tries to make a maximum profit, yet fisheries resources are limited. Exploitation beyond the maximum sustainable yield leads to over-exploitation. Hardin (1968) described a tragedy of commons that can result when individuals attempt to maximize their profit in an open-access resource. Each individual, being rational, will overexploit his/her share of the common in the fear that others will do likewise. In the rush to fully exploit the resource, overcapacity results and individuals bring the ruin to themselves. According to Hardin, there is no technical solution in this situation. The only way to solve the problem is to change human values, ideas (policy) and morality.

Sterner (2003) reports that many fish stocks have indeed been harvested beyond their maximum sustainable yield. Since 1980s, fishing boats have grown in number, size and technology such sonar and global positioning systems (GPS) that help them to locate and identify fish schools at the species-level of accuracy. These sophisticated technologies combined with jumbo fishing net sizes and electronic fishing lures have caused depletion of important commercial fish species in many parts of ocean of the worlds.

In the USA, fish stocks are managed within eight fisheries management council regions, namely New England, South Atlantic, Mid Atlantic, Gulf of Mexico, Pacific, Western Pacific, North Pacific, and Caribbean. As confirmed by Hanna *et al* (2000) some fisheries in these regions have witnessed severe stock depletions, while other fisheries are generally healthy. Nationwide, 30% of the fish stocks are classified as over-fished, 3% are classified as approaching an over-fished condition, and 67% are classified as healthy. In socio-economic terms, overcapitalization and loss of potential productivity due to too many fishing vessels are growing concerns for the US commercial fishing industry. Each stakeholder in a particular fishery has different short run and long run objectives, making management very difficult. Thus, when the government responds to a natural disaster that impacts fisheries, these management conflicts often cause problems in developing recovery programs and policy.

In the case of the hurricanes of 2005, there were numerous proposals for recovery of the commercial fishing fleets and infrastructure. These proposals often had different long run and short run objectives. An initial proposal submitted by NMFS (2005_b) included $1.25 billion for fisheries recovery, but more than half of that funding was budgeted for habitat recovery and capacity reduction. The disaster declarations issued by the US Department of Commerce after Katrina and Rita included a clause which stated that before funds are disbursed, the Secretary must first "determine that the activity will not expand the commercial fishery failure in that fishery or into other fisheries or other geographical regions" (CFDA 2006).

Fisheries Damage Assessment Models

Economic development is not linear, and is sometimes disrupted by disasters (natural or man made). Unfortunately, disasters are perceived as an abnormality outside the mainstream of development theory in macro-economic studies. Integration of disasters and development is needed to protect vulnerable people (Pelling *et al*, 2002)

One of the world's worst natural disasters occurred in Banda Aceh, Indonesia on December 26th of 2004. Borrero (2005) reported that a tsunami was generated by a 9.3 magnitude earthquake. About one and a half hours after the earthquake, the ocean receded more than 500 m, and then penetrated inland three times, reaching sites around 500 m to one km from shoreline with wave heights of 4.2 - 4.7 m above sea level. The tsunami caused extreme flooding and damages along the Northern and Western coast of Sumatra, in which the two largest cities of Banda Aceh and Meulaboh were the most devastated. Then, in a short time, the tsunami reached the shores of Thailand, Sri Lanka, India and Maldives, and even to Somalia and the East coast of Africa continent.

With the exception of the 2004 tsunami, Katrina and Rita were the most costly natural disasters on the record. The Economics and Statistics Administration (ESA 2006) of the US Department of Commerce reported that the 2005 hurricanes disrupted many commercial sectors in the states of Louisiana, Mississippi and Alabama. The hurricanes impacted on banking and business activities, caused higher unemployment rates, reduced housing construction activity, decreased the export and import of goods through the gulf ports, disturbed oil production and distribution, and destroyed some portions of agriculture, forestry, and fishing industries. At national level, both hurricanes impacted on GDP growth, and federal budget deficit and spending

As mentioned by the Committee on Assessing the Costs of Natural Disasters (CACND *et al*, 1999), proper data are required to estimate the losses from natural disasters. There are two types of data, direct and indirect. The direct data should include who bears the losses: government, insurer, business, individual, or NGO; and the type of losses: property, agriculture products, human life; clean up and responses costs, and adjustment costs. Indirect losses were the losses that caused by losses resulting from the consequences of physical destructions. The temporary unemployment rates or business relate activity disruptions are examples indirect losses. These indirect losses are diffused and rarely quantified.

Pielke and Landsea (1998) explained that decision makers in public and private agencies, meteorologists, and even general public across nations are increasingly concerned over global climate and weather changes and how those changes might affect society. The policy-makers require reliable information about frequency, intensify, trends, causes and projections of global climate changes. Other important data needed are coastal population and wealth variability of society in order to set a range of policy alternatives related to disaster mitigation and recovery.

Powell *et al* (1995) developed a real-time damage assessment model for hurricanes. Assessments were based on correlations of observed damages from past-storms, in which predictors were derived from meteorological field information quantities combined with Geographic Information System (GIS), infrastructure and demographic databases. Since, the model captured the real-time information on the actual areas impacted by hurricanes, the results of assessment were even quicker than visual surveys with minimum confusion at the early stage of disaster. Thus the model could be reliable for disaster emergency managers and decision-makers to make quick recovery planning. Quicker recovery, faster community to recover, make less relate damage costs due to disasters.

For hurricane Katrina, Burton and Hicks (2005) conducted preliminary estimates of total commercial and public sector damages. Their estimates were based on an economic model of flood damages that was developed for the upper Mississippi River in 1993. In their model, the dollar value of flood damages was a function of several demographic variables; including but not limited to total population, age distribution and geographic dispersion, a vector of economic variables such as per capita personal income, number of businesses and the value of public infrastructure, and also variables describing the flood events themselves such as maximum stage of water height and the duration of flooding.

Based on the estimated results from the above model, Hurricane Katrina generated commercial structure losses of $21 billion, commercial equipment damages of $36 billion, residential structure damages of $50 billion, residential content damages of $24 billion, commercial revenue losses of $4.6 billion, electric utility damages of $231 million, highway destruction of $3 billion, and sewer system damages of $1.3 billion. The total damages in the three states (Louisiana, Mississippi and Alabama) and those 8 damage categories are approximately $150 billion. Comparatively, Czerwinski (2007) collected several estimates, in which losses ranged between $70 billion to $150 billion.

An assessment of Hurricane Rita was conducted by NCDC (2005b) to estimate overall economic damages. Rita was the second hurricane that reach category 5 Saffir-Simpson scale of 2005 hurricane season. The hurricane hit the Louisiana-Texas border, creating significant storm surge, and landfall damages along the coastal region. Storm surge at landfall reached 15 feet, and flooded coastal towns. Damage across the Louisiana/Texas border was widespread. Many highways and minor roads were impassible due to over 3 million people being evacuated. Preliminary estimate of approximately $16 billion in damage costs, and 119 deaths reported because of direct and indirect causes.

In the fisheries sector, the 2005 hurricanes have had a wide variety of effects on fish, fisheries, and their supporting infrastructure. A number of projects to relieve and reconstruct fisheries have been proposed and planned by a variety of local, state, and regional fisheries institutions. No attempts, however, have been made to prioritize these projects or to provide accurate cost estimates (NMFS 2006). Buck (2005) reported that hurricanes Katrina and Rita hit the some of the important Gulf of Mexico fishing regions. The storms caused severe losses to segments of the fishing industry, including vessels, docks, processor and dealers. According to the author, hurricane Katrina caused damages to the fishing industry of around $1.1 billion and upwards of $2 billion when both Katrina and Rita are combined.

Some have suggested that the variation in hurricane damage estimates from time to time is due more than to a difference in model assumptions and data. Engber (2005) found a wide range of damage costs due to hurricane Katrina were between $9 billion to $100 billion. The author explains that estimations differ because of different goals between institutions. Insurance agencies have always lower estimation compared to public institution. Insurance agency to create own estimation for specific liabilities, while public institution calculated overall damage costs, including indirect costs, thus wide range values of estimate damages justified

Additional models for estimating damages due to natural disasters have been developed individuals in various other disciplines and state and federal agencies. The following sections compare several of these models, and their application to the storms of 2005. These comparisons provide insight on how these models work to estimate damages caused by natural disasters at different places and times.

Input-output

Input-output (I-O) analysis interconnects one industry to another, in which one industry depends on another as a consumer of output and supplier of input. The analysis is based on the concept of economic balances that are embedded in a circular flow of economic activities. The mathematics of input-output economics is straightforward, but the data requirements are large because the expenditures and revenues of each branch of economic activity must be represented.

Input output economics has been used to study regional economics within a nation, to predict flow between sectors (economic forecasting), and as a tool for national economic planning. Rose (2006), Yamano *et al* (2004) and Chang *et al* (1996) state that this input output analysis framework has been widely used in USA, Europe and Asia to evaluate the economic impacts of natural disasters such as earthquake, floods and hurricanes.

Bockarjova (2004) developed Input-output model to estimates the economic impact of major catastrophes including earthquakes, hurricanes and floods. The basic concept of the model is given by equation 2.1:

$$x = A^0 x^0 + f^0 \qquad (2.1)$$

In which damages, given by *x*, are a function of x^0 which is equal to total output, A^0 which is an input coefficient and f^0, final demand before the disaster. If there is a shock due a catastrophe, the final demand will shift, thus affect on the total output of producers. Disasters may also disturb input, thus affect on reduction in production. This shock causes delay for long-term growth.

Chang *et al* (2006) developed an adaptation of the input/output model to estimate impacts of hurricane Katrina on seafood industry in Alabama. The model equation is:

$$L = P + F + R \qquad (2.2)$$

In which, $L =$ losses, $P =$ loss to private properties, $F =$ damage to public infrastructures, and $R =$ lost revenue. Loss to private properties (P) includes losses to seafood plants (P^T), physical damages to commercial fishing boats (P^{B1}), removal costs of displaced commercial fishing boats (P^{B2}), losses to charter boats (P^C), losses to docks & marinas (P^D) and inventory losses (P^V). Losses to private properties are adjusted for past and future payment from insurance (P^N). Damages to public infrastructures (F) includes loss to fishing habitat (P^H), ship channel dredging for debris removal (P^S), and damages to public access to waterfront (F^W).

Moreover, lost revenue and cash flows include gross sales revenue lost during the recovery period from the time hurricane Katrina hit to the time of completing the recovery of damaged private properties (R^G) which include unpaid wages and outstanding debris that incurred but remained during recovery period due to lack of revenue, and future revenues lost due to the lost of marketing channel (R^M). Assume that “a” represents an adjustment factor for the seasonal nature of harvesting as well as changes of fuel prices and new laws. In addition, there is a loss to community through indirect effects known as multiplier effects (m). Thus, the new losses equation is:

$$L = P^{T} + P^{B1} + P^{B2} + P^{C} + P^{D} + P^{V} + P^{N} + P^{H} + P^{S} + F^{W} + (aR^{G} + R^{M})x(1+m) \qquad (2.3)$$

The model estimated actual and potential loss from Katrina to the Alabama seafood industry. The actual loss included net value of damages on boats and facilities ($ 25 million), vessel removal ($3.8 million), lost inventories ($20.5 millions), wages and invoices unpaid ($5.9 millions), and lost revenue and future lost sales ($ 51.1 millions). Potential loss included loans from Small Business Administration (SBA) and loans from other sources were approximately $ 5.8 millions and $61.1 millions respectively. Thus, the total damages loss was about $173.2 millions.

Additive Approaches

Posadas (2006a and 2006b) has developed additive formulas to estimate losses of the commercial fishing fleet, seafood processors, and dealers due to hurricane Katrina. The total commercial damages (TD) were separated and estimated by three industry segments: damages to seafood processors (D^P), damages to dealers (D^D), and damages to vessels (D^V).

$$TD = D^{P} + D^{D} + D^{V} \qquad (2.4)$$

Damages to seafood processors and dealers equaled to the sum of reported damages to buildings, processing, storage, refrigeration, delivery equipment, other accessories, plus damages to cleaning, removal and disposal costs, and inventory losses. Net reported damages were equal to total reported damages, minus total insurance payments received. Damages to the fishing industry were equal to the sum of damages to vessels and engines, damage to fishing gear and other accessories, plus cleaning, removal and disposal costs. The net reported damages equaled total reported damages minus total insurance payments received. Sample data were obstained for each of these categories and then extrapolated to the fishing industry in coastal Mississippi. Total damages for processing plants were $77.8 millions, seafood dealers were $21.3 millions and $2.1 millions for land-based support facilities. Net damages for processing plants, seafood dealers and land-based support facilities were $67.3 millions, $18.7 millions and $1.9 millions consecutively. Net damages to the fishing fleet (1,030 units estimated) equaled $33.6 million.

Structural Damage Models

Hazus is an abbreviation for Hazard United States, a software program based on GIS technology. The software is a national standard for estimating losses due to earthquakes, hurricanes and floods. This program uses an engineering approach and mathematic formulas integrated with the latest GIS technology to produce estimates of physical damage, economic losses, casualties, and other societal impacts before or after a disaster occurs.

For hurricanes, the FEMA developed a wind preview model for Hazus in which users are able to assess hurricane winds and compute basic estimates of potential damage to residential, commercial, and industrial buildings (FEMA, 2004). The model incorporates sea surface temperature in the boundary layer analysis, and calculates wind speed as a function of central pressure, translation speed, and surface roughness. The model addresses wind pressure, windborne debris, surge and waves, atmospheric pressure change, wind duration/fatigue, and rainfall accumulation.

Pagnotti *et al* (2006) applied HAZUS to estimate the direct structural losses and damages of a hurricane directly striking Florida A&M University and its satellite campuses. The simulation result showed that with a category 1 hurricane (wind speed of 74-95 mph) to category

5 (wind speed of greater than 155 mph), the total direct economic loss for three sites (main campus, college of engineering and college of entomology) would be approximately $3.7 millions. The destruction included parts of buildings, contents and inventories.

The Center for Natural Resource and Economic Policy (CNREP 2006) developed preliminary estimates of structural (infrastructure) loss for commercial industry sectors (e.g. shrimp, oyster, crab, etc.) after Hurricanes Katrina and Rita in 2005. There were two models initially used to assess infrastructure damages, both of which utilized highly aggregated commercial sector revenues as a proxy of business sector value. The first is a form of partial income capitalization (AIREA 1983) derived from property appraisal technique in which the value of business's infrastructure is calculated as a function of the net income generated by that infrastructure.

$$\frac{D^S = ((GR^S * NI^S) * z^S)}{r^S} \qquad (2.5)$$

Where D^S is total economic damage in dollars for commercial sector, *S*. GR^S is the average annual gross revenue of sector S (derived from trip ticket data). NI^S is the average net income percentage of sector S (derived from secondary data and industry reports). Z^S is a sector-specific estimate of percent revenue loss, and r^S is an industry-specific capitalization rate ranging from 5 to 15 percent.

The second model was developed by World Bank (2003). This model based on discounted loss approach, in which net income and infrastructures damages are discounted over 5 years period.

$$D^S = ((GR^S * NI^S) * z^S) x (1 + r^S)^{yr}) \qquad (2.6)$$

Where: D^S is the present value of dollars lost to a sector due to infrastructure damage and lost production over 5 years. GR^S, NI^S and Z^S are specified in above equation 2.4, r^S is a risk adjusted capitalization rate ranging from 5 to 25 percent, and yr is years 1-5. These two models are embedded with a damage variable "z^S" that would ideally allow for economic damages to be estimated as function biophysical data (e.g. wind speed and wave height)[2]. These models estimated infrastructure loss for commercial vessels, dealers and processors in Louisiana. The result of estimation was range from $272 millions to $585 millions.

Caffey, Diop, and Liffmann (2006) break down the losses into two sectors: commercial fishing industry and recreational fishing industry. Based on the income capital model, the total estimate loss for commercial fishing industry was $272 millions and $121.5 millions for recreational fishing industry. Then, using the discounted loss approach, the total damages for commercial fishing industry was $585 millions and $358.7 millions for recreational fishing industry

Caffey et al. (2007) developed a more geographically-specific damage models for coastal fishing infrastructures damaged by hurricanes Katrina and Rita in Louisiana. That model was based on a relationship between water level and business damages for fishing dealers and processors. The model form is as follows:

$$Damage = (\beta_1 + proc.\beta_3).MaxWave + (\beta_2 + proc\beta_4).MaxWave \qquad (2.7)$$

[2] No biophysical data were available at the time these preliminary models were first estimated in January 2006, thus a z-value of 50% was assumed for all coastal fishing sectors.

Where *Damage* is the percent damage to business value; proc is 1 if the respondent was processor, zero otherwise; MaxWave is the estimated maximum wave height experienced at the business site (as indicated by the LSU Hurricane Center's ADCIRC Model and ground truth observations); and $\beta 1$ through $\beta 4$ are the estimated parameters. Total estimate economic losses due to hurricanes Katrina and Rita for dealers business was \$103.5 million and processor business was \$63.8 millions. The most damage occurred in Region 2 (Jefferson, Lafourche, Plaquemines, St.Bernard and St.Charles parishes) for dealers business and Region 4 (Acadia, Calcasieu, Cameron, Jefferson Davis, and Vermilion parishes) for processor business. Additional damages were estimated for fishing vessels using a hedonic model based on market values (for sale ads) and a vessel database maintained by the LDWF. That model produced economic damages of \$191 million and \$224 million for commercial and recreational boats, respectively.

CHAPTER 3: DATA AND METHODS

Development of a geographically-specific model for rapid and accurate assessment of the economic losses to coastal fishing infrastructure resulting for hurricanes requires two types of information. Spatial data is required to spatially map commercial fisheries infrastructure and storm surge heights. Economic data is required to estimate the value of that infrastructure.

Spatial Data: Fisheries Infrastructure

In June 2006, 3 years (2002-2004) of pre-storm trip ticket data were obtained from LDWF. Trip tickets are a required record-keeping system that requires commercial fishermen and seafood dealers to report detailed records on any seafood landed at a port in Louisiana. The records include information on the type of species caught, the amount of volume and price received for the catch. Each commercial fishermen and dealer must purchase a license. That license tells where the vessel or dealer is located, or where the business office is located. In addition, production records for Louisiana's coastal seafood processors were obtained from the Louisiana Department of Health and Hospitals. These address data were tabulated, geo-coded and mapped to see their distribution in Louisiana, especially in the 22 coastal parishes[3].

Geo-coding and mapping were conducted using software developed by ESRI Inc. (Environmental Systems Research Institute Incorporation). We used GIS (Geographic Information System) computer software with three programs for our project purposes: 1) ArcMap 9.0; 2) ArcCatalog 9.0; and, 3) ArcView 3.8. The first two programs are integrated into

[3] 22 coastal parishes as main target of our study are; 1.Ascension, 2.Livingston, 3.Orleans, 4.St. John, 5.St. Tammany, 6.Tangipahoa, 7.Jefferson, 8.Lafourche, 9.Plaquemines, 10.St. Bernard, 11.St. Charles, 12.Assumption, 13.Iberia, 14.Lafayette, 15.St. Mary, 16.St. Martin, 17.Terrebonne, 18.Acadia, 19.Calcasieu, 20.Cameron, 21.Jeff Davis and 22.Vermillion

a software called ArcGis 9.0 and can be used separately or together. The ArcMap program enables one to view a map and read and edit geographic data. Geo-coding processes are conducted automatically by ArcMap. Layers and tables in the current target map can be used as input in the geo-coding process, and output can be automatically added to the map as layers (Informatics Center 2004). The accuracy of the geo-coding results depends on the information given. The information should at least contain five variables: street address, city, state, zip-code and country names. The variables must be properly spaced for the geocoding software to work. Variables were separated into spreadsheet columns using Microsoft Office Excel version 2003.

ArcCatalog is designed to organize and manage GIS data. The software also functions as a bridge between the directory and ArcMap. In this case, the ArcMap could only conduct geo-coding processed through the ArcCatalog program. Zeider (2002) introduced that an ArcCatalog program that could browse and find and preview data or attributes. ArcCatalog is also able to organize, distribute, manage and document GIS data. Compared to Microsoft Windows Explorer, ArcCatalog is designed to only view geographic databases, maps, and metadata. ArcView performs mapping of GIS data and transforms longitude and latitude information provided by ArcMap 9.0 into centroid (x,y coordinates) for the particular map. The program also reads the information that is stored in form of shape files. As described by ESRI (2005), a GIS map is different from other static paper maps, and digital or electronic maps. GIS maps are dynamic. They contain real world information such as a city population, distance between cities, street address and the name of buildings or other infrastructures on the map. Since GIS maps are dynamic, we can interactively zoom in and zoom out, increase or decrease the scale of map, and access, integrate and analyze a database of all information about the features shown on the map.

Seafood Processors

Data for 114 seafood processors and plants (2004 data) were obtained from the Louisiana Department of Health and Hospitals (LDHH). These data were geo-coded manually through the free-ware program available via the internet. Initially, we batch-processed 20 - 50 processors at one time, and the internet program converted these addresses to latitude/longitude data. The batches were continued until all 114 processors and plants matched. The ArcView 3.8 program was used to map the geographic distribution of seafood processors and plants in Louisiana (Figure 3.1)

Seafood Dealers

Quantity and value data for 1,136 seafood dealers were obtained from aggregated LDWF records averaged for the years 2002 to 2004. These data were obtained from the LDWF Trip Ticket Information System. Data were tabulated in a spreadsheet (Microsoft Excel version 2003) and then stored in form of data base file (Microsoft Access version 2003) for further application and analysis. Dealer data were imported from the ArcCatalog database and then exported into ArcMap for geo-coding. Fifty five percent of the 1,136 data were matched, in which their latitudes and longitudes were presented. The remainder of data was exported back to the database file for batch processing manually through an interactive program from the internet[4]. After all data were matched and re-matched, the ESRI program (ArcView 3.8) read the matched results and presented the coordinates on the map. The next steps were editing and transforming the map into JPEG file, the distribution of seafood dealers is viewed in Figure 3.2.

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[4]Public domain software developed by Stephen P. Morse (San Francisco, USA) is available on-line at no cost through website: http:// www.stevemorse.org/jcal/latlon.php. This software converts street address to latitude/longitude coordinates and vise versa.

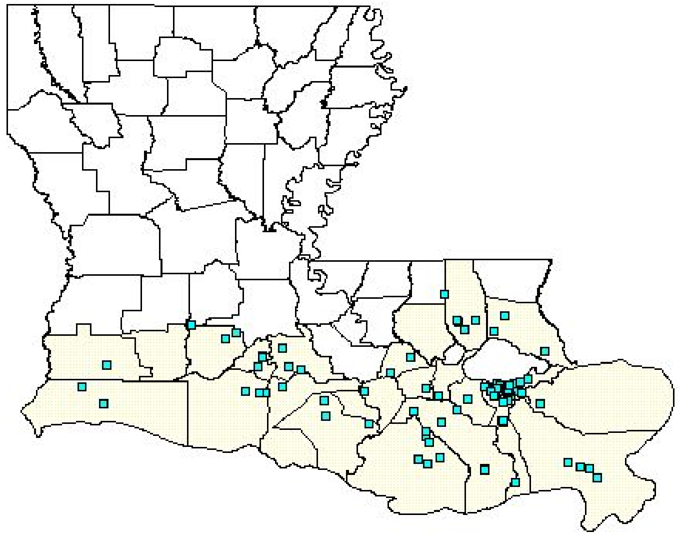

Figure 3.1. Distribution of Seafood Processors in Coastal Louisiana

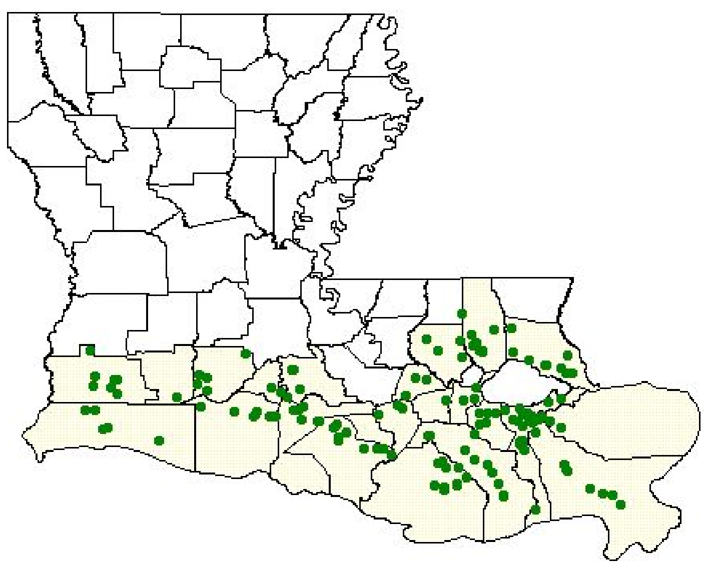

Figure 3.2. Distribution of Seafood Dealers in Coastal Louisiana

Commercial Vessels

Landing and value data for 9,612 commercial fishing vessels (8403 state-licensed and 1209 federally-licensed) were average data from 2002 to 2004, obtained from LDWF. The data were arranged in Microsoft excel version 2003 for geo-coding automatically by ArcMap and ArcCatalog of ESRI programs. The results showed only 60% matched. The remainder of the unmatched data was manually geo-coding through the public domain software available in the internet (morse 2007). After several attempts of batch processing, the 100% of the commercial vessels were matched and geocoded. The distribution of commercial fishing boats in 22 parishes of Louisiana is mapped by ArcView 3.8 (Figure 3. 3).

Recreational Vessels

Data for 159,444 recreational fishing boats located in the 22 coastal parishes of Louisiana were obtained from LDWF license records in 2004. Since there were a much larger number of recreational boats, the data we imported into Microsoft Excel (version 2003) and divided into three worksheets. These date were then imported into ArcMap and ArcCatalog programs to automatically geo-coded the worksheet data. Latitude and longitude positions could only be found for 116, 397 vessels, or 73 percent of the registration data. Time constraints prohibited the manual geocoding of the remaining 43,000 recreational vessels. For this reason, and due to the fact that recreational vessels are much more trailerable[5] than commercial boats, we decided not to incorporate the data for recreational vessels in the economic damage model. The ArcView 3.8 program imported the matched data and transformed them into the map. The distribution of recreational boats in coastal Louisiana is shown at Figure 3.4

[5] It should be noted that geo-coded vessel addresses do not necessarily represent the actual location of the recreational or commercial vessels. These data pertain to the physical address of the license-holder. Recreational vessels are usually much smaller on average and thus more maneuverable when a hurricane threatens the coast.

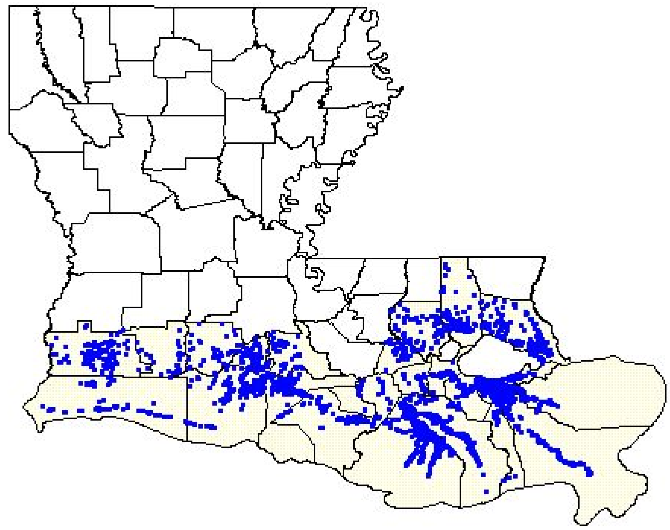

Figure 3.3. Distribution of Commercial Fishing vessels in Coastal Louisiana

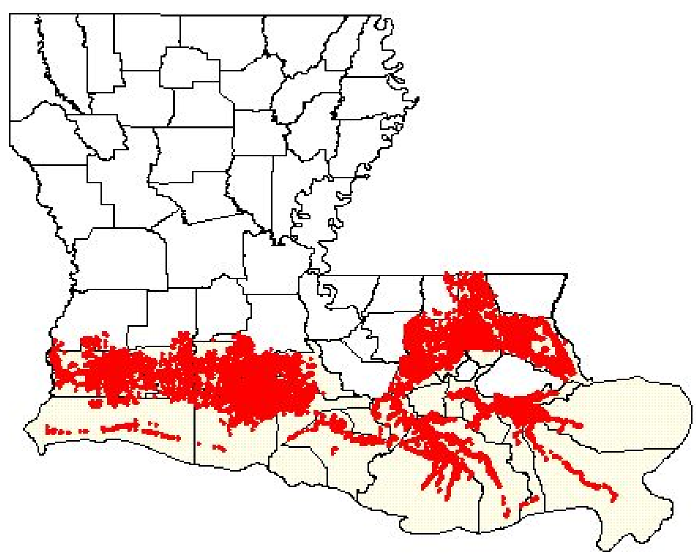

Figure 3.4. Distribution of Recreational Boats in Coastal Louisiana

Combination of Geo-coded Fisheries Data

Distribution of processors, dealers, commercial fishing boats, and recreational boats has been mapped separately in Figures 3.1, 3.2, 3.3, and 3.4 respectively. ArcView 3.8 is used to iintegrate these data layers into a single GIS map. First, we imported the shape file of recreational boats, followed by commercial boats, dealers and processors consecutively. The distribution of this coastal fisheries infrastructure is shown in Figure 3. 5.

Spatial Data: Hurricane Surge

Physical data are needed to find out relationship between storms and damages caused by them. The important physical data are wind speed, tidal height and coastal storm surge. These quantitative data are important in order to look at details of fisheries infrastructures damages along the path of hurricanes Katrina and Rita in Louisiana.

Storm surge is a critical determinant for estimating damage losses due to hurricanes. Storm surge is coastal water pushed inward by hurricanes wind. Storm surge combined with normal tides can increase water levels causing severe flooding in coastal areas. The danger of storm surge is tremendous, especially in the low sea level and dense populated area such as in the gulf states of United States.

Storm surge of hurricanes Katrina and Rita was estimated by Hsu *et al* (2006), using variables of sea level pressure, shoaling factor and correction factor of storm motion. The authors found that maximum storm surge was 26 – 28 feet over western coast of Mississippi for hurricane Katrina, and 16 – 18 feet over coastal areas of Cameron Parish in Louisiana for hurricane Rita. Additional storm surge modeling was developed by the LSU Hurricane Center. Before and after Hurricanes Katrina and Rita, the LSU Hurricane Center used the Advanced Coastal Circulation (ADCIRC) Model to predict maximum surge water levels associated specific storm events. To simulate maximum surge level, ADCIRC incorporates data on storm trajectory and storm magnitude and combines that information with detailed information on coastal bathymetry and elevation (ADCIRC Development Group 2006).

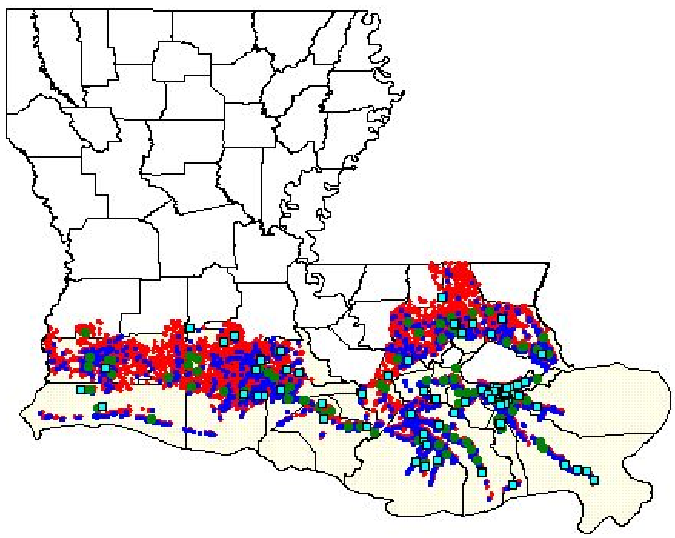

Figure 3.5. The distribution of seafood processors (light blue), seafood dealers (green), commercial fishing boats (blue), and recreational boats (red) in Louisiana

In 2006, the LSU Center for Natural Resource Economics & Policy (CNREP) obtained ADCIRC surge height data for Hurricane Katrina and Rita. This data was developed by multiple storm surge simulations conducted prior to each storm that were later refined by post-storm hind-casting to produce a detailed depiction of the maximum flood heights across coastal Louisiana for Hurricanes Katrina and Rita. Maximum water level records were developed through this process for more than 500,000 coastal Louisiana locations (i.e. simulation nodes). Figures 3.6 and 3.7 depict the maximum water heights at each of these nodes for hurricanes Katrina and Rita. This surge data was previously mapped on a 1-mile grid for the 22 coastal parishes of Louisiana (Caffey et al 2007). When combined with the fisheries infrastructure maps described in the previous section, a maximum water height (for Hurricanes Katrina and Rita combined) could be estimated for each processor, dealer, and commercial fishing vessel location in coastal Louisiana.

Economic Data: Processor and Dealer Revenues

The LDWF has collected commercial trip ticket records since 1999. These data could be formulated and applied for revenue estimated purposes. The data include economic values of fishing infrastructures and fishing related activities (commercial and recreational vessels, dealers, processors and plants, fish species, fishing location, trip length, fishing results and fish prices). The LSU Center for Natural Resource Economics and Policy obtained trip ticket records from

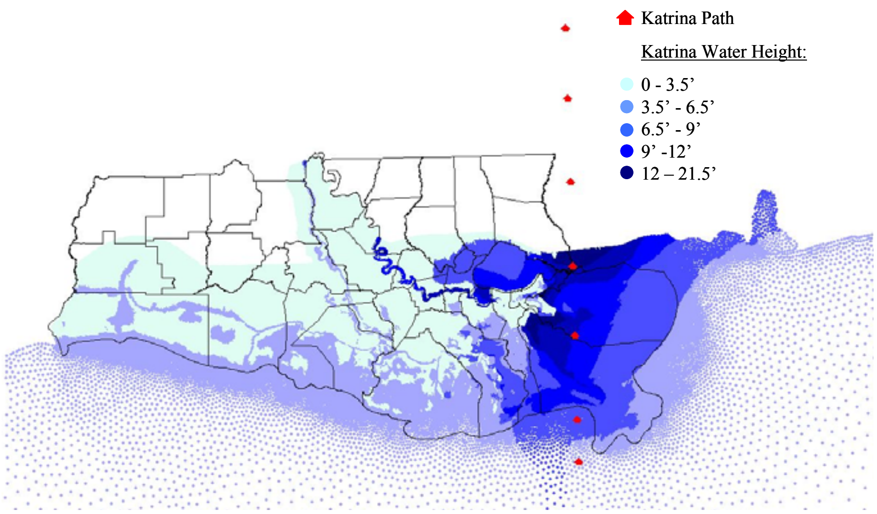

Figure 3.6 Maximum Water Levels for Hurricane Katrina derived from ADCIRC modeling conducted by the LSU Hurricane Center

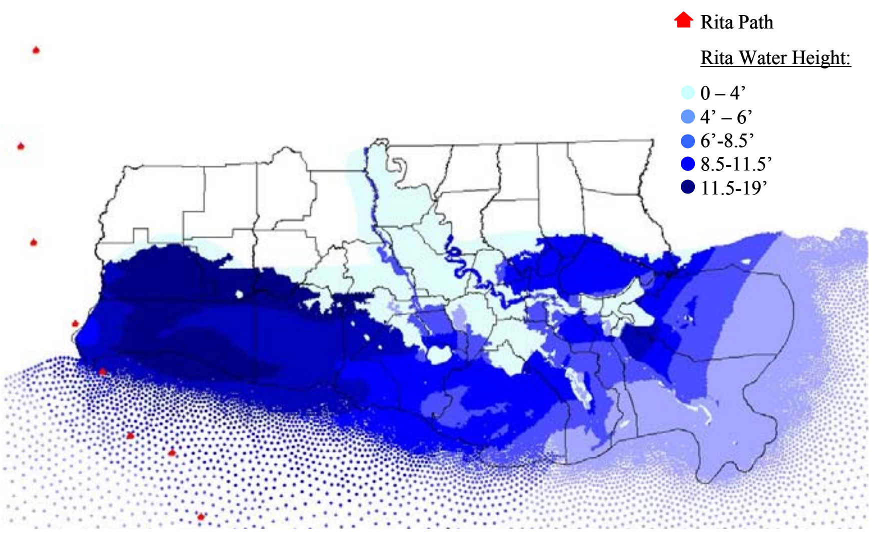

Figure 3.7 Maximum Water Levels for Hurricane Rita derived from ADCIRC modeling conducted by the LSU Hurricane Center.

LDWF for the years 2002-2004. These data were averaged to into a three-year, pre-storm annual average Louisiana landings and revenues. As previously described in Chapter two, the CNREP developed structural damage models in early 2006 using aggregated revenues to produce preliminary infrastructure damage estimates for coastal fisheries sectors. Here, we expand on those models by employing more specific information on individual firm revenues and geographically-specific estimates of storm surge.

The first model, based on a form of partial income capitalization (AIREA 1983), is rewritten as:

$$\frac{D^A = ((GR^A * NI^{AB}) * z^A)}{r^B} \qquad (3.1)$$

Where D^A is total economic damage in dollars for firm A. GR^A is the annual gross revenue of firm A (derived from trip ticket data). NI^{AB} is the net income percentage of firm A in terms of the average returns for a specific fishing sector B (derived from secondary data and industry reports). Z^A is a geographically-specific estimate of percent revenue loss, and r^B is an industry specific capitalization rate ranging from 5 to 15 percent.

The second model, based on discounted loss approach (World Bank 2003), is rewritten as:

$$D^A = ((GR^A * NI^{AB}) * z^A) x(1 + r^B)^{yr}) \qquad (3.2)$$

Where: D^A is the present value of dollars lost to firm due to infrastructure damage and lost production over 5 years. GR^A, NI^{AB} and Z^A are specified in above equation 3.1, r^B is a risk adjusted capitalization rate ranging from 5 to 25 percent, and yr is years 1-5.

As previously noted, these two models are embedded up with a damage variable "z" that allows for economic damages to be estimated as function biophysical data (e.g. wind speed and wave height). In the previous application of these two models, no specific biophysical data were available, and so damages (z) were assumed to be 50% coast-wide. However, the surge data obtained from the LSU Hurricane center establishes a maximum water level for every location of commercial fishing infrastructure (processors, dealers, vessels). In turn, those surge levels can be used to quantify "z^A" using previous studies which establish functional relationship between surge height and economic damage to specific types of coastal fishing infrastructure. Kazmierczak (2007) developed damage curves for seafood dealers and processors based on field surveys conducted in the year following the 2005 hurricane season. A curve fit (R^2 =.98) to the damage function for seafood processors, is given by :

$$z^P = (0.6552x^2 - 4.7132x + 5.4162)/100 \qquad (3.3)$$

And a curve fit (R^2 =.97) to the damage function for seafood dealers is given by :

$$z^D = (41.048 * Ln(x) - 7.9819x)/100 \qquad (3.4)$$

Where z^P is the damage (expressed as percent revenue loss) to seafood processors, z^D is the damage (expressed as percent revenue loss) to seafood dealers, and x is the maximum storm surge height (for Katrina and Rita combined) as estimated by the ADCIRC model.

Economic Data: Commercial Vessel Values

Caffey (2007) utilized a comparable sales method using data from more than 600 fishing vessel for-sale ads issued before and after Hurricane Katrina. A subset of these ads (n=114) was obtained for commercial fishing vessels. Using these data, a regression was developed in which the value of a commercial fishing vessel was described as a function of two attributes for state vessels (R^2=.83):

$$Ln(v) = -67 + 2.5 * Ln(l) + 0.0344(y) \qquad (3.5)$$

and one attribute for federal vessels (R^2=.90):

$$Ln(v) = 2.4 + 2.301 * Ln(l) \qquad (3.6)$$

Where v is the market value of a particular fishing vessel, l is the vessel's length and y is the vessels age in years. Although additional variables were originally incorporated into the model (i.e. hull material, propulsion, fuel, etc) these relatively simple functions do an adequate job of predicting a vessel's market value (Figure 3.8).

The damage function for commercial vessels was estimated using data collected by the US Army Corps of Engineers after flood and storm surge events in Galveston, Texas and the Pearl River Basin, Mississippi (USACE 2006). The USACE report includes a series of tables with water depth and percent damage for a variety of coastal infrastructures. Fitting a curve (R^2=.99) to the damage data reported for commercial fishing boat, yields the equation:

$$z^V = (41.048 * Ln(x) - 7.9819x)/100 \qquad (3.7)$$

Where z^V is the damage (expressed as percent loss in value) to a commercial fishing vessel and x is the maximum storm surge height (for Katrina and Rita combined) as estimated by the ADCIRC model. Figure 3.9 depicts this damage curve along with the damage functions estimated for commercial seafood processors and dealers.

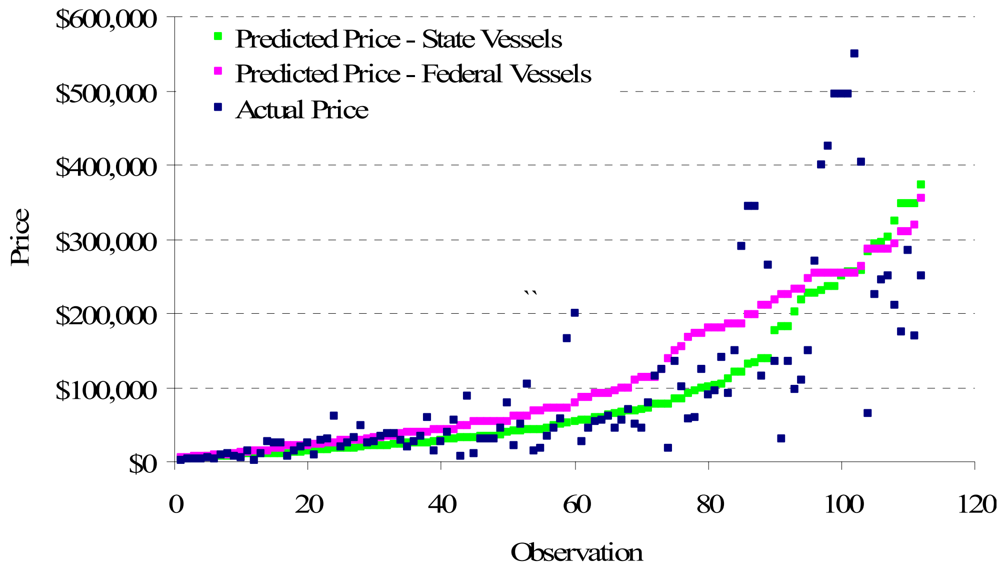

Figure 3.8 Actual and Predicted Values for Used Commercial Fishing Vessels

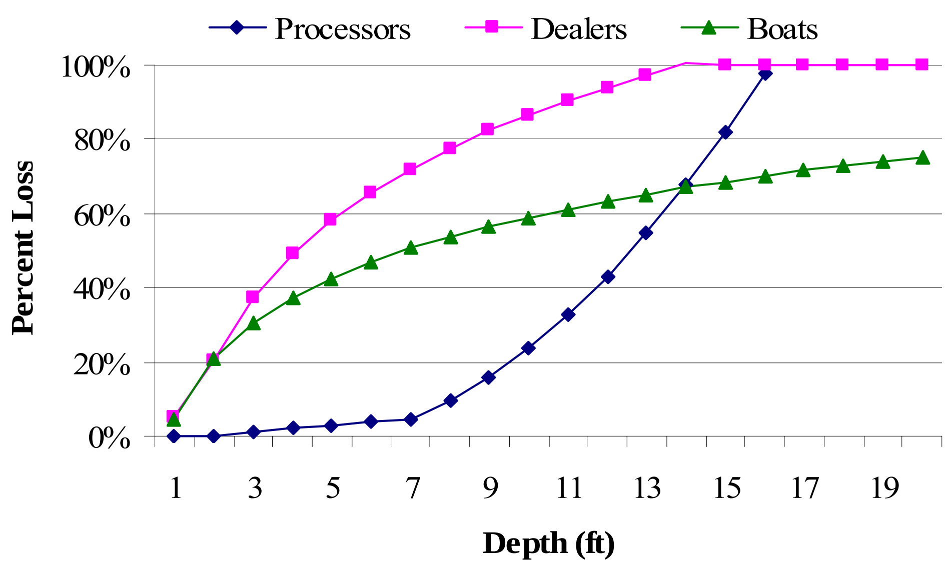

Figure 3.9. Storm Surge Damage Functions for Commercial Seafood Processors, Dealers, and Fishing Vessels in Coastal Louisiana

CHAPTER 4: RESULTS

The initial model runs to estimate infrastructure damage were applied using data for the 114 seafood processors in coastal Louisiana. The estimates for Method 1 included an assumption of 10% net income and an 8% capitalization rate. For Method 2; we likewise assumed a 10% net income, and applied a 25% discount rate over a 5-year discount period. While this discount rate might appear to be high compared to industry standards, this loss estimation method requires a rate that forces the present value of losses to near zero over 5 years.

The results (Table 4.1) of these assessments indicate that damages for Method 2 are substantially greater than for Method 1. The damage estimate for Method 2 ($99,594,135) was more than twice that of Method 1 ($46,268,351). This difference is indicative of the fact that the second method not only accounts for initial damages to infrastructure, but also provides an estimate of lost revenue over a 5-year period. Geographically speaking, the parishes in which the hurricanes made landfall (Plaquemines and Cameron) had some of the highest levels of processor damages overall. These levels, however, must be kept confidential because there were less than three observations in the revenue data. Surprisingly, the highest damage to processors was not in a parish directly impacted by the two storms. Iberia Parish with only 5 processors accounted for almost half of the total processing damages compared to other coastal parishes of Louisiana. This is primarily because seafood processing, especially shrimp processing, is one of the most important industries in Iberia parish, characterized by its locations in the south-central region of Louisiana, which is a deep water access point

Table 4.1 Damage to Seafood Processors

Parish	Method 1	Method 2	N -
Ascension	-	-	-
Assumption	-	-	-
Calcasieu	-	-	-
Cameron	C	C	C
Iberia	$23,195,761	$49,903,917	5
Iberville	-	-	
Jefferson	C	C	C
Jefferson Davis	-	-	-
Lafayette	$79,876	$171,846	6
Lafourche	$30,840	$117,645	-
Livingston	-	-	4
Orleans	$1,897,268	$4,081,828	3
Plaquemines	C	C	C
St. Bernard	$289,370	$622,558	3
St. Charles	C	C	C
St. James	-	-	-
St. John the Baptist	-	-	-
St. Martin	$3,095,090	$6,658,851	15
St. Mary	$48,844	$105,085	5
St. Tammany	-	-	-
Tangipahoa	C	C	C
Terrebonne	$2,522,191	$5,426,302	18
Vermilion	$1,694,410	$3,645,395	4
Totals	$46,268,351	$99,594,135	70

Method 1 = Income capitalization
Method 2 = Discounted Loss
C = confidential (less than three observations)

to the Gulf of Mexico. It is also because the ADCIRC data for lower Iberia parish produced a maximum wave surge height of between 9 to 12 feet, like a result of hurricane Rita. Terrebonne and St. Martin parishes, with more than 30 processors, also account for a substantial amount of the damages to seafood processors ($5.6 to $12 million, depending on the method). Many of these processors, however, are likely to be crawfish processors which are located further inland from the coastal regions of these two parishes. The coastal regions received up to 6 foot storm surge according the ADCIRC model.

The model assumptions for estimating damage to 866 dealers were the same as those used for processor for both Method 1 and Method 2. Again, Method 2 produced higher damage estimate than Method 1 for dealers (Table 4.2). The total estimate of damage lost for Method 2 ($272,412,159), almost twice than Method 1 ($139,809,144). In terms of specific geographic losses, seafood dealers in Plaquemines parish were the most severely impacted by storms, as estimated by Method 1 ($25,367,999) and Method 2 ($49,428,426). This is because Plaquemines Parish had one of the largest regional concentrations of dealers (42) prior to the 2005 storms. As the initial point of landfall for Hurricane Katrina, Plaquemines Parish recorded the highest wave heights (up to 16 feet). Additional parishes with high levels of pre-storm dealer infrastructure and post-storm dealer damage included: Terrebonne, 114 dealers and damages of $21 to $42 million; Lafourche, 80 dealers and $18 to $35 million in damages; Jefferson, 100 dealers and $16 to $33 million in damages; and Calcasieu, 28 dealers and $10 to $19 million in damages.

Table 4.2 Damage to Seafood Dealers

PARISH	DEALERS 1	2	N
Ascension	$0	$0	5
Assumption	$297,733	$580,120	25
Calcasieu	$9,518,404	$18,546,189	28
Cameron	$6,427,859	$12,524,400	60
Iberia	$4,260,978	$8,302,327	42
Iberville	-	-	-
Jefferson	$16,937,349	$33,001,675	100
Jefferson Davis	$71,934	$140,161	7
Lafayette	$0	$0	12
Lafourche	$18,198,214	$35,458,415	80
Livingston	$3,975	$7,745	8
Orleans	$2,273,855	$4,430,506	28
Plaquemines	$25,367,999	$49,428,426	42
St. Bernard	$10,763,045	$20,971,318	44
St. Charles	$1,745,675	$3,401,370	33
St. James	-	-	-
St. John the Baptist	$40,863	$79,619	9
St. Martin	$23,287	$45,374	46
St. Mary	$4,657,589	$9,075,106	70
St. Tammany	$2,523,166	$4,916,277	36
Tangipahoa	$0	$0	28
Terrebonne	$21,769,173	$42,416,272	114
Vermilion	$14,928,046	$29,086,859	49
Totals	$139,809,144	$272,412,159	866

Method 1 = Income capitalization
Method 2 = Discounted Loss

Cameron parish, the point of landfall for Hurricane Rita and a parish which experienced storm surges up to 15 feet, had the only sixth highest level of dealer damages. This is because the parish had a smaller number of dealers and their average revenue (business value) was somewhat lower than that of dealers in more highly populated parishes.

Unlike seafood processors and dealers, revenue data for commercial fishing vessels was difficult to obtain. Therefore, the value of the fishing vessels is estimated by market value. The first step in this process was to geo-code the locations of all LDWF-licensed and USCG-licensed commercial fishing vessels in coastal Louisiana. Then, using SAS software, a hedonic regression model was estimated using sample data (n=112) from for-sale ads, in which vessel value was estimated as a function of age (year) and or length (feet). These models were used to estimate the total value of 8,637 state and 1,199 federally licensed vessels[6].

A damage function, fit from secondary data collected by the US Corps of engineers (USACE 2006), was then used to estimate commercial fishing vessel damages for various storm surge heights. One assumption of this damage functions was that damages were bounded by 0% to 100%.[7] Results (Table 4.3) show that the average damage per-vessel for USCG vessels ($33,690) was much greater than for the LDWF-licensed vessels ($5,201). This is likely because the mean length (59 feet) of the USCG vessels was much greater than the mean length (23 feet) of LDWF vessels. Additionally, federally-licensed boats are usually docked in more vulnerable locations, since they require deepwater ports located closer to the open waters of the Gulf of Mexico. Federally-licensed vessels usually fish offshore (beyond three miles of the coastline), while state-licensed fishing vessels are limited to state waters, within 3 miles from coastline.

[6] It is important to note that these vessels are the ones that appeared in the LDWF trip ticket data during the years 2002-2004, and these are not necessarily all of the commercial fishing vessels located in coastal Louisiana.

[7] Kazmierczak in Caffey et al. (2006) used a double-bounded probit model to address the 0-100% damage boundary. The damage curves from this study were not pre-bounded, rather the resulting damage estimates were limited to the 0-100% continuum by use of sorting and logic formulae in Microsoft Excel.

As seen with seafood dealers, Plaquemines parish had the highest total vessel damages ($21 million), or $9 to $11 million for 1,013 state and 142 federal vessels, respectively. However the parish with the most vessels overall (1,724) was Terrebonne parish, and although the maximum wave heights were significantly lower in Terrebonne than in Plaquemine, the overall level of vessel damage ($18 million) was nearly as high because of the high concentration of vessels. Likewise, substantial levels of vessel damages occurred in other parishes in which maximum storm surge levels were much lower than Plaquemines, including: Jefferson Parish and Lafourche Parish which combined, accounted for 2,596 vessels and more than $16.8 million in total vessel damages. The lower portions of these two parishes received significant storm surges from Hurricane Katrina. For example, Grand Isle Louisiana which is located in lower Jefferson Parish near the Lafourche parish border, received storm surges in excess of 12 feet. This island, and the adjacent communities in Lafourche parish, are home to many coastal fishing villages. In addition, vessels located in Vermilion parish, which houses a deepwater shrimp fleet and a commercial menhaden fleet at the port of Intracoastal City, Louisiana, was also heavily impacted. A total of $6 million in damages was estimated for the 331 commercial fishing vessels in that parish.

As seen before with data from the seafood processors and dealers, Cameron parish did not necessarily have the greatest level of fishing vessel damages. Prior to the 2005 storm season, Cameron parish had 291 commercial fishing vessels recording landings in the LDWF trip ticket data system. While the 15 foot storm surge likely destroyed many of those vessels completely, Cameron parish had only the sixth highest level of vessel damages, at $2.8 million.

Table 4.3 Damage to Fishing Vessels

PARISH	VESSELS LDWF	N	VESSELS USCG	N	VESSELS Total	N
Ascension	$112,568	46			$112,568	46
Assumption	$221,584	116			$221,584	116
Calcasieu	$1,105,060	165	$971,245	20	$2,076,305	185
Cameron	$1,379,172	257	$1,483,858	34	$2,863,030	291
Iberia	$1,371,897	290	$376,940	13	$1,748,837	303
Iberville	$7,625	35	C	C	C	C
Jefferson	$6,018,938	1,220	$3,786,743	170	$9,805,681	1390
Jefferson Davis	$286,100	47	$399,927	8	$686,027	55
Lafayette	$10,226	84	$0	41	$10,226	125
Lafourche	$3,296,531	1,029	$3,730,408	177	$7,026,939	1206
Livingston	$114,026	99			$114,026	99
Orleans	$883,894	207	$467,147	80	$1,351,041	287
Plaquemines	$9,384,871	1,013	$11,610,466	142	$20,995,337	1155
St. Bernard	$4,045,674	668	$1,140,262	54	$5,185,936	722
St. Charles	$1,379,217	298	$52,487	5	$1,431,704	303
St. James	$64,460	54	C	C	C	C
St. John	$237,621	140			$237,621	140
St. Martin	$89,188	103	C	C	C	C
St. Mary	$1,270,150	545	$1,416,128	60	$2,686,278	605
St. Tammany	$1,988,794	333	$737,644	20	$2,726,438	353
Tangipahoa	$64,223	154	$0	7	$64,223	161
Terrebonne	$8,696,544	1,495	$9,341,934	229	$18,038,478	1724
Vermilion	$1,311,651	199	$4,879,381	132	$6,191,032	331
Totals	$43,365,576	8,637	$40,394,570	1,199	$83,760,146	9,836
Average	$5,201		$33,690			

Method 1 = Income capitalization
Method 2 = Discounted Loss
C = confidential (less than three observations)

Table 4.4 compares the total fisheries infrastructure damage as estimated in this study to another study conducted in Louisiana and studies for Mississippi and Alabama[8]. The current estimates reported by this study for fishing vessels are somewhat lower than that of Caffey *et al* (2007), but higher than Posadas (2007) and Chang *et al* (2007) for commercial vessels. This is because Caffey *et al* (2007) included losses of vessel revenue in their estimates. Further more, Posadas (2007) and Chang *et al* (2007) were estimating damages for much smaller commercial fishing fleets than those located in Louisiana.

Damages estimated for commercial seafood dealers estimated by this study were $139 to $272 million. These levels are anywhere from 25 percent to 250 percent higher than the $103 million estimated losses to dealers recorded by Kazmierczak in Caffey *et al* (2007). One possible explanation for this difference is the aggregating technique used in the Caffey study. In that technique, dealers (and processors) were grouped into three revenue size classes and average values and losses were applied to each class. By comparison, this study develops damage estimates at the individual firm level, a method which is less likely to discount any damages to high-value dealers located in areas with high levels of storm surge. Conversely, the estimates for processor losses in this study are more in line with similar estimates from Caffey *et al* (2007). The $63 million estimated in that study lies between the $46 million to $99 million estimated from the two revenue-based damage estimation methods used in this study.

[8] Comparisons to similar studies are limited to only those sectors reported on in this study: commercial seafood processors, seafood dealers, and commercial fishing vessels.

Damages estimated for Louisiana in this paper and Caffey et al (2007) are much greater than those of both Posadas (2007) and Chang *et al* (2007) simply because Louisiana has much more seafood infrastructure (vessels, dealers, and processors). In fact, Louisiana has the largest landings of fisheries annually in the Gulf of Mexico, and is second largest after Alaska in terms of volume landed. By comparison, the states of Mississippi and Alabama have only 16 and 14 percent, respectively of the volume of seafood landing in Louisiana. This fact, and the fact that both Hurricane Katrina and Hurricane Rita made initial landfall are the reason that fisheries infrastructure damages in Louisiana were so much greater.

Table 4.4 Fisheries Infrastructure Damages in Louisiana, Mississippi, and Alabama from Hurricanes Katrina and Rita in 2005

State	Commercial Vessels	Seafood Dealers	Seafood Processors	State Totals
Louisiana	$83,760,146	$139,809,144 $272,412,159	$46,268,351 - $99,594,135	$269,837,641- $455,766,440
Louisiana[1]	$191,297,444	$103,522,186	$63,836,142	$358,655,772
Mississippi[2]	$35,296,545	$77,827,681	$21,313,205	$134,437,431
Alabama*[3]	$25,355,000	$18,642,000	$67,326,000	$111,323,000

* Estimates from AL included additional impacts (e.g. lost wages and inventory) not included in the assessments conducted in LA and MS.

[1] Caffey et al. 2007

[2] Posadas 2007

[3] Chang et al. 2006

CHAPTER 5: SUMMARY AND CONCLUSIONS

Summary of Results

The massive destruction caused by the Gulf of Mexico hurricanes of 2005 has focused attention on the economic impacts of natural disasters. Coping with and mitigating these impacts has been a tremendous challenge for policy makers. The problem is even more complicated due to lack of consistent data and methods for rapid and accurate assessment of the disaster losses. Other issues are institutional capacity and the lack of specific geographic details in damage estimates.

Hurricanes Katrina and Rita made initial landfall in Louisiana on August 29, 2005 and September 24, 2007, respectively. Hurricane Katrina made landfall along the central Gulf of Mexico and impacted five states directly, including Louisiana, Mississippi, Alabama, Florida and Georgia. The most severely impacted states were Louisiana, Mississippi, and Alabama. Katrina was the most expensive and deadliest natural disaster in the USA since Mississippi river flood of 1927. Hurricane Rita made landfall on Louisiana-Texas border, causing major flooding in Port Author and Beaumont (Texas), and severe damages in Louisiana's coastal and offshore areas, especially in Cameron and Calcasieu parishes.

Concerning the fisheries sector, the initial point of landfall for Hurricane Katrina was the fishing port of Empire, Louisiana in lower Plaquemines Parish. In 2004, Empire was in the number one fishing port by volume in the continental United States. Likewise, hurricane Rita destroyed the coastal fishing port of Cameron, which in 2004 was the number four fishing port (by volume) in continental US . Together, these hurricanes caused direct and indirect damages to the commercial and recreational fisheries sectors in these ports and all along the northern Gulf of Mexico.

Preliminary economic assessments of fisheries damages were developed by numerous researchers and institutions following the two storms. Initial estimates varied greatly. For example, preliminary damage estimates for Louisiana fisheries developed separately by the LSU Agricultural Center and the Louisiana Department of Wildlife and Fisheries ranged from $275 million to $3.5 billion, respectively.

The above problems provided the basis for the specific objectives of this study; 1) to review the natural resource damage assessment and disaster recovery literature and describe the different methods used for assessing economic damages; 2) to demonstrate an alternative method for producing a more rapid and spatially accurate estimate of the post-hurricane impacts to fisheries infrastructure; and 3) to compare and contrast the damage assessment methods currently available and make recommendations for application of these methods for future storm events.

A review of the economic literature pertaining to natural disasters shows that natural disasters produced a wide range of impacts and cause changes in economic activities beyond normal, baseline conditions. Immediately after natural disaster, there is short term recuperation period characterized by emergency response and damage assessment. This phase requires rapid and reliable data and effective communications in order to formulate efficient decisions. However, long-term recovery involves a rebuilding process that can take years to restore the economic activities that existed prior the disaster event. There is often some question, however, about what type of recovery assistance should be provided. For example, in open access fisheries that suffer from over capitalization the long-term objective could involve replacing only a portion of the infrastructure and vessels that existed prior to the storms. Additionally, long-term objectives of capacity reduction might emerge in an attempt to address negative externalities associated with a particular fishery. For example, Caffey et al. (2006) describes a failed attempt by NOAA to implement a vessel buyout program in the wake of Hurricanes Katrina and Rita.

More than $250 million was proposed for capacity reduction programs. One driver of this proposal was the problem of incidental bycatch of red snapper by shrimp trawlers. Efforts to address over capacity, however, were rejected by commercial fishermen and state agencies. Instead, the short-term and long-term focus became one of damage estimation and the procurement and allocation of recovery funding.

Although several models for estimating fisheries infrastructure damages were developed by public and private institutions after the 2005 hurricane season, few if any provided the ability to estimate damages on a site-specific basis. Researchers in the LSU Center for Natural Resource Economics & Policy (CNREP) developed a damage assessment approach that incorporated economic and biophysical data to yield site-specific damages estimates on a relatively small geographic scale (Caffey et al. 2007). The research conducted in this study replicates portions of the CNREP study and expands the research by applying the site-specific approach within two alternative revenue-based damage models for seafood dealers and processors and one market-based model for fishing commercial vessels.

Development of a geographically-specific model of the economic losses to coastal fishing infrastructure from hurricanes requires two types of information; spatial data is required to spatially map commercial fisheries infrastructure and storm surge heights. Economic data is required to estimate the value of that infrastructure. In June 2006, 3 years (2002-2004) of pre-storm trip ticket data were obtained from LDWF. In addition, production records for Louisiana's coastal seafood processors were obtained from the Louisiana Department of Health and Hospitals. The data included addresses, these address data were tabulated, geo-coded and mapped to see their distribution in Louisiana, especially in the 22 coastal parishes. Geo-coding and mapping were conducted using software developed by ESRI Inc. (Environmental Systems Research Institute Incorporation). Distribution of processors, dealers, commercial fishing boats, and recreational boats was mapped separately. Physical data are needed to find out relationship between storms and damages caused by them. The important physical data are wind speed, tidal height and coastal storm surge. Storm surge was used as a critical determinant for estimating damage losses due to hurricanes. This study utilized maximum storm surge levels for Hurricanes Katrina and Rita that were simulated by the LSU Hurricane Center using the ADCIRC model and ground-truthed with hind-cast field observation.

The initial model runs to estimate infrastructure damage were applied using data for 114 seafood processors and 866 seafood dealers. The estimates for Method 1 (see equation 3.1, partial income capitalization) included an assumption of 10% net income and an 8% capitalization rate. For Method 2 (see equation 3.2, discounted loss method) ; net income was likewise set at 10%, and a 25% discount rate was applied over a 5-year discount period. This high discount rates is a product of the second method, which is designed to force the present value of infrastructure and revenue losses to near zero over 5 years.

The application of these revenue-based damage models resulted in loss estimates for dealers ranging from $139 million to $272 million and losses to processors ranging from $46 million to $99 million. In all applications, damages resulting from Method 2 are substantially greater (roughly 100%) than for Method 1. This difference is indicative of the fact that the second method not only accounts for initial damages to infrastructure, but also provides an estimate of lost revenue over a 5-year period. Geographically each of the models showed high levels of processor and dealer damages in the parishes in which the hurricanes made landfall (Plaquemines and Cameron). However, several other parishes (e.g. Terrebonne, St. Mary, Iberia) had considerably high levels of economic damage, even though they were not directly in the path of the two storms.

Unlike the processors and dealers, damage to 9,836 state and federal commercial fishing vessels was estimated using a hedonic regression of market value. Once vessel values were established, a separate damage function was developed using secondary data collected by the US Corps of engineers (USACE 2006). Vessel damages were then estimated at each vessel location for the associated maximum storm surge height. Average damage for USCG vessels ($33,690) was much greater than for the LDWF vessels ($5,021). With a mean length of 59 feet, the USCG vessels were more than twice the average size of the LDWF state vessels. Additionally, damages to the federally- licensed fleet are likely due to their increased vulnerability, since they require deepwater ports located closer to the open waters of the Gulf of Mexico. As seen with seafood dealers, Plaquemines parish had the highest total vessel damages ($21 million), or $9 million and $11 million for 1,013 state and 142 federal vessels, respectively. However the parish with the most vessels overall (1,724) was Terrebonne parish, and although the maximum wave heights were lower in Terrebonne than in Plaquemine (Figures 3.6 and 3,7), the overall level of vessel damage ($18 million) was nearly as high because of the high concentration of vessels (Figure 3.3). Substantial levels of vessel damages also occurred in Jefferson and Lafourche Parishes, which combined accounted for 2,596 vessels and more than $16.8 million in total vessel damages. Vermilion parish, which houses a deepwater shrimp fleet and a commercial menhaden fleet at the port of Intracoastal City, Louisiana, was also heavily impacted. A total of $6 million in damages was estimated for the 331 commercial fishing vessels in that parish.

In each of the damage models, (for processors, dealers, and vessels), the maximum level of fisheries infrastructure damages occurred in Plaquemine parish, where the highest level of storm surge was recorded. Cameron, the parish which recorded the second highest overall levels of storm surge, ranked between fifth and sixth in overall economic damages. This result is due to fact that such a large amount of seafood infrastructure was located in parishes outside the direct path of the two storms.

A comparison of the results from this study to existing estimates of fisheries infrastructure damage shows some similarities and differences. Damage estimates from Caffey et al. (2007) for Louisiana seafood processors appear to fall directly within the values estimated by the two revenue methods used in this study. Estimates for dealers and vessels, however, differ substantially between this study and the estimates of the 2007 Caffey et al. report. Possible explanations for these differences lie in the models used for estimating damages, the latter of which involved a three-stage grouping (by revenue class) for processors and dealers and the additional estimation of revenue losses for fishing vessels. The total range of damages estimated by this study, $269 million to $455 million, is much greater than similar estimates of seafood infrastructure damages in Mississippi ($134 million) and Alabama ($62 million) for the same sectors. This is primarily because of the higher levels of fisheries infrastructure in Louisiana compared to these states and the fact that both Hurricane Katrina and Hurricane Rita made initial landfall along the Louisiana coast.

Conclusions

Based on the current study, we could draw several conclusions:

- Current models used in post-disaster assessment situations often lack consistency, repeatability over time, and geographic specificity
- Fisheries revenue and vessel market data, combined with data from new methods for storm surge simulation and ground-truthing, can be used to develop more rapid and accurate estimates of post-disaster impacts.
- The successful and rapid application of the models described in this study requires 1) commercial revenues for seafood dealers and processors and market values for commercial fishing vessels; and 2) biophysical data on maximum storm surge height.

- Results from the application of two revenue-based damage models (Method 1: income capitalization and Method 2: discounted losses) show that the discounted losses model produces substantially greater (2X) estimates of total economic loss.

- Higher estimates from the discounted losses method are due to the fact that model estimates not only losses to the sector from direct infrastructure damages, but also of the present value of lost production revenues over a five-year period.

- Results of the models used in this study show that Plaquemine parish had the highest level of damages for the three sectors modeled: seafood processors, dealers, and vessels.

- In contrast to Plaquemines, Cameron, the parish which recorded the second highest overall levels of storm surge, ranked only fifth to sixth in overall damages. This result is due to the relatively lower level of seafood infrastructure located in Cameron Parish compared to other coastal parishes of Louisiana

- Although not directly inside the path of the Hurricanes Katrina and Rita, several parishes had substantially high damages according to the models used in this study. For example, Terrebonne parish – because of its high levels of infrastructure and/or the particular location (vulnerability) of that infrastructure - had the second highest levels of economic damage to seafood dealers and commercial vessels. This result is indicative of the models' ability to address biophysical and economic information on a spatial scale.

- Model assumptions will greatly affect model outcomes. The assumptions utilized for the revenue-based models in this study (net income percentages and discount rates) are subject to interpretation. The methods and assumptions to be applied, however, depend very much on the intentions and objectivity of sponsor institutions.

- Public institutions could be inclined to use more liberal models and assumptions if larger damage estimates are needed to justify large amounts of recovery funding. Conversely, private institutions (such as insurance companies) might tend to favor more conservative methods and assumptions which yield smaller estimates. To reduce potential bias, third party assessments can be used could to provide more objective damage assessments.

- The models used in this study provide the benefit of geographic specificity down to the individual firm scale. That scale could be useful for resource management agencies in helping to allocate fisheries disaster aid for both short-term and long-term recovery objectives.

- For the purposes of confidentiality, this report only disaggregated damages geographically to the parish scale. Further resolution of damages could be provided at the sub-parish region (cities, towns, ports) provided that the anonymity of individual businesses is protected.

Implications and Additional Research

This study describes alternative methods for providing detailed estimates of commercial fisheries infrastructure damages in the wake of natural disasters such as hurricanes. If the necessary economic and biophysical data are provided in a timely fashion, these methods could be used to develop rapid and spatially-specific estimates of post-hurricane damage. Such estimates, though limited to fisheries infrastructure in this study, could be applied to additional commercial sectors if the necessary data were available. The advantage of these spatially-specific approaches lie in the ability to target recovery funding to the areas most needed, depending on the short-term and long-term objectives of resource management agencies at the state and federal level.

There are numerous limitations to these approaches; however, that should be noted. Firstly, the location of geo-coded infrastructure is based on street addresses. This limits the ability of the models to accurately predict the actual location of moveable infrastructure such as commercial and recreational fishing vessels. The use of high technology instruments such as satellite tracking systems might be useful for better tracking the location of fisheries infrastructures before and after storms. Secondly, the damage curves and market value regressions for this study were obtained from small sample sizes. Additional research is needed to refine these models and produce a more accurate depiction of 1) the relationships between maximum storm surge height and economic losses; and 2) the relationship between a commercial vessel's value and its physical characteristics. Such research would require expanded surveying to collect data from a greater number of respondents that close to real population. In addition, the damage curves utilized in this study are not bounded by the 0 -100 percent maximum. Negative values and values exceeding 100% were manually corrected in this study, but these could be addressed using a different functional form for the damage equations. Finally, it is important to note that the final estimates of this study are limited to only three types of commercial fishing infrastructure (processors, dealers, and vessels). Additional expansion of this study is needed to address other commercial infrastructure such as ports and marinas and recreational infrastructure as well.

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VITA

Tanza Erlambang was born in Tanjung Pinang, Indonesia, in 1965. After graduating from the Fisheries Faculty, University of Riau, Indonesia, in 1989, he pursued a wide variety of careers, from a government agency, to private institutions, to a non-government organization. He also held a position as a journalist for Riau Pos newspaper, a chief editor of Bulletin Serai, a manager of community development at Bintan Resort Corporation, a lecturer at University of Riau, and a researcher and a consultant at the Serai Institute.

The above jobs have allowed him to travel to many countries, including Denmark, Sweden, Norway, Germany, Belgium, Luxemburg, Holland, France, Switzerland, Japan, Thailand, Malaysia, Philippines and Singapore. In January 2005, Tanza Erlambang came to the United States to enroll as a master's student at the Department of Agricultural Economics and Agribusiness at Louisiana State University in Baton Rouge, Louisiana.

Three severe natural disasters-the Indonesian tsunami in late December 2004, and hurricanes Katrina and Rita, which struck the northern Gulf of Mexico in August and September 2005-have stimulated him to conduct research on alternative methods for estimating economic losses due to natural disasters. Tanza Erlambang successfully defended his thesis research on December 14th, 2007, and is currently a candidate for the degree of Master of Science at Louisiana State University.