Assessing Changes in Land Cover in Southeast Louisiana from 2001 to 2011 Using Time-Series National Land Cover Data

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ASSESSING CHANGES IN LAND COVER IN SOUTHEAST LOUISIANA FROM 2001 TO 2011 USING TIME-SERIES NATIONAL LAND COVER DATA

by

Ashley Tarver

A thesis submitted to the Graduate College in partial fulfillment of the requirements for the degree of Master of Arts Geography Western Michigan University April 2017

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Each year, Louisiana loses 20 to 25 square miles of land. If land loss persists at the current rate, a forced migration of the human population with serious implications may be warranted. Although studies have measured land use/land cover change in southeast Louisiana over multiple decades, a recent analysis of landscape changes since Hurricane Katrina’s landfall in 2005 is needed to identify areas with chronic long-term wetland losses and associated economic development patterns. This study, therefore, compares land cover and land use changes including wetland loss, and subsequent increases in developed land in ten parishes from 2001 to 2006 (pre-Katrina), 2006 to 2011 (post-Katrina), and 2001 to 2011. Results shown three times more land loss during the post-Katrina than pre-Katrina years. Over the long term (2001-2011), 97% of total land loss included open water gains from emergent herbaceous wetlands, woody wetlands, and barren land categories. Land use change shown most development occurred in East Baton Rouge, Ascension, and Livingston parishes during pre-Katrina years.

Three times more woody wetlands were lost in pre-Katrina years, and 25% of all increases in development during those years came at the expense of woody wetlands. Both open water and development appeared to be the primary drivers of the losses in woody wetlands.
ACKNOWLEDGEMENTS

I dedicate this thesis in honor of the memory of my Mother, Linda Ann Walley. She always told me I can do anything if I set my mind to it, and I would not be where I am today without her love, wisdom, and encouragement. I know she is in heaven, smiling proudly down at me and cheering, “Go! Go! Go, PJ, go!”.

I would also like to dedicate this work my sister, Cory Ann Budnick, and niece, Brooke Alexis Dubie. Cory, without your love and support, I would not have made it through the past year, and I love you dearly. You are my rock, the one I go to for “adulting” advice when I need to understand things like insurance premiums and taxes.

Brooke, this thesis is a testament to the truth that achieving your goals requires perseverance and determination. You are a force to be reckoned with in this world. I admire your intelligence, but most importantly, I admire your integrity of character that keeps you humble and kind. Here’s to strong women. May we know them. May we be them. May we raise them. Love you girls.

Ashley Tarver
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CHAPTER I

INTRODUCTION

Coastal wetlands have played an important role in shaping Louisiana’s economy and culture throughout history, but these valuable ecosystems are rapidly being lost. Between 1932 and 2010, over 3,000 square miles of land were lost along the coast, and an additional 20 to 25 square miles are lost every year (Couvillion, et al. 2011). If the current rate of coastal land loss persists, it may warrant a forced migration of the human population with serious implications. Economic shocks would be felt at local, state, regional, and national levels. Culture would also be at risk of being lost, as the bayou is the foundation of the Creole and Cajun people’s identity (Marshall 2014). A significant portion of these land losses occur within the southeastern parishes of the state, which is also the region with the fastest population growth.

To address land loss, land use/land cover change must be monitored over time to inform decisions to either mitigate the problem through engineering projects such as levees and sea walls, or adapt to the situation by shifting development and other resources out of high-risk, coastal areas through legislation, regulations, and changes to insurance rates. Quantifying these changes in land use/land cover enhances understanding of the drivers of land loss, allowing policy makers to make informed decisions in regional planning, ecological restoration and wetland conservation efforts that will potentially alleviate the impact of the problem in the most affected areas.
Although many studies have measured land use/land cover change in southeast Louisiana over multiple decades (NOAA 2013; Gagliano et al. 1981; Barras, et al. 2004), a recent analysis of landscape changes since Hurricane Katrina’s landfall in 2005 is needed to identify areas with chronic long-term wetland losses and associated economic development patterns. Because wetlands are ephemeral in nature and possess a remarkable potential for recovery when damaged, a study measuring the change in land cover since 2005 will help to conclude with more certainty whether those wetland losses that have occurred since Katrina are indeed permanent. The area selected for the study includes ten parishes of southeast Louisiana (Figure1). The reasons for this delineation for the research will be discussed at length in chapter six.

The purpose of this study, therefore, is to compare land cover changes including wetland loss, and subsequent increases in developed land in southeastern Louisiana from 2001 to 2006, 2006 to 2011, and 2001 to 2011. Quantifying the recent spread of development within southeastern Louisiana since the landfall of Hurricane Katrina will help emergency managers identify areas where population growth and development may exacerbate flood risk, allowing them to better prepare and strengthen the area’s capacity to withstand future shocks from hurricanes. As areas become more densely populated, there are more potential victims exposed to the danger of storm surge from future hurricanes, while the construction of new buildings increases the likelihood of property damage, injury, or death from flooding (Auf der Heide 1989). Any changes to developed land categories may also point to areas where signs of urban sprawl may warrant closer scrutiny if such expansion poses a risk to wetland degradation.
The definition of ‘land loss’ is used inclusively throughout the thesis, and is measured as areas experiencing open water gains or wetland conversions. Open water gains are defined as an increase of open water at the expense of any other anthropogenic land use or natural land cover category except open water in this thesis. Wetland conversions, on the other hand, are defined as the loss of either woody wetland or emergent herbaceous to any other land use/land cover category. Measuring the change in open water will provide an indicator of both land and wetland loss. The two are not mutually exclusive, as the loss of wetlands to open water will also be accounted for in the land loss (i.e., open water gains) map. Because the majority of Louisiana’s coast consists of wetlands defined by an ever-fluctuating land to water ratio, the terms ‘wetland loss’, ‘land loss’, and ‘open water gains’ are interchangeable; however, an attempt is made throughout the thesis to keep the terms as distinct as possible. Although exploring the land use drivers of land cover change is outside of the scope of this study, findings may be the foundation from which such a study is launched in the future.

The study is based on analyses of datasets from the Multi-Resolution Land Consortium incorporated in a GIS study designed to assess changes in land use/land cover (LULC) categories. The thesis has six chapters.
Figure 1: Ten Parish Study Area

Source: Map created by Ashley Tarver with data from ESRI
CHAPTER II
REVIEW OF THE LITERATURE

Overview

Although coastal Louisiana has lost a significant amount of land over the past 78 years, the average rate of land loss rates has actually slowed in recent years. Compared with the 30 square miles of land lost per year between the years 1956 and 1978, the annual loss decreased to an average of just 16.57 square miles from 1985-2010 (Couvillon, et al. 2011). Upon learning the annual rate of land loss has actually dropped, one may be quick to conclude the issue of land loss is not as serious as it once was.

In reality, it is more serious than ever. It is important to realize that information is lost when the annual rate of land loss is averaged for multiple years, and there are unique circumstances for some of the outlier years that will have a significant impact on the overall average. For example, the hurricanes occurring between the years 2004 and 2008 (Katrina, Rita, and Ike) wiped out approximately 328 square miles of marsh (Palaseanu-Lovejoy, et al. 2013). The amount of land lost to open water over those four years alone was more than the total amount of land lost in the 16 years from 1978-2004 (Barras et al. 2008, Barras et al. 2009). To identify these outlier years, the change in land cover must be monitored over both the short and long term.

Coastal Louisiana has always been a dynamic landscape in an almost constant state of flux, but the combination of natural processes that drive land loss, the influence of human
activities, and the effects of climate change appears to be resulting in permanent losses of land. Although land naturally sinks through the process of subsidence, the rate at which it is being lost is accelerated by human activity including the extraction of oil and other resources (Kolker, et al. 2011). In other words, the natural process of subsidence is influenced by human-related activities, and both factors have a significant impact on the coastal landscape.

A similar relationship exists between land loss and some of the effects the earth is experiencing from climate change. Hotter temperatures associated with global warming are causing sea levels to rise and severe hurricanes to occur more frequently, both of which contribute to land loss in coastal Louisiana. Warmer seas expand in volume and nibble away the coastlines. Warmer water is also fueling the formation of more frequent and severe hurricanes, and these storms are wiping out the very wetlands that serve to buffer its impacts (Engle 2011; Graham and Riebeeck 2006; Palaseanu-Lovejoy, et al. 2013). Consequently, hurricanes are contributing to land loss while also exacerbating the flood risk associated with the occurrence of hurricanes in southeastern Louisiana. To capture these landscape dynamics at play over time, both short-term and long-term snapshots must be taken for a precise measurement of changes in southeastern Louisiana’s land cover.

In order to thoroughly understand the issue of land loss in southeast Louisiana, this chapter will explore the drivers of land loss in further detail. Although the scope of the study is limited to measuring the change in land use and land cover, an understanding of these drivers will provide context for the study and justify why measuring the change is important. The chapter will begin with a historical overview of the formation of the Mississippi River Delta. In the second section, the natural processes that drive land loss will be explained. The third
section will go on to describe the human activities that exacerbate land loss, and the fourth section explores the issue of sea level rise and its impact on land loss. The fifth section describes how saltwater intrusion is affecting forested wetland loss, and the last section of the chapter will provide a brief summary of the past studies that have measured land loss in Louisiana.

**History of the Mississippi River Delta**

In order to understand the issue of land loss, it is important to know how deltaic processes of the Mississippi River have formed and shaped the Louisiana coast and its wetlands throughout history. Louisiana borders the Gulf of Mexico, and its coastal plain was formed by sediment carried by the Mississippi River from the uplands far to the northwest (Rocky Mountains) and northeast (Appalachian Mountains). Tens of thousands of years ago, the events of the last ice age controlled sea level and the rate at which sediment was being discharged down the Mississippi River. As the glaciers retreated and the ice melted, the flow of the Mississippi became more powerful, carrying the sediment further downstream to be deposited in present-day Louisiana. Over time, the sediment settled and eroded to form the 3 million hectare deltaic plain of the Mississippi River, now the central feature of south Louisiana (Coleman and Roberts 1998).

The Mississippi River delta covers an area that accounts for 40% of all wetlands in the United States. Its shape is defined by a vast network of deltas that are disjointedly connected in a kind of piecemeal fashion. Some pieces of land are in the process of being formed, while others are static and some deteriorated. Approximately 7,000 – 8,000 years ago during the Holocene epoch, the Mississippi River’s switch-back cycle first began to influence the
processes of building, abandonment and subsidence of the land (Coleman and Roberts 1998).

Soil-building has been most responsible for the formation of the delta. As the river transported sediment further downstream, it eventually slowed as it reached its intersection with the Gulf of Mexico and encountered resistance from the incoming tides. By the 20th century, most of the sediment had spread out and settled at the mouths of the Mississippi River, forming over five million acres of deltaic wetlands. Throughout the formation of these wetlands, the Mississippi River changed direction at the base of its outlet into the Gulf of Mexico, and this east-west meandering carved the shape of six deltaic “lobes” as a result (Coleman and Roberts 1998).

During that time, spring rains would regularly stir up the silt and sediment at the bottom of the Mississippi River. Regular flooding carried the sediment over the riverbanks along with the water, and this served as a source of nourishment for the surrounding wetlands. During the spring floods, the fast-moving water would also sweep up debris, causing it to spill over the riverbanks and deposit the material into “back swamps” on the other side of the natural levees. Finer sediments were deposited in these back marshes and swamp wetlands. The natural vegetation of southern Louisiana would therefore be fresh or saltwater marshes, with the higher elevations dominated by bald cypress and tupelo swamps (Day, et al. 2002).

Coarser sediments settled and the newer debris accumulated on top of older sediment deposits to form raised banks that were essentially natural levees. During early settlement, the urban and rural areas were in southeast Louisiana were actually built on the natural levees because it was the only areas with well-drained soil good for farming. In fact, New Orleans was settled on natural levels because the fertile soil was ideal for farming, even though most of the
city was below sea level. Founded by French settlers in 1718, the precise location of New Orleans was chosen because it represented the highest point of a bend in the Mississippi River. Lake Ponchartrain (an inlet of the Gulf of Mexico) was located to the north, and wetlands surrounded the city to the east, west, and south.

Before the rapid, suburban expansion of the 20th century, the only part of present-day New Orleans that was not an uninhabitable bog was a crescent-shaped sliver of land surrounded on three sides by the river, which flowed ten to fifteen feet above sea level. This created a giant, semi-circle of habitable land around the city with more natural levees to the north and the land below-sea level to the south creating a bowl-shaped area. Now known as “Mid-City”, this area was a breeding ground for yellow fever and malaria. Between the years 1817 and 1905, the yellow fever epidemic, a disease borne from swamp mosquitoes, eventually killed more than 40,000 residents (Coleman and Roberts 1998).

During that time, many of the wetlands were drained and destroyed because the swamps were viewed as a source for disease and a hindrance to development. To prevent the spread of disease and foster development throughout the area, Congress passed the Swamp Acts in 1849 to encourage the drainage of wetlands. Lower areas that were drained would eventually become the suburbs of New Orleans, with an elevation mere inches above sea level (Tibbetts 2006).

Frequent flooding of the area now known as “Mid-City” caused the French settlers to decide to build higher levees in an attempt to prevent the floodwaters from regularly overtopping the banks of the Mississippi River. By 1812, they had built levees along the eastern riverbank of the Mississippi River as far north as Baton Rouge and along the western
riverbank to Point Coupee (Coleman and Roberts 1998).

Over time, these man-made levees interrupted the flow of sediment that contributed to the soil-building processes of the delta. Today, all the major deltaic lobes are inactive and in the destructive phase, except two: the active Balize Delta at the mouth of the Mississippi River and a small delta emerging in the Atchafalaya Bay. These facts are supporting evidence that indicate the Mississippi River delta is in the latter stages of deterioration. Overall, the time span from the construction of a river delta to its eventual abandonment is about 1,000-2,000 years (Gagliano, et al. 1981).

The extent that land loss is natural or accelerated by human intervention in deltaic cycles is a subject of ongoing debate. Even without human intervention, it is natural for a delta to subside until only a small chain of islands or even just a shoal remains. Although these changes are seldom permanent and a delta will typically build itself anew following its eventual demise, there are other factors that are currently preventing the Mississippi River delta’s from naturally replenishing itself (Gagliano, et al. 1981). These factors will be explored in further detail later on in this chapter.

*Natural Factors Driving Land Loss*

As explained in the previous section, the formation of any delta involves a natural cycle that consists of land loss and gain. Subsidence is among the most significant drivers of land loss. The previous section described how wetlands were drained to further develop the land in southeastern Louisiana. As the water was sucked out of the peaty soils of these lowlands, the land compressed and began to sink through a natural process called subsidence, one of the most detrimental drivers of land loss. Subsidence results in a decrease in elevation that makes
wetlands more vulnerable to impacts at the surface level. Marsh vegetation is unable to survive if it cannot meet the minimum elevation requirement needed to maintain an equilibrium with sea level (Reed and Wilson 2004). Wetlands are very fragile, and easily damaged if the ingredients of its surrounding biotic ecosystem begin to fall outside of their functional range.

Land loss is naturally offset by the process of land gain, also known as accretion. Deltaic land is built vertically through accretion, which involves a soil-building process where sediment accumulates, compacts, then builds up the land. As organic material is deposited, plant roots and other flood-deposited matter stabilizes the ground and keeps it firmly in place as accretion occurs. In other words, the plant roots serve as the foundation from which the soil-building process is supported. In this respect, the vegetation plays an important role in preventing subsidence because it cohesively holds the surrounding ground into place to prevent further sinking. Accretion also helps to maintain the delicate balance of the ecosystem by maintaining elevation in spite of the subsidence of the land, which serves to mitigate the effect of sea level rise by keeping the wetland from being completely submerged by saltwater. After the sediment has settled, it also subsides and the cycle starts anew (Tibbets 2006).

Wetlands accrete in locations where sediment is deposited by pulses of water. Typically, “pulsing” is a short-term, high impact event influenced by the regular flow of the river or by the tides and/or currents during storms and hurricanes (Day, et al. 2002). The flow of the Mississippi River has the biggest influence on where sediment is being actively deposited to accrete wetlands. The massive river delivers about 600 billion kilograms of sediment each year to the Gulf Coast. In the past, more sediment was deposited throughout the various distributaries in the delta, but at present, due to the levees and channelization, most of the sediment is currently being carried on to the very end of the Mississippi River and ultimately
deposited in deeper offshore Gulf waters (Blum and Roberts 2009).

Although a portion of sediment is currently being deposited in the two active deltas (Balize Delta and Atchafalaya Delta), the altered hydrology of the Mississippi River has reduced the sediment loads to these areas and transported the sediment directly into the Gulf.

Historically, the sediment distribution to old deltas like LaFourche maintained soil-building the worked to slow the natural degradation and subsidence. More recently, the reduced sediment load deposited in deltaic wetlands has caused the accretion rate to be exceeded by the subsidence rate. A recent study (Blum and Roberts 2009) calculated the amount of sediment accumulated in the delta for the past 12,000 years, and found the average amount needed to construct land on the floodplain and delta over this time period exceeded the amount that was actually being deposited. The results of the study also indicated the reduced sediment loads will eventually lead to the submergence of an additional 10,000-13,500 squared kilometers of land by the year 2100. Even if the state of the Mississippi River was restored is such ways as to allow the deposition of the additional 18-24 billion tons of sediment needed to sustain the existing surface area of the delta, land loss is inevitable because sea level is currently rising at least three times faster than during delta-plain construction (Blum and Roberts 2009).

Historical records have shown land building and decay patterns at different time scales, from days to hundreds of years. However, the natural cycle was disrupted in Louisiana during the mid to late 20th century, as land was lost more quickly and land building processes remained static or declined. In other words, the rate of subsidence began to exceed the rate of accretion (Coleman and Roberts 1998). This trend results from a number of inter-related
An additional driver of wetland loss was due to the shift in the geologic faults located within the Gulf of Mexico region. From 1969-1971, the shift in the Michaud fault shifted caused New Orleans to experience a slip of 16.9 mm. Afterwards, the region experienced a period of relatively rapid subsidence from 1971-1977 of 7.1 mm, then a deceleration of slipping until the 1990s (Kolker, et al. 2011). Although natural geologic processes are partially responsible for the significant land loss in Louisiana, in reality most of Louisiana’s wetland losses were caused indirectly as a result of human activity interrupting land building processes. Such drivers of land loss will be discussed in the following section.

**Human Activities Influencing Land Loss**

Over the course of the past 150 years, the natural deterioration and subsidence of the Mississippi River delta has been exacerbated in many ways by human activities. Levee construction has significantly altered the hydrology of the Mississippi River (Figure 2), thus preventing the transport of fresh water, nutrients, and sediment that serve to nourish and accrete wetlands. Although the anthropogenic levees are an integral piece of the hurricane protection system in southeastern Louisiana, the construction of over 2,000 miles of these makeshift walls has had diverse effects on the natural environment. Since levee construction began in 1727, the floodplain wetlands surrounding the Mississippi River have been reduced in area by approximately 90%. Today South Louisiana is one of the most intensively engineered places in the United States (Gagliano et al. 1998).
Figure 2: Hydrology of Mississippi River floodplain before and after levee constructions


Canal construction is another example of how the human footprint on the earth has accelerated the rate at which wetlands are being lost in southeastern Louisiana. There are
approximately 9,000-11,000 kilometers of canals that were dug in coastal Louisiana wetlands for purposes of navigation and resource exploration and extraction. The soil that was dredged was deposited alongside the canals, which eventually formed between 18,000 and 22,000 kilometers of spoil banks that blocked the natural flow of freshwater exchange between wetlands throughout the region. Larger canals were dredged to accommodate the navigation of pull boats, causing further damage. These canals were 3 to 12 meters wide and 2.4 to 3 meters deep, decreasing the swamp’s capacity for drainage and resulting in an increased tidal exchange within many swamps throughout south Louisiana (Gagliano, et al. 1981).

The most well-known canal is the Mississippi River Gulf Outlet, constructed between the years of 1963 and 1965. The purpose of the channel was to provide a shorter route between the Gulf of Mexico and the port in New Orleans. Over 527 ha of wetlands were destroyed during the dredging phase of the Mississippi River Gulf Outlet, and the canal was further expanded by the effects of erosion over time. Today, the canal directly links the Gulf of Mexico with the Lake Ponchartrain Basin, and subsequent saltwater intrusion flowing through the canal has extensively damaged the freshwater wetlands in the surrounding area. The shipping channel continues to be the primary cause of salinization in both Lakes Ponchartrain and Maurepas, which has resulted in the loss of much of the once-extensive freshwater wetlands around both lakes that cannot survive this prolonged exposure to saltwater (Coleman and Roberts 1998).

Petroleum oil and natural gas exploration has also taken its toll and contributed to subsidence in the Gulf of Mexico region. Many studies have indicated the change in subsidence rates is influenced by the amount of subsurface fluids (i.e., oil and groundwater) withdrawn from
the earth. Subsurface fluid withdrawal decreases the pressure in the ground and alters the grain-to-grain contacts in the sediments (Chang and Zoback 2007). Because there are multiple factors that influence subsidence, a causal relationship has not been linked between drilling and subsidence, but numerous studies have shown a strong positive correlation between the two (Kolker, et al. 2011). Patterns linking oil production with subsidence rates have been evident upon the analysis of historical data in southern Louisiana from 1954-1971. Subsidence in southern Louisiana was highest during the years when oil production was at its peak, and a decrease in subsidence occurred as oil/gas production slowed down (Kolker, et al. 2011). Such a tight temporal coupling between these two variables suggests these landscapes and related ecozones are quite sensitive to the slightest change in fluid withdrawal, and that these anthropogenic activities can have a rapid influence on earth processes (Kolker et al. 2011). The byproduct of burning the fossil fuels that are being extracted from the coast of Louisiana is the emission of carbon dioxide. Over time, the buildup of these gases trap heat within the earth’s atmosphere, thus accelerating the rate at which the earth is warming. This is just one measurable and indisputable effect of climate change that is having serious implications on the environment, and on economic uses for the land, including agriculture, fisheries, and tourism. Another is the rise in sea level, an issue that will be further explored in the following section.

**Sea Level Rise & Its Impact on Land Loss**

Warmer temperatures are resulting in a rise in sea levels worldwide, and this is accelerating the rate of wetland loss in many regions. As water warms, it expands in volume, and the hotter temperatures have resulted in rising sea levels that make the issue of land loss even worse. The change in the height of the ocean as a result of warming seas is referred to as
eustatic sea level rise, or the absolute measurement of the rise in the water. Eustatic sea level is expected to increase by 30 cm across the globe by the middle of the 21st century (Glick, et al. 2013).

Deltaic wetlands are most sensitive to eustatic sea level rise because the area is already subject to regional subsidence. In other words, seas rise and encroach further upon the coastline while the land simultaneously sinks. Relative sea level rise is a fixed measure that accounts for the difference between eustatic sea level rise and subsidence. Since the land underneath the ocean may rise and fall, it is important to measure the sea level rise relative to that movement of the land in order to get an accurate measure of the extent the seas are actually rising. To offset relative sea level rise, wetlands must be able to accrete at rates greater than or equal to the rising water level. Historically, coastal wetlands have been able to keep up with the rise in sea levels over time, but the projected increase in eustatic sea level rise is expected to result in the complete submergence of many more coastal wetlands in the future (Glick, et al. 2013).

It is important to note that historical records indicate sea levels tend to follow a natural cycle of both lows and highs. During the period of falling sea level, such as occurred during the ice ages, land formation will accelerate. During periods of rising sea levels, deposition by the river may fail to keep pace, and saline water may move inland, converting the freshwater swamps and marshes back into brackish marsh, salt marsh, or open water and dramatically altering the ecosystems in affected areas. The latter is occurring at present, and the rate at which the seas are nibbling away at the Louisiana coast is unprecedented (Kolker, et al. 2011).
In fact, the Gulf of Mexico region is experiencing a more drastic rise in sea level than almost anywhere else in the world. In 2012, global average for sea level rise increased by approximately 3 mm per year, but within the northwestern Gulf of Mexico that rate increased to 10 mm for the same year. Historical data were analyzed from a gage located on the southern end of the Interstate 55 Bridge across Pass Manchac to measure long-term changes to eustatic sea level rise. Since the Louisiana Department of Transportation has determined that Interstate 55 does not subside with the surrounding wetlands, the datum are considered ideal for such a study (Day, et al. 2002). In general, water levels in the area usually rises in the spring, then falls to its lowest level in the summer, then rising to its highest level in the fall, and again falling to the low levels in winter. The high stages recorded in the fall are attributed to tropical storms such as Hurricane Katrina in late August of 2005. Increased flood duration can be attributed to two causes, either a rise in sea level and/or subsidence. The mean sea level from 1957-2000 measured 1.6 mm each year, up a total of 0.07 mm for this period. For the same area at the Manchac land bridge, subsidence has measured 2.0 mm each year, meaning the Manchac area currently floods twice as much as 50 years ago (Day, et al. 2002).

Areas with low tidal range such as the Gulf of Mexico are especially vulnerable to rising sea levels. Over time, low tides have defined the salinity threshold that can be tolerated by the deltaic ecosystems, meaning the rise in sea level has severe consequences for freshwater wetlands with low tolerance to salinity that increases significantly during hurricane pulsing events. Under natural conditions, wetlands strive to attain a balance between the presence of
freshwater and saltwater, and pulsing is one source from which the presence of water is derived. The future state of wetland ecosystems depends on the dynamic equilibrium sustained between these two opposing set of pulses, but a single stable set is not expected in the future. Instead, the dynamic equilibrium will exist around a mean, and the most recent pulses will determine the magnitude and direction of the deviations from that mean (Day, et al. 2002; Reed and Wilson 2004).

Increased sea level rise is expected to skew the balance even further in the future. Even a rise of a few centimeters in sea level can make a huge difference in the duration of flooding in wetlands, and hence the plant communities that grow there. Wetland vegetation is highly sensitive to these changes because the hydrology of an ecosystem determines the type of plants that will grow there in the first place. In other words, wetland vegetation is a product of its hydrologic regime and is conditioned by surroundings of its natural environment. For example, marshes are more tolerant to saltwater flooding because they border the coast and have adapted to periodic salt water intrusions (Glick, et al. 2013). In fact, the herbaceous species that are dominant in marshes are actually nourished by saltwater flushes associated with pulsing, which stimulates the productivity of these plants. Whereas marshes can typically withstand being inundated by saltwater more frequently and for longer periods of time, the areas less frequently inundated with saltwater at higher elevations were conditioned over time and were nourished by freshwater pulsing (Day, et al. 2002). The effects of saltwater flooding on freshwater wetlands will be explored in the following section.
Effects of Saltwater Intrusion on Freshwater Wetlands

Freshwater wetlands are comprised of bottomland hardwood forest, freshwater marsh, and swamp forest. Bottomland hardwood forests are typically found in areas of lower elevations with less frequent flooding. Land cover of bottomland hardwood forests consists of American elm (*Ulmus Americana*), sweetgum (*Liquidambar styraciflua*), sugarberry (*Celtis laevigata*), and swamp red maple (*Acer rubrum var. drummondii*). Freshwater marsh is comprised of “flotant”, a vegetative cover of detritus, algae, and plant roots that support maidencane (*Panicum hemitomon*), spikerush (*Eleocharis sp.*), and bulltongue (*Sagittaria falcate*). Finally, swamp forests were the wetland type discussed in the previous section, and are comprised of bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) (Keddy et al. 2007).

The Maurepas swamp is located within the Upper Ponchartrain Basin, and is one of the largest freshwater wetlands in North America. This extensive swamp surrounds the shorelines of Lake Ponchartrain and Lake Maurepas in southeastern Louisiana, just northwest of New Orleans. The swamp consists of over 147,000 ha of wetlands, mostly dominated by bald cypress and water tupelo. Within the past 50 years, the Maurepas swamp has also become among the most damaged freshwater wetlands in the nation, with a decline in wetlands and a commensurate increase in areas of marsh and open water (Keddy, et al. 2007)
In the past, these freshwater swamp forests have been quite resilient to ecosystem shocks. Although most of the old growth forests had been clear cut by the early 20th century, most had regenerated as secondary growth swamps in later years. Figure 3 shows the current extent of bottomland forest in the Mississippi River Alluvial Plain. Historically, the control of flooding allowed the clearing of the floodplain forest and the valley’s conversion to agriculture. Approximately 80% of the original 22 million acre forest in the valley has been cleared. (Figure 3) and the vast majority of the remaining forest has been logged repeatedly, leaving only several hundred acres of old growth forest.
Figure 3: Cleared bottomland hardwood forest of the Mississippi Alluvial Plain
By the mid-1960s, however, many areas within the Maurepas swamp had begun converting to marsh and open water. The problem has only worsened since. To better understand the loss of wetlands to open water, it helps to think about the distribution of wetland types in terms of their distance from the Gulf of Mexico.

Coastal marshes are usually the first areas of land lost to open water because they border the ocean’s edge and lay at a lower elevation. Freshwater forested wetlands are located further inland at higher elevations. Although further in distance from the Gulf of Mexico, the low tolerance to salinity of freshwater ecosystems has made surviving the increased frequency and intensity of saltwater intrusion difficult for these wetlands. Over time, there has been a steady loss of freshwater wetland area, and a gradual conversion of fresh water to salt water vegetation types. There are many potential future states for this ecosystem, but the rising sea levels and warmer climate has increased the probability the area will eventually become a salt and brackish embayment fringed with mangroves (Keddy, et al. 2007).

Multiple factors have contributed to saltwater intrusion within freshwater wetlands of the study area. The construction of the Mississippi River Gulf Outlet, a canal that is ever-widening due to erosion, has provided an entry point for storm surges during proximate hurricanes. In 2005, Hurricane Katrina’s storm surge pushed through the outlet and flooded the forested wetlands of the Lake Maurepas swamp for months afterward. Bald cypress and water tupelo (Nyssa aquatic), the tree species that are dominant in these ecosystems, can tolerate some moderate saltwater exposure, but during Katrina the swamps remained inundated with saltwater even months after Katrina (Day, et al. 2007).
Within the past decade, there has been an increased number of intense hurricanes, and the storm surge has pushed further inland to infiltrate the freshwater forested wetlands. These pulses of saline water that are driven inland by tropical storms are thought to significantly reduce plant diversity in fresh marshes and prevent the regeneration of swamps (Day, et al. 2002).

Not only are tupelo and bald cypress saplings unable to survive when completely submerged by saltwater, seedlings are unable to germinate without bare ground with only intermittent flooding from freshwater pulses. To make matters worse, on average, flood durations in the Maurepas Swamps have doubled over the past half-century. Continuous flooding, although not immediately detrimental to cypress-tupelo swamps, will lead to their gradual death over time (Shaffer, et al 2009). The four different habitats identified in the Maurepas swamp appear to be in various stages along this trajectory of swamp decline. In terms of productivity, the vast majority of the Maurepas swamp, including interior, intermediate, and lake sites, was typical of swamps identified as either nutrient-poor and stagnant, stagnant, or near-continuously flooded. If the high mortality rates for “keystone” species continue, some areas along the southern shore of Lake Maurepas may be completely deforested within the next 2-5 years (Shaffer, et al. 2009). Because flood duration and salinity control species composition, the vegetation of fresh water swamps and marshes will likely be converted to types found in salt marshes and open water, a process already documented in historical photographs (Keddy, et al. 2007).

On the other hand, there are other threats to these ecosystems. Freshwater forested wetlands that are not converted to saline marshes or open water are at risk of being heavily
logged. Deforestation has been common in those areas throughout history, a fact confirmed by the evidence of large stumps and draglines through the marsh. Cypress wood, while very soft, is highly sought due to its natural resistance to rot. Consequently, the demand for the wood was satisfied through the logging industry.

The start of the logging industry began with the Timber Act of 1876, when swampland was declared unsuitable for cultivation. Large tracts were sold for 25-50 cents per acre (0.4 ha), and pull boats further mechanized the logging industry. Teams of loggers harvested the enormous cypress trees. Pull boats then used cables and winches to drag the fallen trees to the open water, from as far away as 1,524 meters. Canals were excavated at 3,048 meter intervals, allowing entire forests to be clear-cut by boat.

Lumber extraction reached a maximum in the early 1900s, and by 1934, the state of Louisiana had more than 647,497 ha of cutover swamp, with only 8,093 ha remaining in cypress forest. The stumps from this period remain a testimony to the durability of the wood. The end of the booming cypress industry had negative impacts on the furniture and boat-building industries. Spanish moss gathered from the trees sold for up to 60 cents per pound, and was used to stuff upholstery for furniture or for mattresses. Boat-building was also affected, mostly the larger boats that required cypress planks over 7 inches thick (Shaffer, et al. 2009).

Logging continued for decades, albeit most recently at a much slower pace due to the drastic decrease in forested area. Until 2005, the U.S. Army Corps of Engineers could restrict logging near waterways, but a last-minute provision in the Water Resources Development Act of 2005 removed this managerial power from the Corps. The action was strongly supported by
the Louisiana Forestry Association because it would allow for more logging in swamps. Because freshwater swamps in the immediate vicinity of coastal Louisiana are near waterways, the risk of intense logging and further swamp degradation has increased in those areas. Albeit to a lesser degree, freshwater swamps are also at risk of being converted for use in agriculture or for land acquisitions for urban development (Shaffer, et al. 2009).

**Previous Land Use/Land Cover Change Analyses**

Many studies have examined the changes in land use and land cover within Louisiana. A recent National Oceanic and Atmospheric Administration (NOAA) report on the change in regional land cover in the Gulf of Mexico found that in just 14 years, 13% of land cover had changed in the Gulf of Mexico region. Between 1996 and 2010, approximately 64,967 square miles in coastal region had experienced changes in land cover-equivalent to an area the size of Florida. Wetlands and forest cover losses were among the most significant changes, of which development was an attributing factor (NOAA 2010).

Another study by Nelson, et al. (2002) quantified land cover change in the upper Barataria basin in Louisiana over the 20 years from 1972 to1992. The Upper Barataria basin can be divided into 3 zones based on a salinity gradient. The lower portion is known as the coastal marsh zone, the middle zone consists of brackish marsh, and the natural land cover of the upper freshwater portion consists of swamp forests and freshwater marshes. The most dominant land cover change identified in the study was the increase in swamp forest at the expense of the bottomland hardwood forest. Swamp forests are typically located at a lower elevation than bottomland hardwood forests and flood more frequently. Therefore, possible causes for the transition may be related to subsidence or an encroachment of wetter swamp
forest areas into higher elevation edges.

A longer-term analysis by Gagliano et al. (1981) compared maps, black and white aerial photographs, and color infrared imagery at five year intervals to measure land loss over 11,500 square miles in the Mississippi River Deltaic Plain from 1890-1978. The results show that the long term trend of net delta expansion, which had remained consistent throughout the past 5,000 years, had been reversed during the late nineteenth century while land loss rates actually accelerated in the twentieth century. In 1913, an average of 6.7 square miles of land were lost, and in 1980 approximately 39.4 square miles of land were lost (Gagliano, et al. 1981).

Another study by Barras, et al. (2004) used Landsat Thematic Mapper satellite imagery to measure land loss in coastal Louisiana since 1978 so as to predict future changes through 2050. Historical trends associated with both land loss and land gain were identified, and future trends were projected based on the past. Assuming past trends continue in the future and excluding uncertainties associated with variables including sea level rise, the authors predicted that of the 5,841 square miles of land that existed in 2000, approximately 513 square miles would be lost by 2050. When land gain estimates were incorporated alongside land loss, the net loss from 1956-2050 was estimated at 2,038 square miles. Without incorporating the projected gain in land, the estimated total loss amounted to 2,199 square miles (Barras, et al. 2004).

Another study measured land loss in coastal Louisiana from 1932-2010. To overcome the challenges associated with quantifying the loss of land that is in a constant state of flux, Couvillion, et al. (2011) overlaid 17 datasets to identify the 30 square meter pixels that were persistently classified as “loss” or “gain” for at least two consecutive time periods before
determining that any given pixel had permanently changed. Such methods are beneficial in that they compensate for factors such as seasonal variability, which could occur if a coastal area with wetlands experienced a particularly dry or hot year at the time and date when the aerial or satellite image was taken. The larger sample size of n=17 datasets also ensured a more accurate average because it reduced the variability in estimates of land to water ratios over time.

Since the 1980s, remote sensing and geographic information system (GIS) techniques have been used in land use and land cover change analyses to address a wide range of resource management problems. Although Louisiana has been a popular focal point for such studies, few have spanned the region of southeast Louisiana from New Orleans to Baton Rouge. Fewer still have examined the changes in “snapshots” of time over both the short and long term. By examining these changes from 2000-2006, 2006-2011, and 2000-2011, a better, more comprehensive view of how the landscape existed before Hurricane Katrina landed in 2005 can be developed. Such a study will also allow me to assess how well the wetlands lost to Katrina have recovered in years since, if at all. Measuring the change in open water will provide another indicator of wetland loss, while any changes to developed land categories may point to areas where signs of urban sprawl may warrant closer scrutiny if such expansion poses a risk to wetland degradation, etc.
CHAPTER III

STUDY AREA AND METHODOLOGY

Again, as noted in chapter one, the rationale behind the study design was to choose an area of interest large enough to capture the widespread land cover changes throughout the region without compromising the level of resolution needed to make meaningful assessments of land change including wetland loss and urban sprawl at a local level. In order to achieve the research goal of monitoring land cover changes throughout the pre- and post-Katrina eras, the study area would incorporate all of the developed and natural lands of southeast Louisiana. In an effort to assess and measure urban sprawl that may have been associated with migration in the wake of the hurricane, the study area encompasses the entire ten parish region from New Orleans to as far north as Baton Rouge. The final list of parishes chosen for the study area include: St. Bernard, Plaquemines, Jefferson, Orleans, East Baton Rouge, Livingston, Ascension, St. James, St. John the Baptist, and St Charles. Overall, the research area measures approximately 19,958 square kilometers.

Land cover analyses should be prioritized within these parishes for many reasons. Figure 1 illustrates the population growth pattern of all five parishes from 2000 to 2011. Although the population decreased significantly across parishes after Katrina hit in 2005, each one shows steady population growth from 2007 to 2011. Orleans, East Baton Rouge, and Jefferson were three of the four most heavily populated parishes in the state for the three years under study in this thesis (U.S. Census Bureau 2000). Because there are large metropolitan areas in these parishes, more people and businesses are at risk of land loss. Livingston and Ascension are
among the fastest growing parishes, making it important to monitor the land cover change in those areas to ensure wetland conservation goals are being met in light of increased economic development. Growth in these areas may also spur the demand for property, causing an increase in property values that make the stakes associated with land loss even higher (U.S. Census Bureau 2000). Figure 4 shows the change in population from 2000 to 2011 for the five most densely populated parishes incorporated in the study.

![Figure 4: Change in population for five of the ten parishes in study area](image)

**Source:** US Census 2000; American Community Survey 2007 & 2011

Although the remaining five parishes in the study areas (St. Bernard, Plaquemines, St. James, St. John the Baptist, and St. Charles) are not counted among the fastest growing or most densely populated, these parishes should still be prioritized for the monitoring of land loss. St. Bernard and Plaquemines are at a very high risk of continued land loss because both are coastal parishes significantly impacted by the forces discussed previously. Also, the Port of South Louisiana stretches for 54 miles through St. James, St. John the Baptist, and St. Charles, making
them of strategic economic importance at local, regional, and even national levels.

The port is the largest in the Western hemisphere, meaning the economic losses from interrupted shipping logistics associated with land loss would be significant. In the past, the nearby Maurepas Swamp has protected the towns located within these parishes from storm surge during hurricanes, but the swamp has degraded over time and is converting to open water (Keddy, et al. 2007). Identifying the extent to which the area seen an increase in developed land, a loss of wetlands and an increase in open water is valuable information for use in future planning.

To enhance understanding of the many facets that define the issue of land loss, the primary goal of this research is to analyze the land cover changes in southeast Louisiana for the five years before and after Hurricane Katrina’s landfall in 2005. To achieve this goal, land loss was measured by open water gains and wetland losses from 2001 to 2006, from 2006 to 2011, and from 2001 to 2011. Another emphasis of the analysis is to measure the increase in developed land from Baton Rouge to as New Orleans to monitor sprawl and identify areas that may be at high risk of future flooding. Measuring conversions to development may also help identify whether these area threats to wetland conservation and to better understand the ecological risks associated with land loss.

To achieve the research goals noted above, three change index datasets derived from the National Land Cover Databases for years 2001-2011, 2001-2006 and 2006-2011 were sourced from the Multi-Resolution Land Consortium (MRLC) website and mapped within ESRI’s ArcGIS to monitor land use and land cover change for those time periods.

The MRLC is regarded by the scientific community as a reputable source for land cover datasets, which are products of the satellite imagery sourced from remote sensors. A web server
was used to process the data request for the study area, and the extent of its area was specified by the corresponding latitude and longitude geographic coordinates. The datasets were derived from Landsat 5 Thematic Mapper satellite imagery and registered to an Albers Equal Area projection. Each pixel in the map measures 30 square meters in resolution. The classification system for the NLCDs used in this study was based on a Level II categorization in the Anderson land cover classification system, and included the 15 land cover classes shown in Table 1.

**Table 1**: National land cover database legend for years 2001, 2006 and 2011

<table>
<thead>
<tr>
<th>Class/Value:</th>
<th>Classification Description for the 2011 National Land Cover Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td><strong>Open Water</strong> - areas of open water, generally with less than 25% cover of vegetation or soil.</td>
</tr>
<tr>
<td>Developed</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td><strong>Developed, Open Space</strong> - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.</td>
</tr>
<tr>
<td>22</td>
<td><strong>Developed, Low Intensity</strong> - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.</td>
</tr>
<tr>
<td>23</td>
<td><strong>Developed, Medium Intensity</strong> - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units</td>
</tr>
<tr>
<td>24</td>
<td><strong>Developed High Intensity</strong> - highly developed areas where people reside or work in high</td>
</tr>
</tbody>
</table>
Table 1 - continued

<table>
<thead>
<tr>
<th>Barren</th>
<th>Numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover</td>
</tr>
<tr>
<td>Forest</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.</td>
</tr>
<tr>
<td>42</td>
<td>Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.</td>
</tr>
<tr>
<td>43</td>
<td>Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.</td>
</tr>
<tr>
<td>Shrubland</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.</td>
</tr>
<tr>
<td>Herbaceous</td>
<td></td>
</tr>
<tr>
<td>71</td>
<td>Grassland/Herbaceous - areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas</td>
</tr>
</tbody>
</table>
Table 1- continued

<table>
<thead>
<tr>
<th>Planted/Cultivated</th>
<th>Pasture/Hay - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td><strong>Pasture/Hay</strong> - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.</td>
</tr>
<tr>
<td>82</td>
<td><strong>Cultivated Crops</strong> - areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wetlands</th>
<th>Woody Wetlands - Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically covered with water.</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td><strong>Woody Wetlands</strong> - Areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically covered with water.</td>
</tr>
<tr>
<td>95</td>
<td><strong>Emergent Herbaceous Wetlands</strong> - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.</td>
</tr>
</tbody>
</table>

Source: Multi Resolution Land Consortium website

James Anderson created the classification system in 1976, which grouped satellite imagery into four different categories based on resolution. His purpose for developing the classification system was to inform the recipients of the potential use and limitations of satellite imagery with varying levels of resolution. The four categories in the Anderson classification system represent different levels of detail that result from various types of resolution, with Anderson Level I representing the category with the least amount of detail and Anderson Level IV representing the category with the most detail (Table 1). For this thesis, the land cover...
datasets used were byproducts of Landsat Thematic Mapper satellite imagery, which falls within the Anderson Level II classification scheme shown in Table 1.

Table 2: Representative image interpretation formats for various land use/land cover classification levels

<table>
<thead>
<tr>
<th>Land Use/Land Cover Classification Level</th>
<th>Representative Format For Image Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Low to moderate resolution satellite data (e.g., Landsat MSS data)</td>
</tr>
<tr>
<td>II</td>
<td>Small-scale aerial photographs: moderate resolution satellite data (e.g., Landsat TM data)</td>
</tr>
<tr>
<td>III</td>
<td>Medium-scale aerial photographs: moderate or high resolution satellite data (e.g., IKONOS data)</td>
</tr>
<tr>
<td>IV</td>
<td>Large-scale aerial photographs: high resolution satellite data (e.g., Quickbird data)</td>
</tr>
</tbody>
</table>

Each pixel measured 30 square meters in size, a moderate resolution that generally depicts the landscape at a smaller scale. Although 30 meter resolution provides less detail for the viewer, its broader perspective that allows them to identify landscape patterns at a more regional level (Congalton & Green 2009).

Thematic accuracy is also influenced by the level of detail provided by a satellite image, which varies based on its resolution. It is important to assess the classification accuracy of land cover categories before using the datasets. Error matrixes are often created to produce three outputs that are descriptive statistics used to assess the accuracy in different ways: overall accuracy, producer’s accuracy and user’s accuracy. The overall accuracy (also known as the Kappa coefficient) represents the probability the assessed error did not occur by random chance alone. In other words, the higher the Kappa, the more certain one can be that the assessed error is an accurate depiction of reality and not just a random fluke (Congalton & Green 2009). User’s accuracy is the second descriptive statistic to measure the classification accuracy of satellite imagery, and takes the errors of commission into account by telling the user that, for all areas identified as category ‘X’, a certain percentage were correctly classified pixels. Producer’s accuracy is the final descriptive statistic in the error matrix, and measures the errors of omission. It represents the number of pixels correctly classified in a particular category as a percentage of the total number of pixels actually belonging to that category in the image. Whereas the denominator in user’s accuracy is based on the total number of pixels identified as a category, the denominator in producer’s accuracy represents the correct total number of pixels actually belonging to that category.
Each change index dataset used in this thesis was assessed for accuracy by Wickham, et al. (2017). Agreement between map and reference labels for the binary change versus no change was assessed for the 2001-2011 (Table 3), 2006-2011 (Table 4) and 2001-2006 (Table 5) change datasets using a stratified random sampling method. Interpreters assigned each random point selected both ‘primary’ and ‘alternate’ labels, which represented the: 1) most likely, and, 2) second most likely land covers for that pixel, respectively. After the pixels classified in the NLCD were cross-checked with the Google Earth reference data for agreement, the error matrix was created to find out how many pixels were misclassified or wrongfully excluded from a category (Wickham, et al 2016).

Tables 3, 4 and 5 shows the error matrix results for the NLCDs measuring land use and land cover change from 2001 to 2011, 2006 to 2011 and 2001 to 2006. Agreement was defined as a match between the map and primary reference labels. Cell entries represent percent of area. The labels User, Prod and OA refer to User’s, Producer’s, and overall accuracies. The labels Auser and Aprod refer to user’s and producer’s accuracy when the alternate label is also included in determining agreement. The labels OA1 and OA2 are overall accuracies for agreement defined as a match between the map and primary label only and a match between the map and either the primary or alternate reference labels, respectively. Standard errors are reported in parentheses.

Overall accuracy (OA1) for 2001-2011, 2006-2011 and 2001-2006 was 93.7%, 95.4% and 95.3%, when agreement was defined as a match between the map and primary reference labels, respectively. When agreement was defined as a match between the map and either primary or alternate labels, the overall accuracy (OA2) for 2001-2011, 2006-2011 and
2001-2006 was 97.1%, 98.3% and 98.3%, respectively. Overall accuracy was significantly higher when agreement was expanded to include matches based on primary or alternate labels, rather than matches based on primary labels alone, because the probability a pixel has been classified correctly is higher when it is assigned two possible labels instead of one.

User’s accuracy (Total Users) for changed pixels used in this analysis from 2001 to 2011, 2006 to 2011 and 2001 to 2006 was 58.2%, 59.8% and 62.4%, when agreement was defined as a match between the map and primary reference labels, respectively. When agreement was defined as a match between the map and either primary or alternate labels, the user’s accuracy (AUser) for changed pixels used in this analysis from 2001 to 2011, 2006 to 2011 and 2001 to 2006 was 81.7%, 82.5% and 83.6%, respectively.

Producer’s accuracy for changed pixels used in this analysis from 2001 to 2011, 2006 to 2011 and 2001 to 2006 was 35.7%, 33% and 27.2%, when agreement was defined as a match between the map and primary reference labels (Prod), respectively. When agreement was defined as a match between the map and either primary or alternate labels (AProd), the producer’s accuracy for changed pixels used in this analysis from 2001 to 2011, 2006 to 2011 and 2001 to 2006 was 62.5%, 65.9% and 59.2%, respectively.
Table 3: Agreement between map and reference labels for binary change versus no change for 2001-2011 for the eastern U.S. region

<table>
<thead>
<tr>
<th></th>
<th>Map</th>
<th>NoChange</th>
<th>Reference</th>
<th>Change</th>
<th>Total</th>
<th>Users</th>
<th>Auser</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NoChange</td>
<td>91.255</td>
<td>4.472</td>
<td>95.727</td>
<td>95.3 (0.4)</td>
<td>97.8 (0.3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Change</td>
<td>1.784</td>
<td>2.488</td>
<td>4.272</td>
<td>58.2 (1.9)</td>
<td>81.7 (1.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>93.039</td>
<td>6.96</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prod</td>
<td>98.1 (0.1)</td>
<td>35.7 (2.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aprod</td>
<td>99.2 (0.1)</td>
<td>62.5 (3.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Table 4: Agreement between map and reference labels for binary change versus no change for 2006-2011 for the eastern U.S. region

<table>
<thead>
<tr>
<th></th>
<th>Map</th>
<th>NoChange</th>
<th>Reference</th>
<th>Change</th>
<th>Total</th>
<th>Users</th>
<th>Auser</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NoChange</td>
<td>93.710</td>
<td>3.448</td>
<td>97.158</td>
<td>96.5 (0.4)</td>
<td>98.8 (0.2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Change</td>
<td>1.143</td>
<td>1.7</td>
<td>2.834</td>
<td>59.8 (2.3)</td>
<td>82.5 (1.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>94.853</td>
<td>5.148</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prod</td>
<td>98.8 (0.1)</td>
<td>33.0 (2.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aprod</td>
<td>99.5 (0.04)</td>
<td>65.9 (4.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Agreement between map and reference labels for binary change versus no change for 2001-2006 for the eastern U.S. region

<table>
<thead>
<tr>
<th></th>
<th>NoChange</th>
<th>Reference</th>
<th>Total</th>
<th>Users</th>
<th>Auser</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Map</td>
<td>93.852</td>
<td>3.847</td>
<td>97.699</td>
<td>96.1 (0.4)</td>
<td>98.6 (0.2)</td>
</tr>
<tr>
<td>Change</td>
<td>0.866</td>
<td>1.435</td>
<td>2.301</td>
<td>62.4 (2.6)</td>
<td>83.6 (2.2)</td>
</tr>
<tr>
<td>Total</td>
<td>94.718</td>
<td>5.282</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prod</td>
<td>99.1 (0.1)</td>
<td>27.2 (2.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aprod</td>
<td>99.6 (0.1)</td>
<td>59.2 (4.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


To measure the change in open water, developed land, and wetlands over time, numerous land cover maps were created for this phase of the analysis. Definitions for the development rankings by level of intensity (open space, low, medium, and high) and wetland types (woody wetland and emergent herbaceous wetland) will be provided in the results sections.

Again, the maps were derived from datasets of land cover change indexes corresponding to the 2001-2011 (Homer, et al. 2015), 2001-2006 (Fry, et al. 2011), and 2006-2011 (Homer, et al. 2007) time periods. Each dataset consisted of a raster layer of change pixels identifying a ‘from’ and ‘to’ land cover class index value label for each pixel. The total number of records for each dataset represent all possible land cover change combinations.

ArcGIS software was used to clip each NLCD change index layer to the outline of all ten parishes in the study area. Then, the field containing the ‘from’ and ‘to’ land cover class index values was reclassified to only show the change in land cover categories of interest (open water, developed land, and wetlands). The reclassification methods used to create the maps showing open water gains, increases in developed land, and wetland loss and gains are detailed in Tables 6, 7, and 8, respectively. The same method was also used to reproduce all subsequent maps for the different time periods.

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Table 6: Reclassification method for land loss maps

<table>
<thead>
<tr>
<th>Old Value; “From” Category</th>
<th>“To” Category</th>
<th>New Reclassified Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Water to Open Water</td>
<td>“0”; No Change</td>
<td></td>
</tr>
<tr>
<td>Non-Open Water Converted to Open Water</td>
<td>“1”; Open Water Gains</td>
<td></td>
</tr>
<tr>
<td>Non-Open Water Converted to Non-Open Water</td>
<td>“2”; Other Categories</td>
<td></td>
</tr>
</tbody>
</table>

Source: MRLC website

Table 7: Reclassification method for increases in developed land map: 2001-2011

<table>
<thead>
<tr>
<th>Old Value; “From” Category</th>
<th>“To” Category</th>
<th>New Reclassified Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Developed Land to Non-Developed Land</td>
<td>“0”; Other Categories</td>
<td></td>
</tr>
<tr>
<td>Non-Developed, Open Space to Developed, Open Space</td>
<td>“1”; Open Space Gains</td>
<td></td>
</tr>
<tr>
<td>Non-Developed, Low Intensity to Developed, Low Intensity</td>
<td>“2”; Low Intensity Gains</td>
<td></td>
</tr>
<tr>
<td>Non-Developed, Medium Intensity to Developed, Medium Intensity</td>
<td>“3”; Medium Intensity Gains</td>
<td></td>
</tr>
<tr>
<td>Non-Developed, High intensity to Developed, High Intensity</td>
<td>“4”; High Intensity Gain</td>
<td></td>
</tr>
<tr>
<td>Open Water to Open Water</td>
<td>“5”; Open Water</td>
<td></td>
</tr>
</tbody>
</table>

Source: MRLC website
Table 8: Reclassification method for wetland gain & loss maps

<table>
<thead>
<tr>
<th>Old Value; “From” Category “To” Category</th>
<th>New Reclassified Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Woody Wetland &amp; Non-Emergent Herbaceous to Non-Woody Wetland &amp; Non-Emergent Herbaceous</td>
<td>“0”; Other Categories</td>
</tr>
<tr>
<td>Woody Wetland to Non-Woody Wetland</td>
<td>“1”; Woody Wetland Losses</td>
</tr>
<tr>
<td>Emergent Herbaceous to Non-Emergent Herbaceous</td>
<td>“2”; Emergent Herbaceous Wetland Losses</td>
</tr>
<tr>
<td>Open Water to Open Water</td>
<td>“3”; Open Water</td>
</tr>
<tr>
<td>Non-Woody Wetland to Woody Wetland</td>
<td>“4”; Woody Wetland Gains</td>
</tr>
<tr>
<td>Non-Emergent Herbaceous to Emergent Herbaceous</td>
<td>“5”; Emergent Herbaceous Wetland Gains</td>
</tr>
<tr>
<td>Woody Wetlands to Woody Wetlands</td>
<td>“6”; No Change in Woody Wetlands</td>
</tr>
<tr>
<td>Emergent Herbaceous to Emergent Herbaceous Wetlands</td>
<td>“7”; No Change in Emergent Herbaceous Wetlands</td>
</tr>
</tbody>
</table>

Source: MRLC website

The reclassifications allowed for the creation of maps from the NLCD data with themes that were unique to each land cover under analysis for each of the corresponding time periods. For each land cover map, the parishes where most of the change occurred were identified and selected for inclusion in the maps in order obtain a closer look at the changes. If all 10 parishes were included on all maps, the scale would be too small for visual evaluation. Therefore, only the most relevant parishes are included in each of the resulting figures (maps) that follow.

For example, the final open water gains map excluded parishes located at higher elevation (St. James, East Baton Rouge, and Ascension) to make it easier to see the more prominent changes that occurred in the other parishes closer to the coast. Only Plaquemines, Orleans, St. Bernard, Jefferson, and St. Charles are the parishes included in the final open water gains map.
For the map illustrating the increases in developed land from 2001-2011, the parishes located along the coast (St. Bernard and Plaquemines) are excluded because most of the change occurred within parishes further inland. Only East Baton Rouge, Ascension, Livingston, St Charles, St. James, St. John the Baptist, Orleans, and Jefferson parishes are included in the final change in development map. In lieu of including the development maps for the 2001-2006 and 2006-2011, Figure 2b is included in the results section so as to allow a comparison of change in levels of development for those time periods that are not visible to the naked eye in the maps.

In the wetland gain and loss map for 2001-2011, all ten parishes are included to provide an overview of the changes in woody wetlands further inland, as well as the changes in emergent herbaceous wetlands closer to the coast. For the other two time periods (2001-2006 and 2006-2011), only Orleans, Plaquemines, Jefferson, St. Bernard and St. Charles are included in the maps because most of the change in woody and emergent herbaceous wetlands occurred within those parishes.

After maps were created for each content area, an extra field was added to the attribute table. The field calculator tool was then used to multiply the cell count by the pixel size (900 square meters) to obtain the area in meters. Then the product for each category was again multiplied, this time by 0.09 to convert to hectares, the international system units used in all scientific research.

The following section will include all the maps and provide my assessment of the changes in the total number of hectares of land loss and built-up developed land (open space, low, medium, and high intensity categories) for the areas. Total gains, losses, and the net change for all years will also be provided for the wetland change map.
CHAPTER IV
RESULTS

Land Loss

The first part of the analysis measured land loss for all time periods by quantifying the hectares gained in open water relative to the area of the land. “Open water” is defined in the classification system for the NLCDs, and is modified from the Anderson Land Cover Classification System. The NLCD legend defines “open water” as areas that are mostly open water, with less than 25% cover of vegetation or soil (Homer, et al. 2015 and Fry, et al. 2011).

Table 9 shows the total land loss (as measured by open water gains) for Plaquemines, St. Bernard, Orleans, Jefferson and St. Charles parishes relative to the whole study area. The five parishes experienced the majority of total land loss for the ten parish study area from 2001-2011, 2001-2006 and 2006-2011.

Figure 5a illustrates the total land loss from 2001 to 2011 for the five parishes noted above. The most obvious gains in open water occurred close to the border of St. Bernard and Plaquemines parishes near the Delacroix area, in Orleans parish near the Bayou Savage Wildlife Park, and at the tip of the “boot” in Plaquemines parish.

Table 9: Land loss for select parishes relative to whole study area

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Selected Parishes</td>
<td>19,115</td>
<td>4,494</td>
<td>15,365</td>
</tr>
<tr>
<td>Total Study Area</td>
<td>19,924</td>
<td>4,814</td>
<td>15,922</td>
</tr>
</tbody>
</table>

Source: MRLC website
Table 10 shows that woody wetlands, emergent herbaceous, and barren land were the top three land cover categories that were converted to open water for all three time periods. The next map (Figure 2b) compares land loss from 2001 to 2006. Some land loss to open water is visible in Orleans parish east of Lake Ponchartrain near the Bayou Savage Wildlife Park. Another area of land lost to open water is visible directly south of there (just southeast of Pen Lake in Jefferson parish).
Table 10: Open water gains by land cover category in hectares for:  

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Barren Land</td>
<td>227</td>
<td>331</td>
<td>454</td>
</tr>
<tr>
<td>Deciduous</td>
<td>0.73</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Evergreen</td>
<td>5</td>
<td>39</td>
<td>61</td>
</tr>
<tr>
<td>Mixed</td>
<td>0.73</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Shrub Scrub</td>
<td>14</td>
<td>70</td>
<td>67</td>
</tr>
<tr>
<td>Grassland</td>
<td>55</td>
<td>42</td>
<td>80</td>
</tr>
<tr>
<td>Pasture/Hay</td>
<td>31</td>
<td>80</td>
<td>101</td>
</tr>
<tr>
<td>Cultivated Crops</td>
<td>67</td>
<td>110</td>
<td>142</td>
</tr>
<tr>
<td>Woody Wetlands</td>
<td>177</td>
<td>303</td>
<td>448</td>
</tr>
<tr>
<td>Emergent Herbaceous</td>
<td>4,199</td>
<td>14,932</td>
<td>18,496</td>
</tr>
</tbody>
</table>

Source: MRLC
Figure 5b: Land loss for Plaquemines, St. Bernard, Orleans, Jefferson & St. Charles parishes: 2001-2006

Source: Map created by Ashley Tarver (2017) using data from the MRLC (2011)

In the 2006-2011 map (Figure 2c), increases in the open water category is more pronounced. However, the Pen Lake and Bayou Savage Wildlife Pares areas that experienced a gain in open water from 2001-2006 have reverted back to different types of land sometime during the 2006-2011 time period. Overall, the Delacroix area (located southeast of New Orleans) and the tip of Louisiana’s ‘boot’ recorded the greatest increases in the “open water” class during the post-Katrina years (2006-2011).
Figure 5c: Land loss for Plaquemines, St. Bernard, Orleans, Jefferson & St. Charles parishes: 2006-2011

**Source:** Map created by Ashley Tarver (2017) using data from the MRLC (2011)

The next map (Figure 2d) shows land loss for Jefferson and Orleans parishes from 2001 to 2006. It provides a closer view of the increases in open water areas described earlier that occurred in the Pen Lake and Bayou Savage Wildlife Park areas from 2001 to 2006. During those years, Jefferson parish lost 655 hectares of land, and Orleans parish lost 539 hectares of land.
Figure 5d: Land loss for Orleans & Jefferson parishes: 2001-2006

Source: Map created by Ashley Tarver (2017) using data from the MRLC (2011)
The next map (Figure 2e) illustrates increases in the open water class for the same parishes from 2006 to 2011. Jefferson parish lost 46 more hectares of land in the pre-Katrina (2001-2006) years than the post-Katrina (2006-2011) years. On the other hand, Orleans parish lost more land in the post-Katrina years (Figure 2e). In fact, Orleans parish lost 1,027 hectares of land from 2006 to 2011, nearly twice as much as its total land loss from 2001 to 2006.
Figure 5e: Land loss for Orleans & Jefferson parishes: 2006-2011
Source: Map created by Ashley Tarver (2017) using data from the MRLC (2011)
Increases in Developed Land

The second part of the analysis measures change in built-up land (urban, transport, etc.). The data from MRLC uses a classification system employment four groups including: open space, and low, medium, and high levels of built-up land. The developed categories are defined in the classification system for the NLCDs (Table 2), and are all modified from the Anderson Land Cover Classification System.

Table 11: Percentage of land use/land cover converted to developed land for three time periods

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Barren Land</td>
<td>1%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>4%</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>4%</td>
<td>7%</td>
<td>4%</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>3%</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td>Shrub/Scrub</td>
<td>6%</td>
<td>11%</td>
<td>7%</td>
</tr>
<tr>
<td>Grassland/Herbaceous</td>
<td>6%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Pasture/Hay</td>
<td>35%</td>
<td>18%</td>
<td>34%</td>
</tr>
<tr>
<td>Woody Wetlands</td>
<td>23%</td>
<td>33%</td>
<td>25%</td>
</tr>
<tr>
<td>Emergent Herbaceous Wetlands</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Cultivated Crops</td>
<td>13%</td>
<td>10%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Source: MRLC website

Table 11 shows the percentage increase in all four development types (open space, low, medium, and high intensity) that occurred at the expense of the land use/land cover categories listed above. For all three time periods, pasture/hay and woody wetlands were the two land covers with the highest development conversion rates.

Most of the increases in developed land from 2001 to 2011 occurred in the area where East Baton Rouge, Ascension, and Livingston parishes intersect (Figure 3a). In fact, between
those same years, approximately 78% of all open space, 71% of all low intensity, 69% of all medium intensity, and 43% of all high intensity development occurred within these three parishes of the total ten parishes included in the study.

Figure 6a: Increases in developed land in East Baton Rouge, Ascension & Livingston parishes: 2001-2011

Source: Map created by Ashley Tarver (2017) using data from the MRLC (2011)

When development for each level of intensity is compared between the years from 2001 to 2006 and from 2006 to 2011, it is evident there was much more development that occurred during 2001-2006 compared to 2006-2011 (Figure 3b).
Figure 6b: Comparisons among four types of developed land for two time periods
Source: Chart created by Ashley Tarver (2017) using data from the MRLC (2011)
Wetland Gains and Losses

The final portion of the analysis involved measuring gains and losses for two wetland types for all three time periods. The two wetland categories (“woody wetland” and “emergent herbaceous wetland”) are also defined in the classification system for the National Land Cover Database legend (Table 2), and again are all modified from the Anderson Land Cover Classification System.

Both wetland types were analyzed to identify gains and losses. Over the long-term (2001-2011), Figure 4a indicates the majority of emergent herbaceous wetland losses occurred in Orleans, St. Bernard, and Plaquemines parishes. At the tip of Louisiana’s ‘boot’ (at the edge of Plaquemines parish) there were emergent herbaceous wetland gains alongside losses, although to a lesser degree. Woody wetland losses were much less prevalent. Areas that did experience some woody wetland loss include Jefferson parish and the Maurepas Swamp area.
**Figure 7a:** Wetland gains & losses for the ten parish study area: 2001-2011

**Source:** Map created by Ashley Tarver (2017) using data from the MRLC (2011)
Figure 7b: Wetland gains & losses for Plaquemines, St. Bernard, Jefferson & St. Charles parishes: 2001-2006

Source: Map created by Ashley Tarver (2017) using data from the MRLC (2011)
Figure 7c: Wetland gains & losses for Plaquemines, St. Bernard, Jefferson & St. Charles parishes: 2006-2011

Source: Map created by Ashley Tarver (2017) using data from the MRLC (2011)

Surprisingly, there is more than three times the woody wetland loss in the pre-Katrina (2001-2006) era than the post-Katrina (2006-2011) era (Table 12). The opposite was true for the emergent herbaceous wetlands. Approximately two and a half times more emergent herbaceous wetlands were lost during the period from 2006 to 2011 than for the period from 2001 to 2006.
Table 12: Wetland losses & increases for two types of wetlands for two time periods

<table>
<thead>
<tr>
<th>Wetland Losses &amp; Gains (In Hectares)</th>
<th>2001-2006</th>
<th>2006-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woody Wetland Losses</td>
<td>6,907</td>
<td>2,299</td>
</tr>
<tr>
<td>Emergent Herbaceous Wetland Losses</td>
<td>6,594</td>
<td>1,6342</td>
</tr>
<tr>
<td>Woody Wetland Gains</td>
<td>813</td>
<td>1945</td>
</tr>
<tr>
<td>Emergent Herbaceous Wetland Gains</td>
<td>421</td>
<td>6595</td>
</tr>
</tbody>
</table>

Source: Calculated by Ashley Tarver (2017) using data from the MRLC (2011)

It is possible that the increased amount of saltwater exposure to woody wetlands after Katrina prompted their transition from freshwater to emergent herbaceous wetlands, which are more tolerant of salinity. Further investigation in ArcGIS confirmed that 738 of the 2,299 hectares of woody wetlands lost from 2006 to 2011 had, in fact, changed over to emergent herbaceous wetlands.

Because the land to water ratio for wetlands is constantly fluctuating, the net difference between gains and losses for wetlands must be measured for multiple time periods in order to conclude the actual long-term wetland loss with certainty. Figure 4d provides estimates of the net loss for both emergent herbaceous and woody wetlands. From 2001 to 2006, there was a net loss of 6,094 hectares for land classified as woody wetlands, and a net loss of 6,173 hectares for those in the emergent herbaceous wetland category.

In contrast, for the years from 2006 to 2011, there was only a net loss of 354 hectares for woody wetlands, but an alarming net loss of 9,747 hectares for emergent herbaceous wetlands over the same period.
**Figure 7d:** Wetland change across two periods: 2001-2006 & 2006-2011

**Source:** Chart created by Ashley Tarver (2017) using data from the MRLC (2011)
CHAPTER V
CONCLUSION

Of the entire ten parish study area, Plaquemines, St. Bernard, Orleans, Jefferson, and St. Charles parishes experienced the most significant land loss. In fact, 95% of total land loss from 2001 to 2011 occurred within these five parishes. During this time, the most pronounced gains in open water occurred in Orleans parish, the tip of the “boot” and surrounding Lake Lery in Plaquemines parish. The land lost in Orleans and Jefferson parishes from 2001 to 2006 appeared to have converted back to land in the 2006-2011 map. Overall, the land loss in all five coastal parishes was much greater in the post-Katrina (2006-2011) time period than the pre-Katrina (2001-2006) time period. In fact, Plaquemines, St. Bernard, Orleans, Jefferson, and St. Charles parishes lost more than three times the hectares of land from 2006 to 2011 than from 2001 to 2006.

For all three time periods, emergent herbaceous, woody wetlands, and barren land were the three land covers that lost the largest areas to open water. From 2001 to 2011, over 18,496 hectares of emergent herbaceous wetlands, 448 hectares of woody wetlands, and 454 hectares of barren land were lost to open water. Open water gains from these three categories represent 97% of all land loss from 2001 to 2011.

For the second part of the analysis, the increase in four types of developed land (open space, low, medium, and high intensity) was measured for all three time periods. When the increases in each level of development (measured in hectares) from 2001 to 2006 was compared with the 2006 to 2011 time period, it was evident much more development occurred in the pre-
Katrina (2001-2006) time period. Medium-intensity development outranked all other types during all time periods.

Of the entire ten parish study area, the majority of the increases in developed land from 2001 to 2011 occurred in East Baton Rouge, Ascension, and Livingston parishes. In fact, between those same years, approximately 78% of all open space, 71% of all low intensity, 69% of all medium intensity, and 43% of all high intensity development occurred within these three of the ten parishes included in the study area.

Upon further investigation of the drivers of this development, woody wetlands and pasture/hay were the two land covers that had the highest rate of conversions to developed land. In fact, approximately 34% of the total land developed from 2001 to 2011 was converted from pasture/hay, and 25% was converted from wetlands.

The final portion of the analysis measured the gains and losses for woody wetlands and emergent herbaceous wetlands for all three time periods. Similar to the land loss maps, from 2001 to 2011 the majority of the wetland losses occurred in Plaquemines, St. Bernard, and Orleans parishes. Whereas more emergent herbaceous wetlands were lost from 2006 to 2011 than from 2001-2006, the opposite was true for woody wetlands. There was more than three times the number of woody wetlands loss during the pre-Katrina time period than the post-Katrina time period. Upon closer examination, 738 of the 2299 hectares of woody wetlands lost from 2006 to 2011 had converted to emergent herbaceous. Because woody wetlands consist of mostly freshwater and emergent herbaceous are saltwater tolerant, the transition of woody wetland to emergent herbaceous is indicative of saltwater intrusion of these freshwater ecosystems. For the same years (2006-2011), another observation was that ~33% of all
increases in developed land was converted from woody wetlands. Together, these observations suggest both open water and development are drivers of the losses in woody wetlands.
BIBLIOGRAPHY


