Effects of Landscape Fragmentation on Land Loss

Weijia Cheng
Louisiana State University and Agricultural and Mechanical College

EFFECTS OF LANDSCAPE FRAGMENTATION ON LAND LOSS

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Environmental Sciences

by
Weijia Cheng
B.S., Southwest Petroleum University (Chengdu, China), 2013
August 2016

ACKNOWLEDGMENTS

Firstly, I would like to thank my supervisor Dr. Nina Lam for her guidance and support throughout my master studies. Her instruction and experience gave me much confidence when I started working on my research. It is my honor to complete my master study under her supervision.

I would also like to thank Dr. Crystal Johnson and Dr. Matthew Bethel for the time and support they have given me while serving as my committee members. Especially, I am grateful to Dr. Yi Qiang for providing me the data and technical support which is helpful for my research. I thank the generous help from Mengqiu Ye, who helped me throughout my research.

Last but not the least, I would like to thank my parents, Lufeng Cheng and Qin Liu, for supporting me throughout writing this thesis and my life in general. Without their continued support, I would not be where I am today.

This research is supported in part by two grants from the U.S. National Science Foundation under the Dynamics of Coupled National Human Systems (CNH) Program and Coastal Science, Engineering, and Education for Sustainability (Coastal SEES) Program (award number 1212112 and 1427389). Any opinions, findings, and conclusion or recommendations expressed in this material are those of the author and do not necessary reflect the views of the funding agencies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Coastal Louisiana, the seventh largest delta on earth, is one of the most vulnerable coastal areas in the United States of America (USA) because of its land loss problem. Coastal land loss is usually caused by many complicated factors. With the rapid increase in human activities, more studies on land loss have focused on the anthropogenic elements, but less on the pattern of the landscape. It is expected that the type of spatial arrangement, such as high degree of fragmentation, would affect the degree of land erosion. A quantitative evaluation of coastal landscape fragmentation and its influences on land loss would help coastal protection. The purpose of this research is to study the effects of landscape fragmentation on land loss in the Lower Mississippi River Basin (LMRB) region. The main scientific question addressed in this study is: does the degree of fragmentation influence the degree of coastal land loss? This thesis applied fractal analysis and spatial autocorrelation statistics to calculate the degree of fragmentation, using Landsat-TM land cover data in 1996 and 2010 with a pixel size of 30m * 30m. First, 100 samples of a 50-percent land-water ratio for each of the three box sizes – 101*101, 51*51, and 31*31 pixels – were extracted from the study area. Linear regressions were conducted to compute the relationship between fragmentation and land loss. The hypothesis is that the higher the degree of spatial fragmentation, the greater the degree of land loss. The results show that boxes with a higher degree of fragmentation had more land loss for box sizes of 51*51 and 31*31 with p-values less than 0.001. The relationship is not

significant for 101*101 with p-values greater than 0.05. Thus, land fragmentation is a worthy element to be considered as a land loss factor. These results should be useful to the development of better strategies to strengthen the protection of a highly fragmented coast.

CHAPTER 1. INTRODUCTION

1.1 Background

Over the past 200 years, coastal lands in the United States have been drained, dredged, filled, leveled and flooded for urban, agricultural, and residential development (Mitsch and Gosselink 1993). Due to these activities, 22 coastal states have lost more than 50-percent of their wetlands. In Louisiana, from 1932 to 2000, the coastal zone of southern Louisiana lost an estimated 1,900 square miles of land to open water (Tibbetts 2006). It has been estimated that there will be a land loss of around 1,750 square miles by the year 2060 (Barnes 2015). Louisiana is currently experiencing 90% of the total marsh loss of the continental United States (Sorensen et al. 2005). In summary, Louisiana could potentially lose almost a third of its coast (Tibbetts 2006). Because of the land loss process, the coastal lands are subject to shoreline retreat. This situation would not only have an impact on the overall existing coastal infrastructure, but also on economic activities and development in these areas.

Thus, finding out which types of land pattern are prone to land loss is useful for prevention. Few studies have indicated the relationship between spatial arrangement and land loss, which is highly necessary for land loss prevention and management. The degree of fragmentation is one important attribute of land pattern. Analysis of the influence level of spatial arrangement on land loss, especially the degree of fragmentation, would help land protection. There have been many studies on the effects of climate change, like sea level rise on the decline of land, as well as the

effects of human activities such as canals and levees on land loss (Turner 1987; Tweel and Turner 2014). This study focuses on land pattern evaluation, and how fragmentation of land pattern influences land change.

Fragmentation derives from the word ‘fragment’, which refers to a small or incomplete part or piece broken off and separated from the whole to which it originally belongs (Demetriou 2013). Land fragmentation, which is also known as pulverization, parallelization, or scattering (Bentley 1987), is defined as the situation whereby an individual holding is split into many non-contiguous parcels.

One of the most harmful impacts of land loss is that it not only affects the area where land was lost, but also threatens areas which are in close proximity to that the land lost. Some of the lands which were lost in Louisiana were economic centers in the past. These places have been inundated in the present times and their economic value has been significantly reduced. Also, land loss and land damage have been contributing to the retreat of the coastal line (Baustian and Turner 2006). The ultimate impact of all these activities is that Louisiana is losing its valuable wetland and coastal resources. This land had helped reduce the storm effects for inland areas. Because of the land loss, there has been an inward land migration and degradation of the remaining landscape. Also, there will be a greater risk of damage because of the loss of storm protection services along the coast. The most harmful impacts of the land loss include the widespread impact on the natural and manmade assets (like the

wetland forest and private houses close to the wetland) which will also be affecting the economic activities and the ecosystem.

Thus, the problem of land loss is a long-term challenge which has to be faced by multiple groups. Analysis of the land loss problem in coastal Louisiana has to incorporate many factors to include the uncertainty over the location, timing, and severity of the land loss. Understanding the effects of land fragmentation on the degree of land loss is an essential step towards understanding the greater climate change and land loss problem (Reyes et al. 2000).

1.2 Objectives and Hypothesis

The objective of this thesis research is to study the effects of landscape fragmentation on land loss in the Lower Mississippi River Basin (LMRB) region. The hypothesis is that the higher the degree of spatial fragmentation, the greater the degree of land loss.

In this thesis research, the total loss and gain of the land in the study area from 1996 to 2010 will be analyzed using Landsat 5 TM data with a pixel size of 30m*30m. The study area is the Lower Mississippi River Basin (LMRB), which is located in southeastern Louisiana, USA, and extends from the parishes north of Lake Pontchartrain to the coast. The southeastern part of the study area suffers great land loss; the problem has been a great concern both to the government and to the locals.

In this thesis, the triangular prism method and the Moran's I method in ICAMS will be used to calculate the fragmentation degree (Lam et al. 1998 and Lam 2012).

To facilitate the research, the raster calculator and the focal statistics in ArcGIS and Erdas Imagine software will be used to develop samples of areas with a 50-percent land-water ratio. Then, 100 sample boxes for each of the three box sizes will be randomly chosen from the study area. The three different box sizes are 101*101 pixels, 51*51 pixels, and 31* 31 pixels. To better identify the effect of landscape fragmentation on land loss, selected boxes are required to have a 50-percent land-water ratio. Correlation and regression analysis between fragmentation indices in1996 and land loss percent in 2010 will then be conducted to test the hypothesis.

With the limitation of the available land area and the increase in population, many studies have been conducted to increase the efficiency of land management. Specifically, properly understanding the type of land pattern can hugely benefit land preservation. Land fragmentation is an important indication of land erosion. This research examines whether a fragmented coastal landscape is more prone to land loss. The results should provide useful insights into the land loss problem.

CHAPTER 2. LITERATURE REVIEW

2.1 Overview of Land Loss and Fragmentation

Land loss refers to the process that includes the complete erosion or losses of beaches and coastal lands around the interior bays of land and estuaries. Land loss is a major environmental problem being faced by a number of countries in the present times. Louisiana is one such place facing a huge problem of land loss. Although these coastal lands were once the most diverse and productive ecosystems in the U.S., at present, it can be observed that the coastal lands in Louisiana are in a state of degradation and fragmentation at a rapid rate. “By 2050, if nothing is done to stop this process, the state could lose another 700 square miles (Figure 1), and one-third of 1930s coastal Louisiana will have vanished” (Tibbetts 2006). Every year, the state is losing around 25,000 acres (Figure 2). The land loss includes commercial lands which were used for a number of efforts.

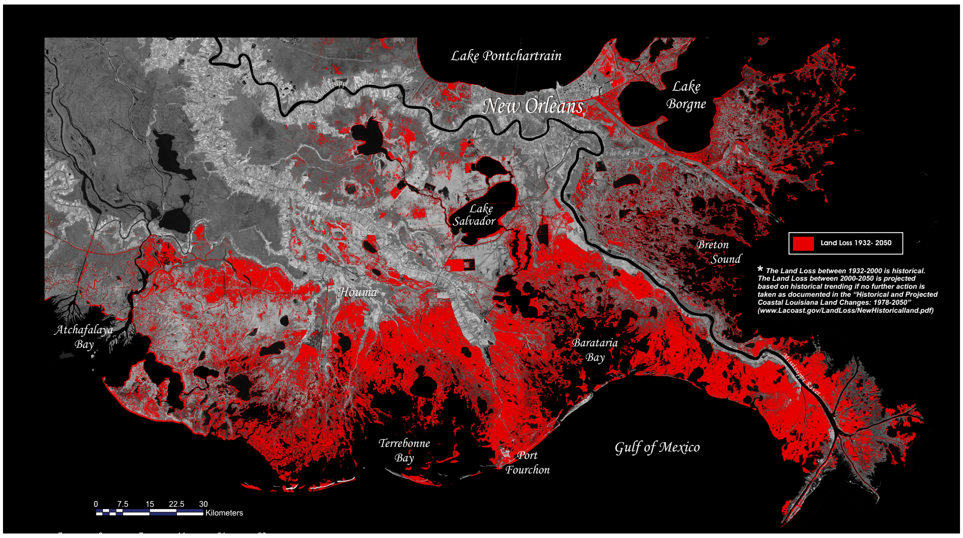

Figure 1. Louisiana coastal erosion, 1932-2050.
(Source: Barras et al. 2003)

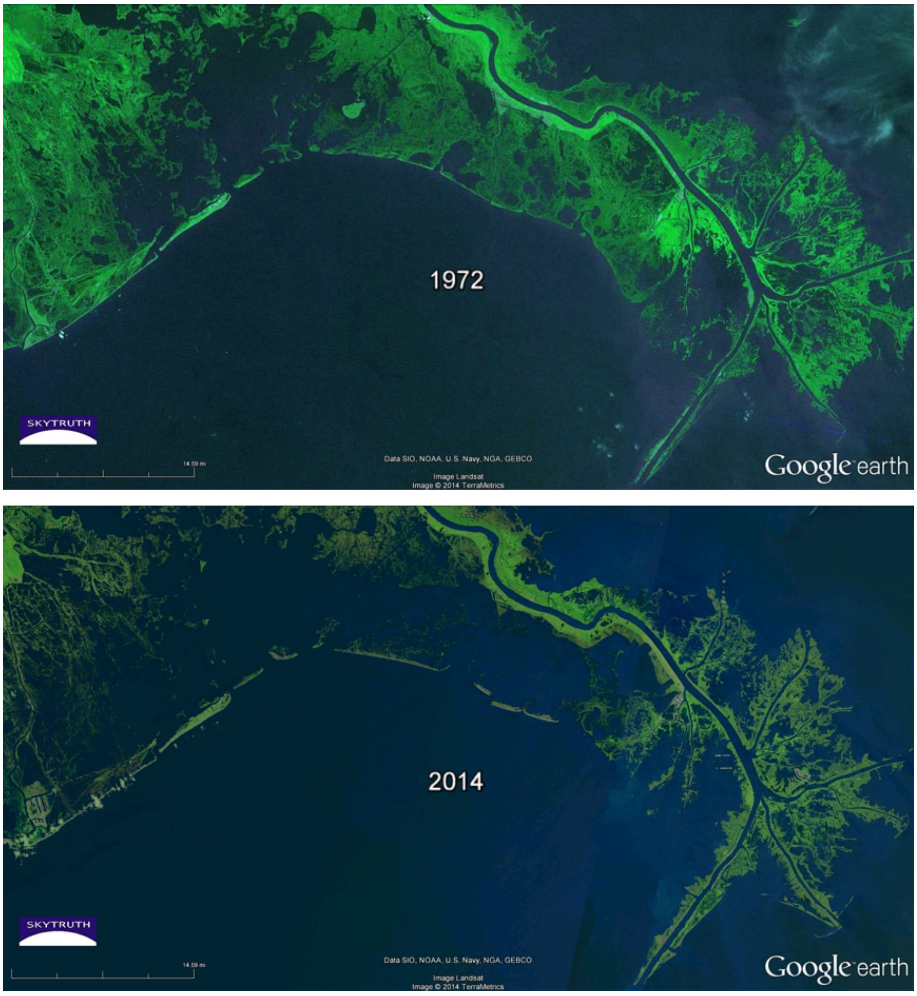

Figure 2. Mississippi Delta and Louisiana coastline as seen in 1972 and 2014 (Source: Amos 2014)

Fragmentation of land is defined as the separation of different portions of land due to natural and human activities. Because of this, the land is often impacted and it leads to land loss (Forman 1995). The word fragment means a small piece of land separated from other parts. Couvillion et al. (2016) regarded the process of fragmentation of the land as the division of the same in different and distinct pieces. Fragmentation and land loss are the critical processes which have influence over the entire landscape. There are many consequences of fragmentation and land loss on the environment such as increase in isolation of some of the patches of land and reduction

in the size of the land pattern (MacArthur and Wilson 1967; Hudson 2012). The patch area reduction and the increase in isolation have a number of detrimental impacts on the abundance and richness of different patches of land (Shaffer et al. 2015). As King and Burton (1982) stated, fragmentation is a major problem in the present times which occurs mostly in coastal areas as a result of the impact of human activities. Peyronnin et al. (2013) stated that fragmentation of land is a very serious issue. Another argument on the issue of land fragmentation has been put forward by McCulloh and Heinrich (2013) who stated that land fragmentation needs special attention and more studies.

There are a number of examples of fragmentation and land loss in the world. Khalil et al. (2013) stated that land loss is the major problem for the Louisiana costal ecosystem. Fragmentation of land often leads to isolated habitats which will decrease the abundance and diversity of flora and fauna in those locations, causing more fragmentation problems (Britsch and Dunbar 1993).

Some studies suggested that fragmentation of land occurs because of a number of water divisions in the land (Demetriou 2013). As a result of different kinds of water divisions and creation of different patterns such as canals, ditches, and levees both in the wetlands and the agricultural lands, there is fragmentation on the land. Also because of the high-speed flow of water along canals and ditches, there is fragmentation of land into small patches, leading to land loss Penland et al. (2000)

observed that as a result of constant fragmentation, there is loss of land and disturbance in the landscape patterns.

At present there are a number of control structures which have been created over different parts of the land. Fragmentation in coastal areas is both the cause and consequence of a huge decrease in sedimentary load for and reduction in the amount of marshes in the land (Houck 1983).

The increase in the fragmentation of land is a major threat to the efficiency in economic and ecological production. As a result of more and more fragmentation, more and more land is getting submerged into water. Also, this decreases the quality of water (Ingebritsen and Galloway 2014). Further, land loss is harmful as it can have an impact on biodiversity by isolating one region from another and endangering healthy vegetation growth.

The coastal land loss in Louisiana is caused by both human activities and natural processes (Hitch et al. 2011). The natural processes include coastal erosion, subsidence, and sea-level rise. The human activities of building dams and levees have led to substantial reduction of sediments to replenish the land (Scaife et al. 1983). In addition, certain human activities related to water transportation and navigation, such as boat wakes, alter the water circulation and can lead to land loss (Faulkner 2004). Another cause of coastal land loss is the creation of coastal structures including seawalls, groins, etc (Dijk 2003). Also the discharge of pollutants and the burning of

vegetation will destroy the soil structure and lead to fragmentation and land loss (Allison et al. 2014).

The most important cause of land loss is submergence, which affects many coastal areas. This refers to permanent flooding in the coastal areas which may be caused by the overall rise in the sea level. It has been observed that every year there has been a global rise of around 1.8 mm in the sea level (Pachauri et al. 2014). This sea level rise would lead to a large amount of coastal land hat will be submerged (Pachauri et al. 2014).

2.2 Methods for Measuring Fragmentation

Fractal analysis and spatial autocorrelation will be applied for calculating the land fragmentation, and the calculation will be achieved by using ICAMS.

There are a number of landscape indices and software packages that can be used. FRAGSTATS is a spatial statistics program that helps in the comparison of the landscapes of different varieties for a number of purposes (McGarigal and Marks 1995). The landscape subject to analysis is user-defined, and it can represent any spatial phenomenon. FRAGSTATS is useful to identify areas where land use activities have resulted in fragmentation of the landscape. It is incumbent upon the user to build a sound basis for defining and scaling the landscape regarding thematic content and resolution and spatial grain.

FRAGSTATS calculates several simple statistics, including the number or density of patches, the average size of patches, and the variation in patch size at the

class and landscape level. There are several different approaches for measuring contagion and interspersion like contagion index and interspersion and juxtaposition index. FRAGSTATS computes the contagion indices and the percentage of like adjacencies, which is calculated as the sum of the diagonal elements of the adjacency matrix divided by the total number of adjacencies. FRAGSTATS computes the mass fractal dimension for each class, which is based on the scaling relationship between box mass and the size of the box defining the window (McGarigal 2014).

In the year 2002, the program was combined and revamped with ArcGIS10 (McGarigal et al. 2012). FRAGSTATS accepts raster images in a variety of formats, but it does not support ArcGIS vector coverages or shapefiles (McGarigal et al. 2012).

ICAMS (Image Characterization and Modeling System) is a non-commercial software package designed to visualize, measure, and characterize landscape patterns as manifested in remote-sensing images by focusing on a number of spatial analysis tools (Lam et al. 1998). The main functions of ICAMS are analysis of fractal dimension, spatial autocorrelation, texture, land/water and vegetated/unvegetated boundary delineation, and spatial aggregation routines (Quattrochi and Lam 1997). ICAMS was built as a module compatible with two widely used Geographic Information Systems (GIS) software, Intergraph-MGE and ArcInfo. Also, ArcInfo has a link with Erdas IMAGINE. Because these platforms have been widely used, a specialized module designed to be compatible with these systems will encourage a wider access of ICAMS. ICAMS has been described in details by Quattrochi et al.

(1997) and Lam et al. (1998). The software has been updated in 2009 to include additional functions such as lacunarity and wavelet calculation and to improve the algorithm for calculating the fractal dimension (Ju and Lam 2009). Three fractal dimension measurement methods are provided in ICAMS: isarithm, variogram, and triangular prism (Lam et al. 2002). The fractal dimension and spatial autocorrelation functions will be used to calculate the degree of fragmentation in this study.

2.2.1 Fractal Method

Fractal analysis provides tools to measure the geometric complexity of imaged objects (Mandelbrot 1983). Lam (1990) gives a succinct review of the fractal concepts. Read and Lam (2002) observe that the fractal dimension D has been used to characterize land use/land cover changes in remote sensing.

The fundamental concept of fractal is the use of self-similarity to define D (Lam 1990). Fractals, as used in remote sensing, tend to emphasize the spatial relationships between adjacent cells (Lam and De Cola 1993). In geography, various fractal algorithms like isarithm, triangular prism, and variogram have been described (Lam and De Cola 1993). All the fractal methods above, along with other spatial methods, are included in ICAMS (Lam et al. 1998). Lam et al. (2002) found that in comparison with the isarithm and variogram methods, the triangular prism method is more accurate for estimation of fractal dimension of surfaces with high spatial complexity, which is a characteristic of remote sensing imagery (Clarke 1986). Therefore, the modified triangular prism method was chosen for this study.

Figure 3 shows how the triangular prism method works. For each pixel, it has the x, y coordinates and the value of the pixel is taken as the z coordinate. The four corners A, B, C, and D of the pixels show the z values. A center point connecting with the four corners creates four triangular prisms with a three-dimensional top area. The value of the center pixel is the mean value of the four corners. The relationship between the triangular prism area and the step size can be used to determine the fractal dimension. A log-log plot (Figure 4) is drawn to show the linear regression of total prism area and step size (number of pixel on a side).

$$LogA = a + (2 - D)LogS \tag{1}$$

where A = total surface area of the prism "facets",

S = step size,

a = intercept of regression plot,

D = fractal dimension

The fractal dimension of a point pattern can have any value between 0 and 1, a curve pattern, between 1 and 2, and a surface pattern, between 2 and 3. The images in this study are surfaces, so the values of fractal dimension will be between two and three.

The step size, the number of pixels on the side, is 5 in this study (Ju and Lam 2009).

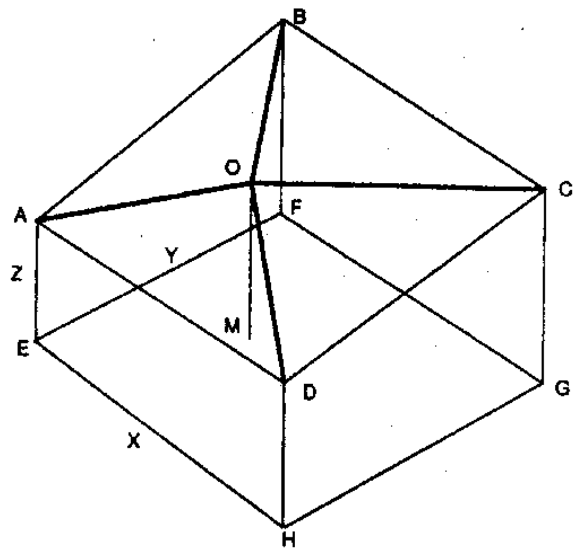

Figure 3. Coordinate structure for triangular prism method
(Source: Jaggi et al. 1993)

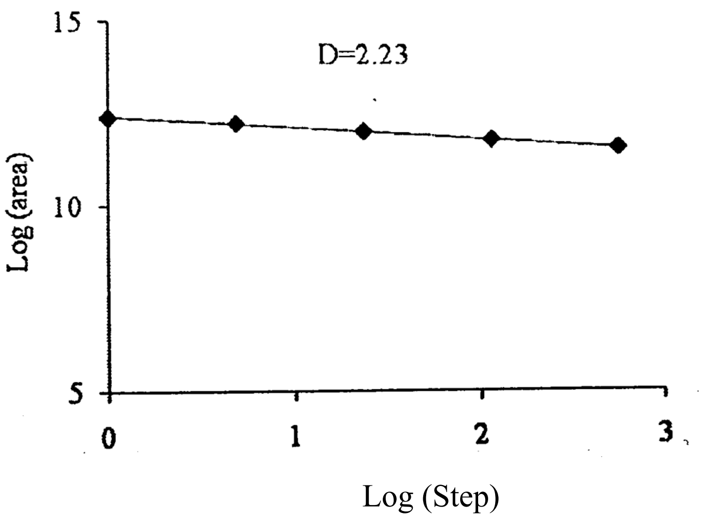

Figure 4. A sample regression plot
(Source: Ju and Lam 2009)

2.2.2 Spatial Autocorrelation

Another important measure of fragmentation for the analysis of land loss is by the use of spatial autocorrelation measure. Spatial autocorrelation of raster images can be

characterized by statistics such as Moran's I (Cliff and Ord 1973), which reflects the differing spatial structures of the smooth and rough surfaces. Moran's I is calculated from the following formula (Lam et al. 2002):

$$I(d) = \frac{n \sum_i^n \sum_j^n w_{ij} z_i z_j}{W \sum_i^n z_i^2} \quad (2)$$

where:

w_{ij} = weight at distance d, so that

z's = deviations (i.e., $z_i = x_i - x_{mean}$ for variable x);

W= the sum of all the weights where $i \neq j$.

Moran's I varies from +1.0 to -1.0, the higher the degree of fragmentation, the lower the Moran's I value (negative value). Positive autocorrelation occurs when Moran I's value is close to +1. This indicates that the pixels are clustered together (Figure 5). Negative autocorrelation implies rugged surface. The Moran's I value of a perfect negative autocorrelation is -1.0, such as a checkerboard pattern (Figure 5).

(a) (b) (c)

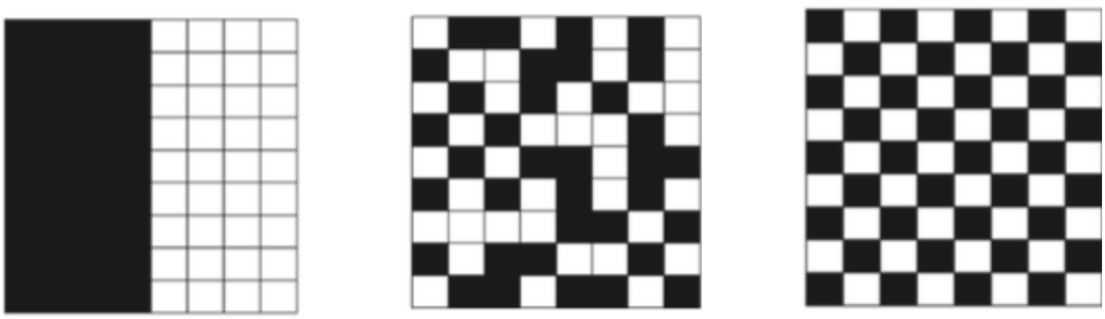

Figure 5. Examples of Moran's I index of spatial autocorrelation.
(a) Clumped pattern I≈+1.0; (b) Random pattern I≈0.0; (c) Rugged pattern I≈-1.0.
(Source: Emerson et al. 2005)

CHAPTER 3. DATA ANALYSIS AND PROCEDURE

3.1 Study Area

The principal study area in this study is the Lower Mississippi River Basin (LMRB), which is located in southeastern Louisiana, USA. The study area extends from the parishes north of Lake Pontchartrain to the coast (Figure. 6). Louisiana currently has more than 4 million acres of wetlands (Davis-Wheeler 2000), representing 40% of the nation's total (Penland et al. 1990). The Southern coastal region of Louisiana has lost about 2,000 square miles land in the past 80 years (Davis-Wheeler 2000). Figure 7 is the original land-cover map. The recoded land-water maps are shown in Figure 8 and Figure 9 (1996 and 2010).

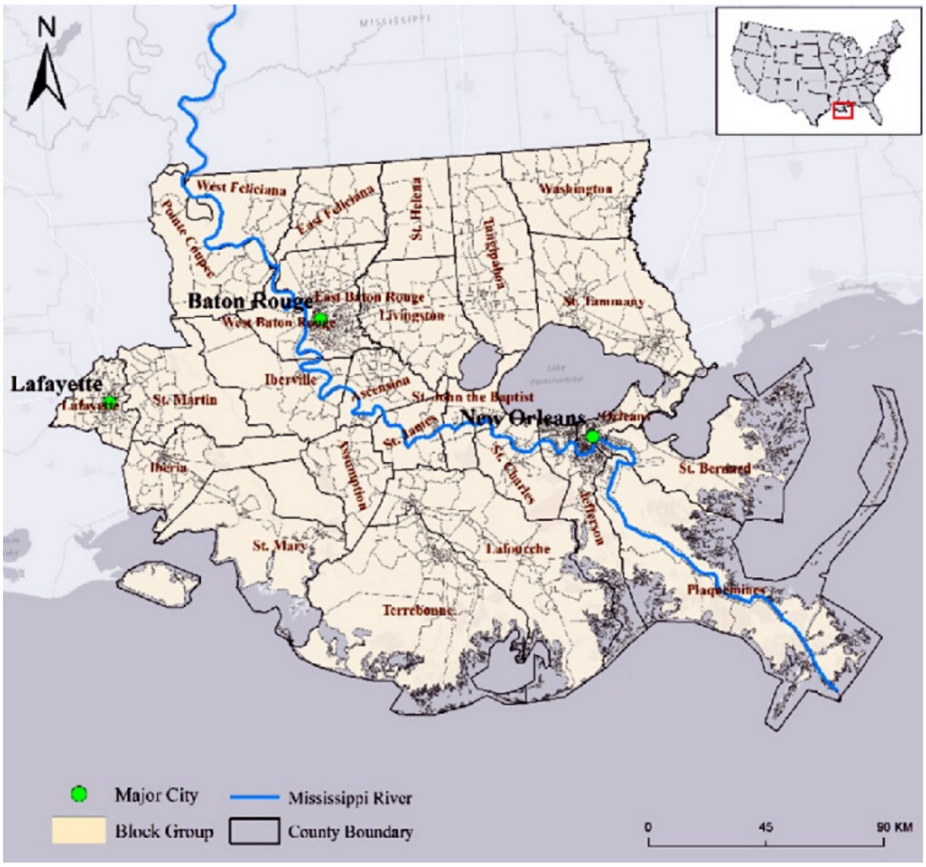

Figure 6.The Lower Mississippi River Basin
(Source: Cai et al. 2016)

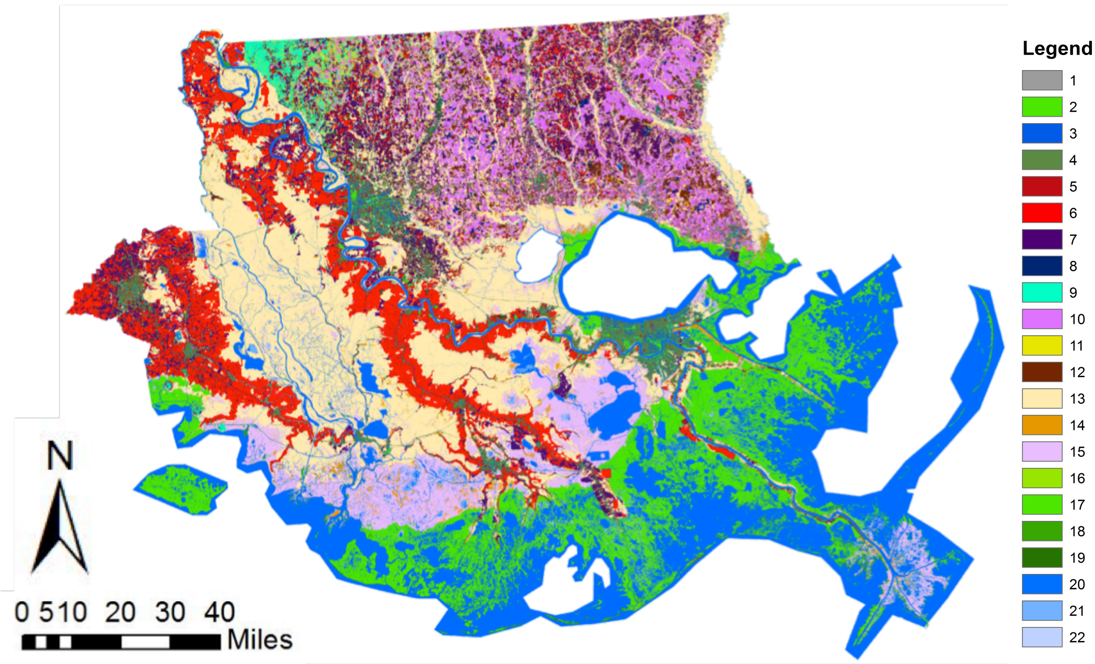

Figure 7. Original land-cover map of study area from Landsat-TM, 1996
(See Table 1 for legend)

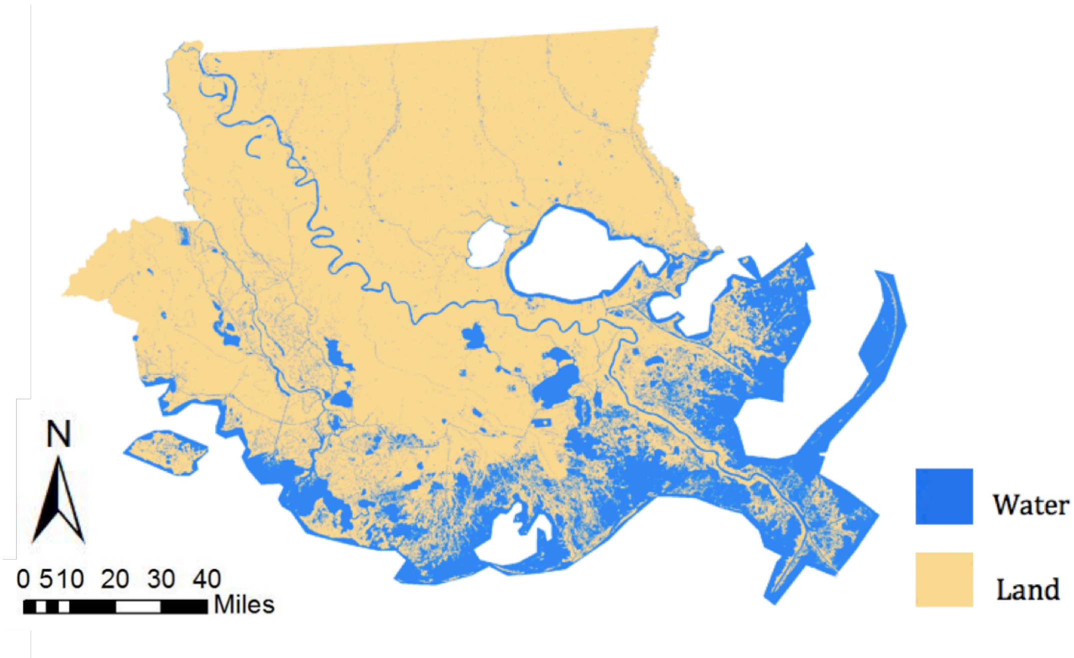

Figure 8. The Lower Mississippi River Basin recoded as land and water 1996

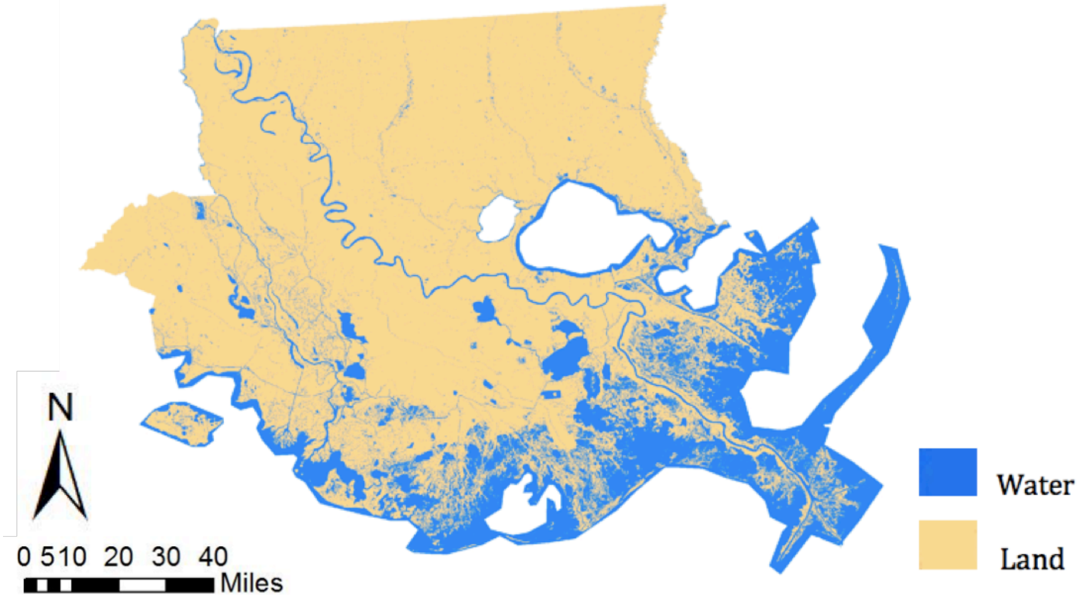

Figure 9. The Lower Mississippi River Basin recoded as land and water 2010

3.2 Sampling

Two Landsat TM images from USGS were used for this study: land-cover image in 1996 and 2010 (downloaded and produced by Yi Qiang). The land-cover image categories are based on the Coastal Change Analysis Program classification. In this study, the images have 21 land use categories. This research recoded the categories into either water or land, by defining water pixel value as 1 and land pixel value as -1. Table 1 below displays the recoding of land-cover categories into water or land areas. Three sizes of sample boxes were used in this study, which are 101*101 pixels (3*3 km) because it was considered the best size for analyzing coastal line change (Twilley et al. 2016), 51*51 pixels, and 31*31 pixels (about 10 football fields). For each box size, 100 samples clipped randomly from the study area were selected for analysis. The location of the sample boxes with different sizes are displayed in Figures 10-12.

Table 1. Re-coded original habitat categories

Original Category Number	Original Category	Pixel Value	New Category
1	Developed. High Intensity		
2	Developed. Medium Intensity		
3	Developed. Low Intensity		
4	Developed. Open Space		
5	Cultivated Crops		
6	Pasture/Hay		
7	Grassland/Herbaceous		
8	Deciduous Forest		
9	Evergreen Forest		
10	Mixed Forest	-1	Land
11	Scrub/Shrub		
12	Palustrine Forested Wetland		
13	Palustrine Scrub/Shrub Wetland		
14	Palustrine Emergent Wetland		
15	Estuarine Forested Wetland		
16	Estuarine Scrub/Shrub Wetland		
17	Estuarine Emergent Wetland		
18	Unconsolidated Shore		
19	Bare Land		
20	Open Water		
21	Palustrine Aquatic Bed	+1	Water
22	Estuarine Aquatic Bed		

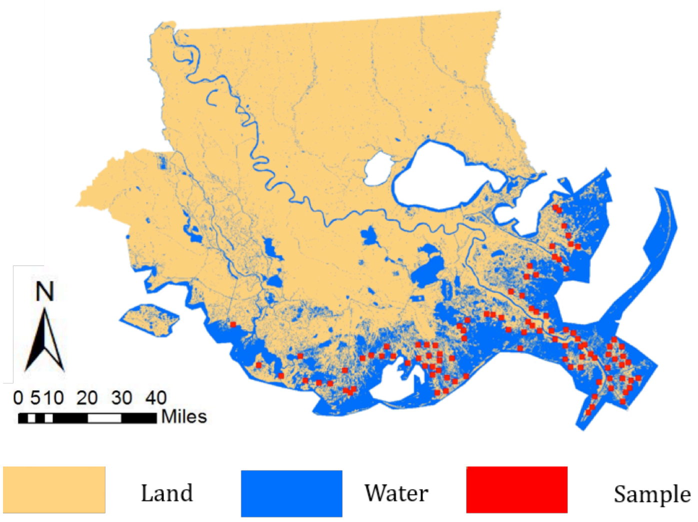

Figure 10. 101*101 pixel boxes sampling

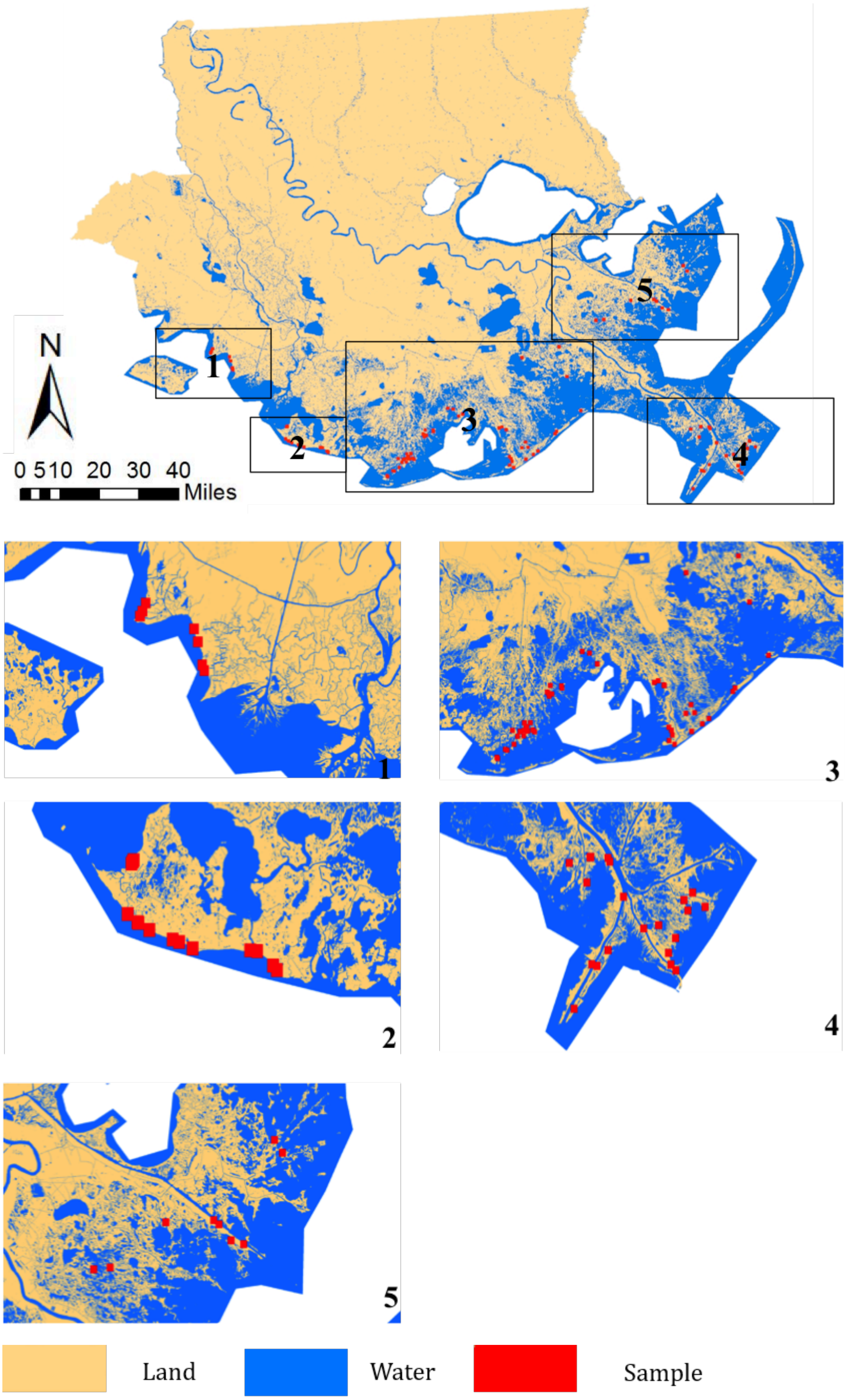

Figure 11. 51*51 pixel boxes sampling

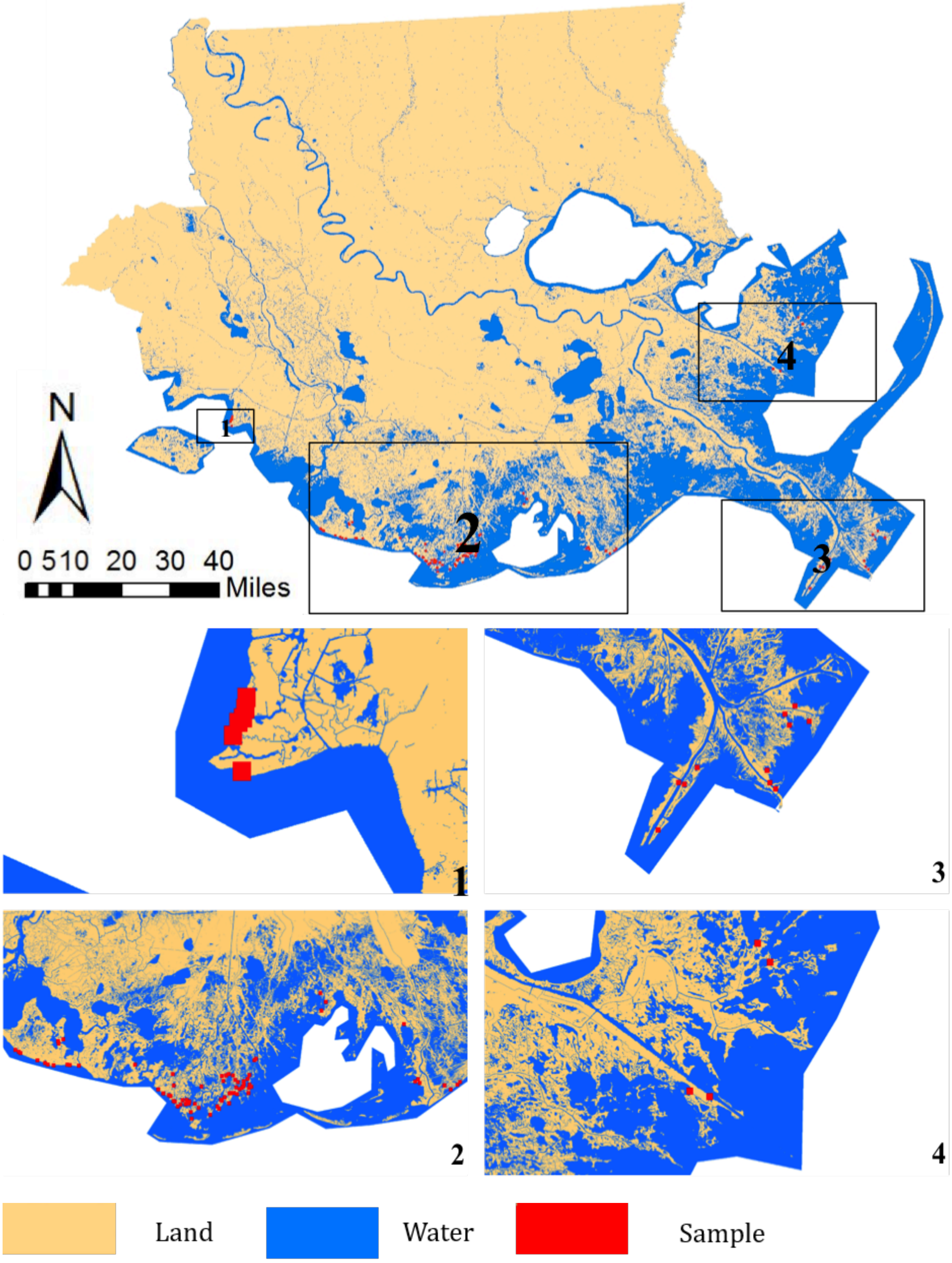

Figure 12. 31*31 pixel boxes sampling

To isolate other effects, only boxes with 50-percent land-water ratio were used, so that fragmentation statistics of these sample boxes can be analyzed. The next two sections describe the software tools used and the analysis procedure.

3.3 Software Tools

3.3.1 ArcGIS

ArcGIS was used to calculate the land and water ratio. First, the focal statistics tool was used to compute the land and water ratio of every pixel. Then, the raster calculator was used to filtrate the 50-percent land and water ratio.

3.3.1.1 Focal Statistics Tool

The focal statistics tool calculates for each input cell location a statistic of the cell value within a defined neighborhood around it. In this study, focal statistics was used in order to calculate the land-water ratio with a given box size for each cell in the study area. The output image shows the mean of the neighborhood value in each cell as center pixel. For the 1996 and 2010 images, this tool was used to calculate the land-water ratio. The resultant image with a box size of 101*101 for 1996 is shown in Figure 13. In every pixel, the darker the color, the higher the land-water ratio it has. Pixels with absolute values less than one imply a land-water ratio of 50 percent in the 101*101 neighborhood.

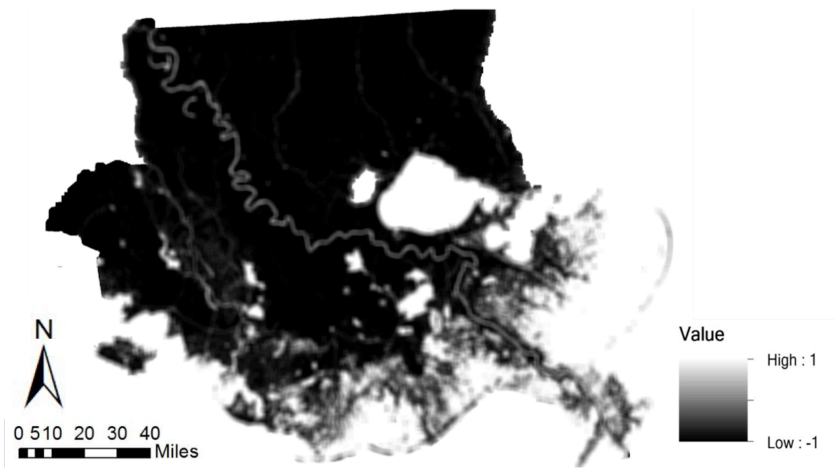

Figure 13. Focal statistic resultant image in 1996

3.3.1.2 Raster Calculator

The raster calculator tool builds and executes a single Map Algebra (a set-based algebra for manipulating geographic data) expression using Python syntax programming language in a calculator-like interface. In this study, the raster calculator was applied for selecting the 50-percent land-water ratio from the focal statistic resultant image. The output image selects the pixels that have 50-percent land-water pixel value. This tool was used for sample filtration and selection.

3.3.2 Erdas Imagine

Erdras imagine is a commercial remote sensing software package which uses the raster based graphics (Mostowy 2008). It is mainly used for the editing of raster graphics. It can be used for preparation, enhancement, processing of digital images for the purpose of mapping and analysis. In this research, Erdas was applied for clipping the sample boxes and reformatting the sample images.

3.4 ICAMS

ICAMS (Image Characterization and Modeling System) was developed by Dr. Nina Lam and co-PIs and was subsequently modified by Drs. Wei Zhao, Guiyun Zhou, and Wenxue Ju (Lam et al. 1998 and 2002; Quattrochi et al. 1997). ICAMS is designed to provide scientists with innovative spatial analytical tools to visualize, measure, and characterize landscape pattern so that environmental conditions or processes can be assessed and monitored more effectively. In this study, it was used to calculate the fractal dimensions and spatial autocorrelation statistics of the samples.

3.5 Analysis Procedure – A Summary

1. The original land-cover maps of 1996 and 2010 from USGS include 22 land cover categories. These maps were recoded into two types, which are land (1-19) and water (20-22).

2. For each box size (101*101, 51*51, and 31*31), the focal statistics tool in ArcGIS was used to calculate the number of water pixels for each center pixel of the re-coded map of 1996.

3. For each box size, the raster calculator tool in ArcGIS was used to extract the center pixels that have 50 percent of water.

4. For each box size, randomly selected 100 samples from the raster calculator resultant images.

5. For each box size, Erdas Imagine was used to clip out the sample boxes.

6. ICAMS software was used to calculate the fractal dimensions (triangular prism methods) and the spatial autocorrelation (Moran's I) of each sample.

7. The focal statistics tool of ArcGIS was reapplied to calculate the land and water ratio of the re-coded map of 2010.

8. Erdas Imagine was applied to find the amount of land loss in 2010 for every sample box.

9. Linear regression was used to calculate the relationship between fractal dimension in 1996 and land loss in 2010, and the relationship between Moran's I in 1996 and land loss in 2010.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 Results

In the study area (841,746 acres), the total land loss was 140,239 acres and the total land gain was 82,466 acres from 1996 to 2010 (Table 2). Three box sizes were examined, which are 101*101 pixels, 51*51pixels, and 31*31 pixels, these boxes all have a 50-percent land-water ratio. The 101*101 box size was used because it was considered the best size for analyzing coastal line change (Twilley et al. 2016). For the 100 samples of 101*101 box size, 56 of them had the center pixels as land, and 9 of the land pixels became water in 14 years (2010). For the box size of 51*51, 58 of the 100 boxes had land as the center pixel, and 25 of them turned into water in 2010. For box size of 31*31, 79 of the 100 center pixels were land in 1996, and 37 of the 79 pixels vanished to water after 14 years (Table 3). For all box sizes, the mean fractal dimensions of lost land were higher than those that had land without change. Similarly, the mean Moran's I values were lower (meaning more fragmented) when the land was lost.

Table 2. Land change from 1996 to 2010
(TL=Total loss, TG=Total gain, TA=Total area).

Size (pixel)	TL (pixel)	TL (acres)	TG (pixel)	TG (acres)
101*101	75,151	16,713	51	11.34
51*51	48,821	10,858	0	0
31*31	25,271	5,620	0	0
TA	630,587	140,239	370,810	82,466

Table 3. Land pixel parameter summary
(CPL=Center pixel was land, L-W=Land became water from 1996 to 2010, MFD L-W=Mean fractal dimension of land became water, MI L-W=Mean Moran's I value of land became water, MFD L-L=Mean fractal dimension of land without change, MI L-L=Mean Moran's I value of land without change)

Size (pixel)	CPL (pixel)	L-W (pixel)	MFD L-W	MI L-W	MFD L-L	MI L-L
101*101	56	9	2.59	0.806	2.52	0.812
51*51	58	25	2.53	0.79	2.41	0.85
31*31	79	37	2.65	0.76	2.55	0.81

The regression figures in each box scale show the relationships between fragmentation indices (fractal dimension and Moran's I) and percent of land loss. The percent of land loss was calculated using the following formula:

$$percent\ of\ land\ loss = \frac{number\ of\ land\ pixels\ in\ 1996 - number\ of\ land\ pixels\ in\ 2010}{number\ of\ land\ pixels\ in\ 1996} \times 100\% \quad (3)$$

The study hypothesis is that the degree of land fragmentation and land loss has a positive correlation, which means the higher the fragmentation, the more lands will be lost. The following evaluates the hypothesis for the three box sizes.

4.1.1 Results of Size 101*101

Figure 14 shows the relationship between the percentage of land loss and the fractal dimension. There were two outliers that may have caused the low R^2. When the two outliers were deleted, R^2 increased from 0.009 to 0.045 and the p-value decreased from 0.358 to 0.036. In the case of Moran's I (Figure 15), the same low R^2 was found. After re-running the regression with the two outler deleted, R^2 increased to 0.015 from 0.002.

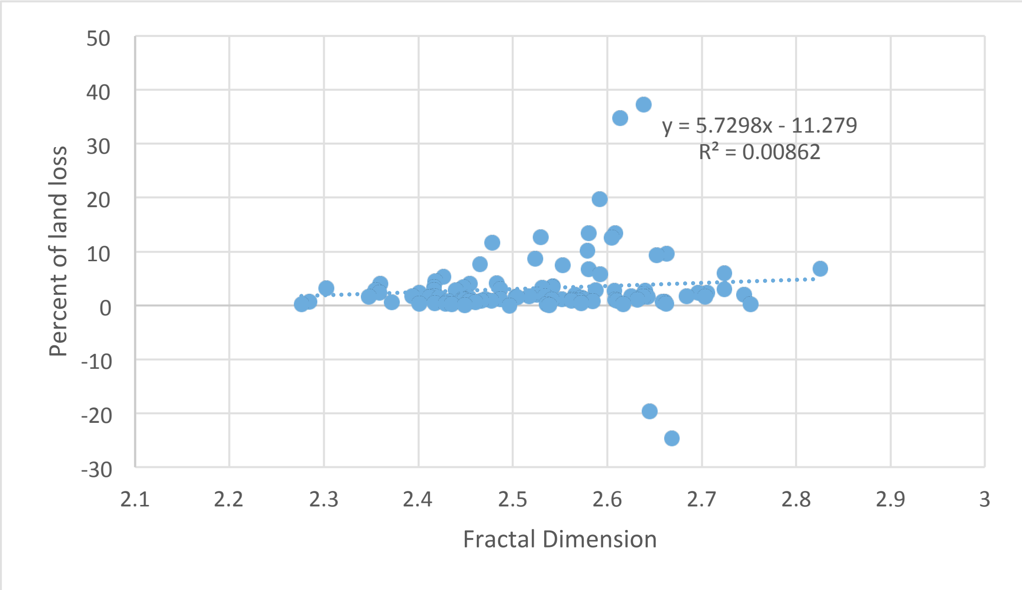

Figure 14. Relationship between Fractal Dimension and Land loss with size 101*101

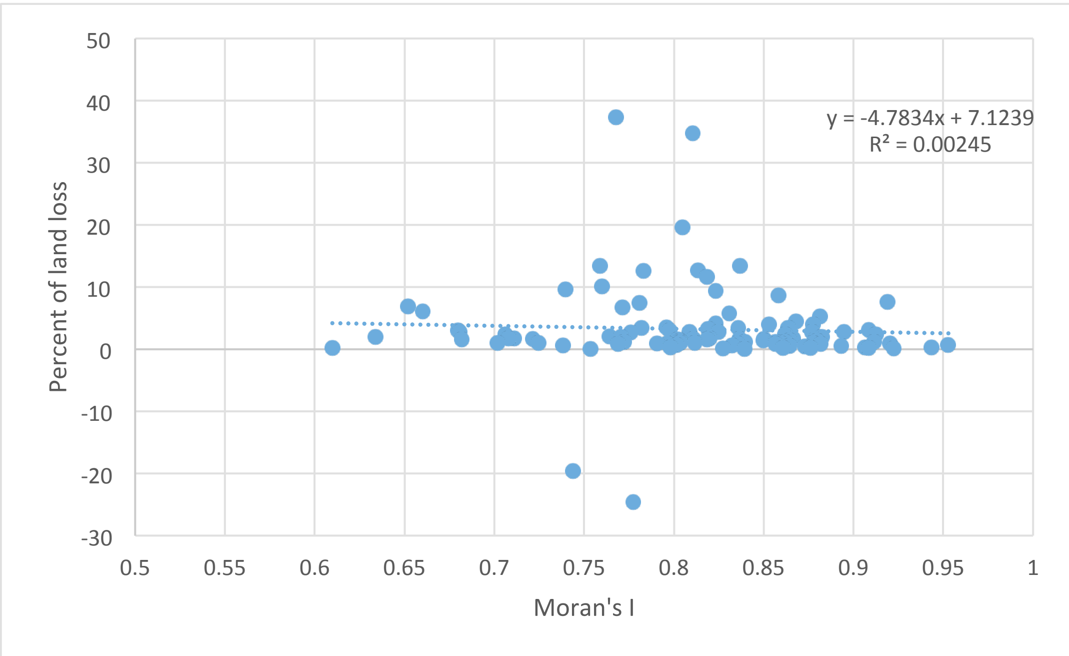

Figure 15. Relationship between Moran's I value and Land loss with size 101*101

The two outliers were found to be located in the Wax lake-Delta and Little Lake (Figure 16). Wax Lake outlet and Atchafalaya Basin are two artificial channels that were created by the United States Army Corps of Engineers in 1942 (Davidson 1988). The land growth of the two channels in the 14 years are prominent (Figure. 17). One

of the 100 samples of the 101*101 box scale located in this area had land gain instead of land loss, due to human intervention. The satellite images released by the National Aeronautics and Space Administration (NASA) are shown in Figure 18.

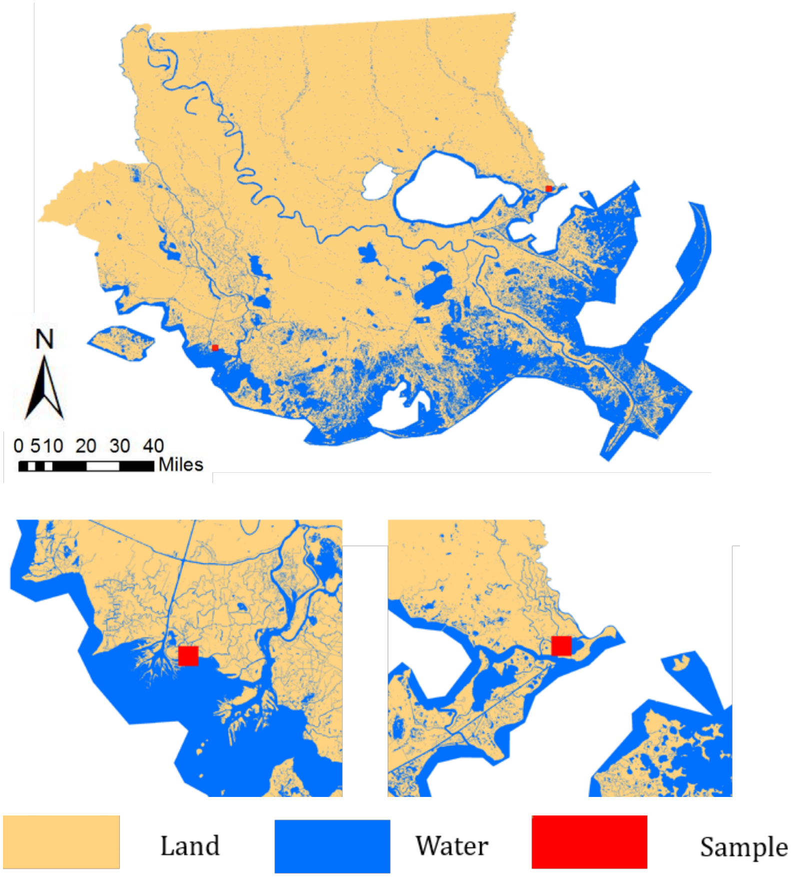

Figure 16. Two land gain samples located

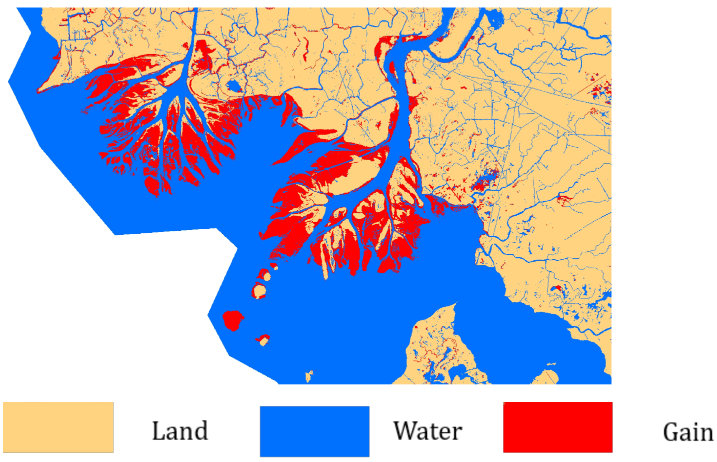

Figure 17. Most obvious land gain region in the 14 years

(a)

(b)

Figure 18. Land growth of Waxlake-Delta and Atchafalay Bay from 1984 (a) to 2014 (b)
(Source: NASA)

Although the R^2 increased and became significant at the $p<0.05$ level for the measure of fractal dimension. In general, R^2 s are low, meaning low correlation between fragmentation and land loss at this scale. The most and the least fragmented sample boxes are shown in Figure 19. Based on the regression result, the hypothesis that the higher the fragmentation, the more land loss is not true at this 101*101 box scale.

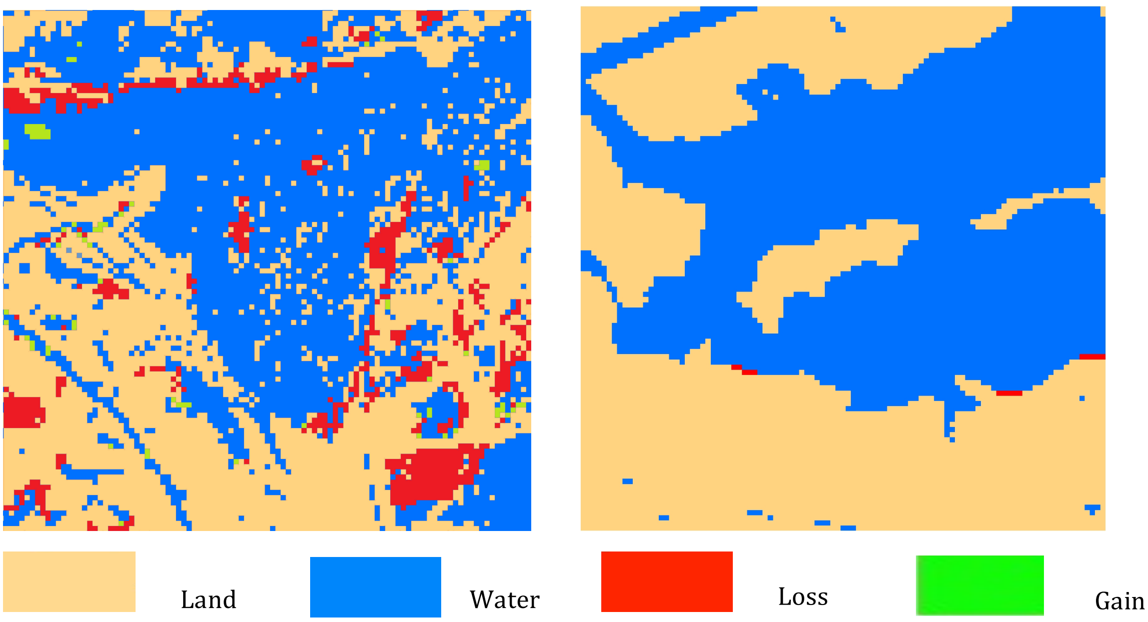

Figure 19. The most and the lest fragmented sample boxes of size 101*101
(D_{max} =2.83, I_{max}=0.65; D_{min}=2.28, I_{min}=0.92)

4.1.2 Results of Size 51*51

Figure 20 shows that the relationship between the percentage of land loss and the fractal dimension, and Figure 21 shows the relationship between the percentage of land loss and Moran's I value. The significant levels of the two relationships are less

than 0.001, which means the dependent and independent variables are significantly related. The R^2s are 0.401 and 0.451 respectively (Table 4).

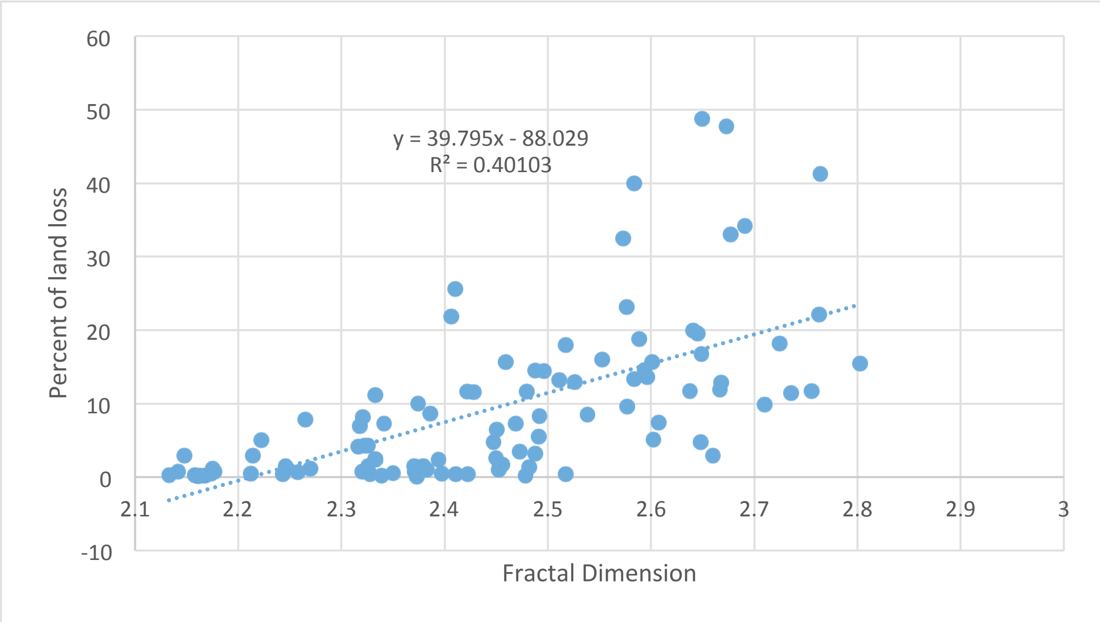

Figure 20. Relationship between Fractal Dimension and Land loss with size 51*51

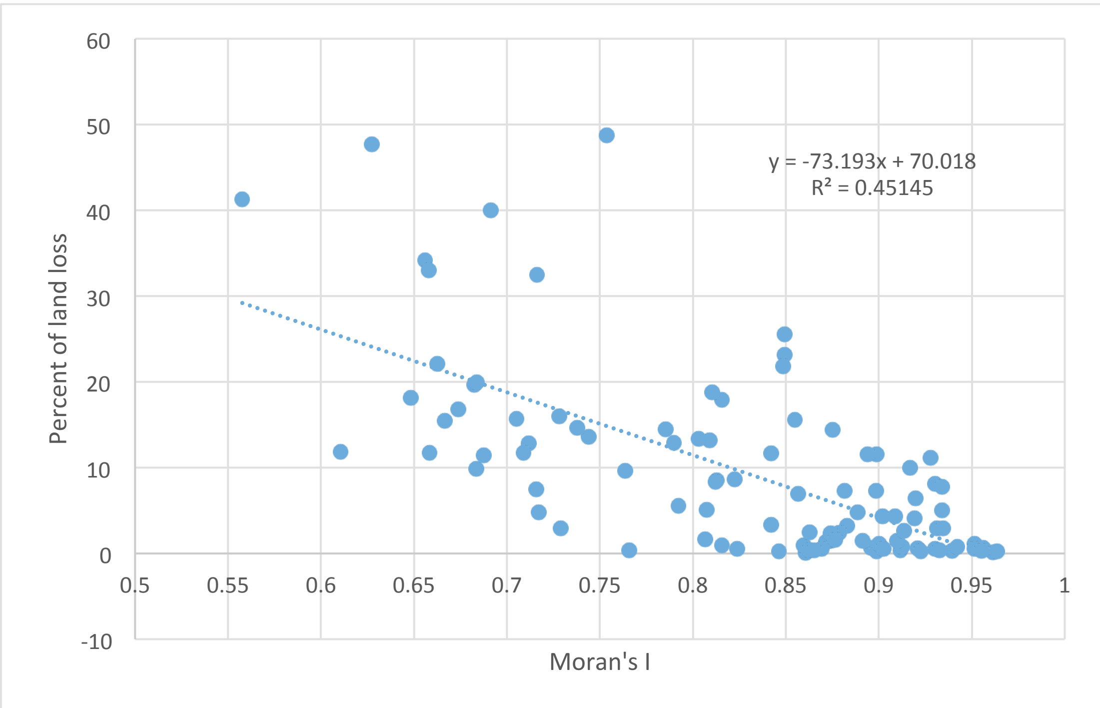

Figure 21. Relationship between Moran’s I value and Land loss with size 51*51

Table 4. Linear regression results
(FD=Fractal Dimension, I=Moran's I)

Box size （pixels）	Index	R^2	Sig.
101*101	FD	0.009	0.358
	I	0.002	0.625
101*101 (without 2 outliers)	FD	0.045	0.036
	I	0.015	0.227
51*51	FD	0.401	<0.001
	I	0.451	<0.001
31*31	FD	0.347	<0.001
	I	0.352	<0.001

There is no obvious land gain samples or outliners used in the 100 samples of 51*51 box size. The higher R^2s might be caused by the scale of the box. Figure 22 shows the most and the lea st fragmented samples boxes of size 51*51. Based on the regression results, the hypothesis that the higher the fragmentation, the more the land loss is true at the 51*51 box scale (1.5*1.5 km^2).

4.1.3 Results of Size 31*31

The significant levels of the two relationships are both less than 0.001, which mean that the hypothesis that fragmentation affects more land loss is true.

The relationship of land loss and fractal dimension in Figure 23 presents a positive correlation with R^2 being 0.347. Similarly, in Figure 24, the graph shows a clear negative correlation between land loss and Moran's I with an R^2 value of 0.352. The R^2s of the two regressions are not as high as those of the 51*51 box scale, but the *p*-values are less than 0.05, which means the relationships are statistically significant.

There is also no prominent land gain in the selected samples. The most and the least fragmented sample boxes are shown in Figure 25.

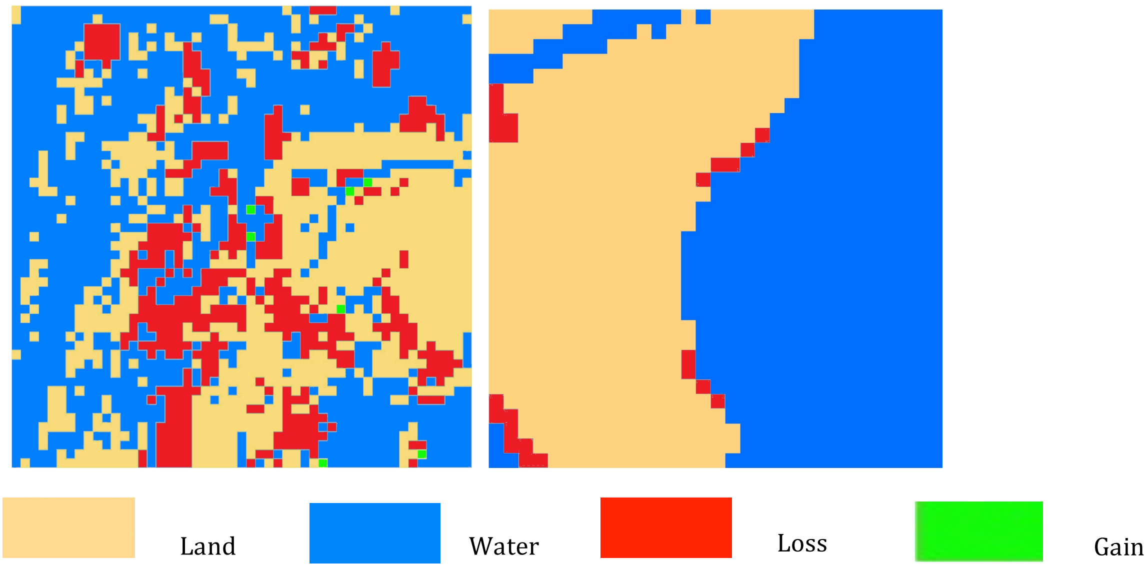

Figure 22. The most and the least fragmented sample boxes of size 51*51 (D_{max} =2.80, I_{max}=0.67; D_{min}=2.13, I_{min}=0.95)

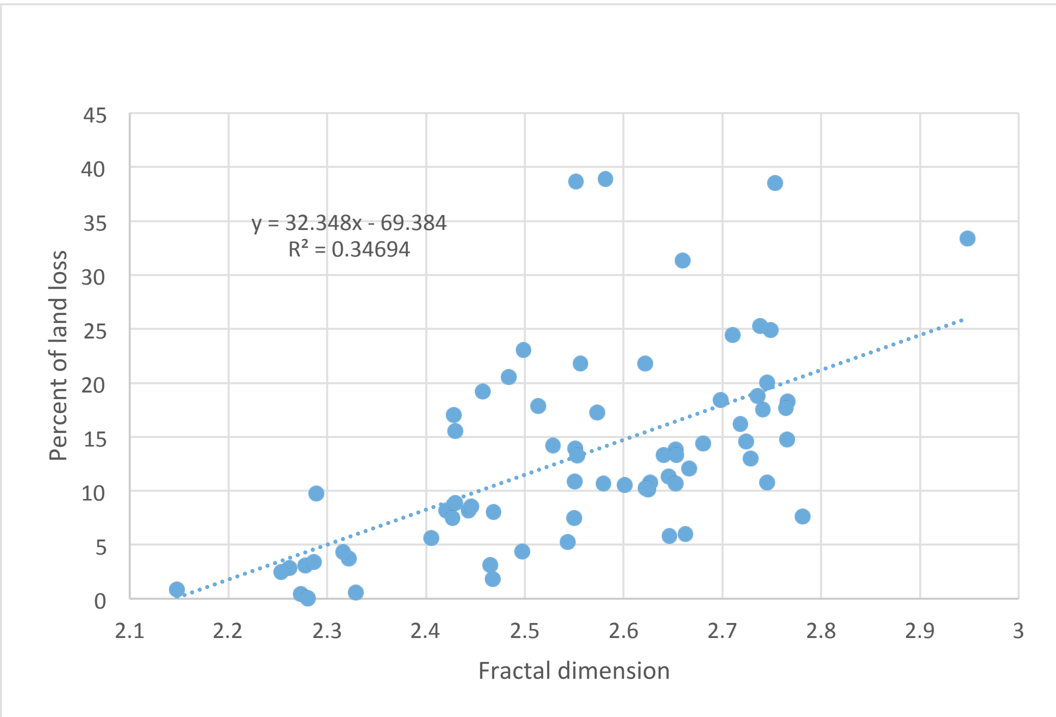

Figure 23. Relationship between Fractal Dimension and Land loss with size 31*31

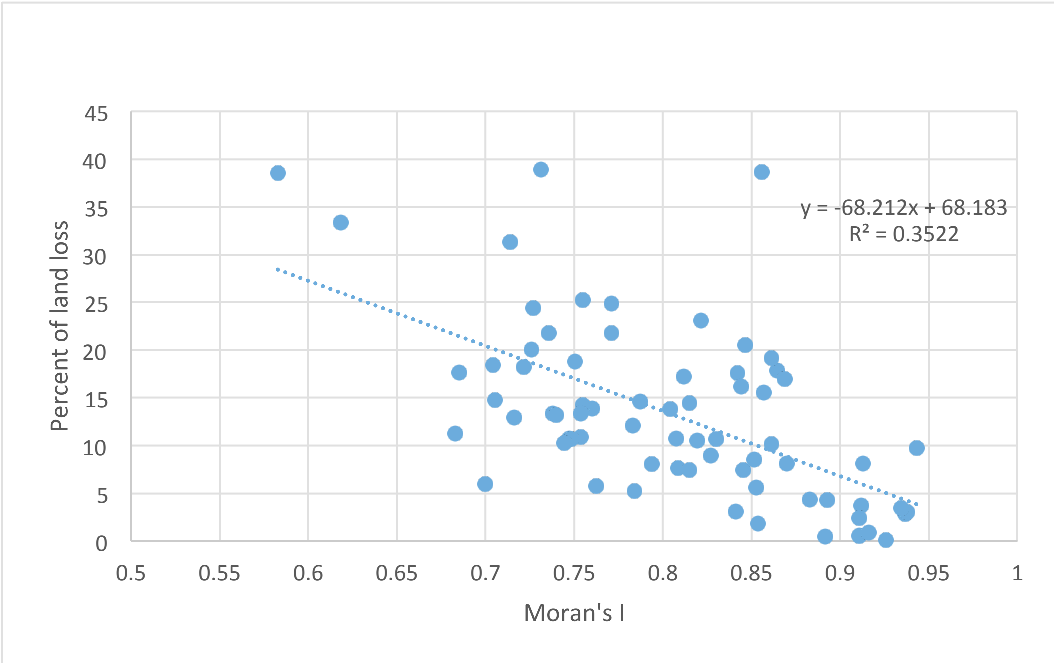

Figure 24. Relationship between Moran’s I value and Land loss with size 31*31

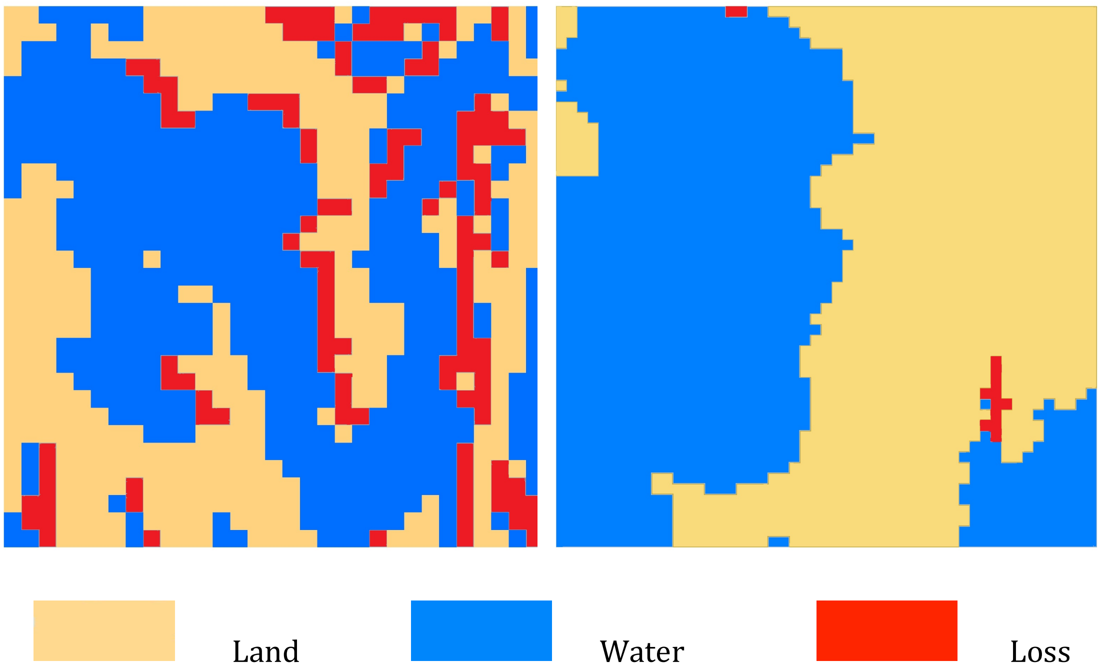

Figure 25. The most and the lest fragmented sample boxes of size 31*31 (D_{max} =2.95, I_{max}=0.62; D_{min}=2.14, I_{min}=0.92)

4.2 Discussion

There is a global interest in the research that examines the relationship between land loss and land fragmentation. Here, we demonstrate that the fragmentation effects are significant and best observed at the 51*51 box and 31*31 box scales (pixel size is 30m), but not at the 101*101 scale. This means that the zone of influence by fragmentation on land loss is most likely to be at the 51*51 box scale (1.5*1.5 km^2), and at the 31*31 box scale (0.9*0.9 km^2). Thus, in future studies, the scale factor and other factors should be considered.

In the 100 samples of the 101*101 box size, 85 of the center pixels were land pixels in 1996, but only 9 of them became water in 2010. The factor influencing the land loss percentage could be the box size. Larger box sample area covers more land, many of the 101*101 pixel samples cover a big part of land that is less fragmented, like Figure 26.

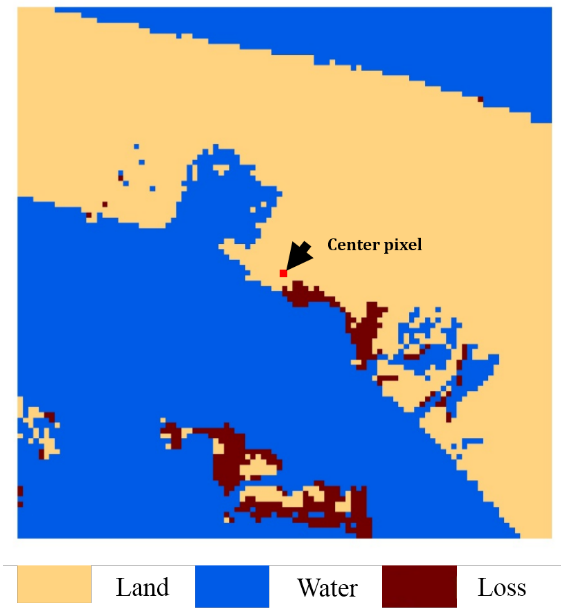

Figure 26. Example boxes of size 101*101

The center pixel is on the mainland; the dark red is the land loss during the 14 years. The mainland is more durable when the center pixel is a part of it, even if the degree of fragmentation is high, and thus the center pixel and surrounding land pixels will be less likely to lose land.

In future studies, additional factors need to be considered. First, the study area could be separated by elevation level, because lower elevation will be more affected. Distance to the coast could be a factor, as land towards the coast would be more prone to land loss. Other factors could also be added, such as storm surge, hurricane frequency, and human disturbance. Second, only three sample box sizes were tested. Further research needs to test the best box size. Finally, the number of samples could be increased to increase the confidence of the results. Since this research only selected 100 samples at each box size in the study area, they may not be sufficient to represent the large study area. More samples will help to improve the accuracy.

After making predictions of land loss for years, what land we have left at important locations could be a goal of coastal restoration and preservation activities. One of the key things which can be done for the purpose of preventing land loss is to ensure that there is a controlled diversion from the river which will help the process of revitalizing the land from being lost. Some of these processes include pumping the river water into some of the ailing marshes, increasing the overall sediment load, and reducing the salinity. Some of these diversions have been in use at the present times and a large number of structures have been further proposed. An

example is the Bohemia Diversion which had helped by bringing around 30 % of the overall Mississippi sediment load into the area of Breton Sound and helped in the creation of marshes of an area around 89,000 acres. In this solution, there will be the formation of an alternate canal through the Plaquemines Parish marsh and there will be a complete removal of all the sediment retention structures. Vegetative planning is another solution which can be implemented. Through this method, the land will have better formation of root systems, which will help the formation of more solid basis for the soil.

Coastal land protection and restoration is important because if nothing is done for the control of land loss, there will be an additional loss of land by approximately 1,000 square miles by 2050 (Caffey 2003). This land is an important habitat for fishes and the wildlife. In addition, the land proves to be an important buffer for a number of communities and supports various transportation and other infrastructure. This research contributes by demonstrating the relationship between land fragmentation and land loss. The results imply that land protection might be most effective by prioritizing land patches that have the least fragmentation.

CHAPTER 5. CONCLUSION

This thesis has attempted to find the relationship between land loss and land fragmentation during 14 years in the southeastern coastal region of Louisiana. The hypothesis of the study was that higher fragmentation would lead to more land loss. After analyzing images of 1996 and 2010, the results demonstrate that the degree of land loss of the southeastern coastal region in Louisiana did relate to the degree of land fragmentation at the 51*51 and 31*31 box scales, but not at the 101*101 box scale. Moreover, the average fractal dimension values were always higher and the mean Moran's I values were always lower for those center land pixel that had lost than for those pixels that did not change in 14 years. Also, there are small regions that have obvious land gain in the southwest part of the study area.

In this research, fractal analysis (triangular prism surface area method) and spatial autocorrelation (Moran's I) in ICAMS were applied to compute the degree of fragmentation. For the 51*51 and 31*31 box sizes, the fractal dimension had a positive relationship with land loss and Moran's I value had a negative relationship with land loss. The *p*-values of the regressions were all significant which were less than 0.05. However, the results of the 101*101 box scale were not obvious. Even after removing the two land-gain samples (outliers), the *p*-values were still greater than 0.05 and the R^2 values were lower than 0.05. Based on the regression results, we can conclude that the hypothesis is true when the box sizes were 51*51 and 31*31; it is false when the box scale was 101*101.

The purpose of the study was to provide scientific results to help people understand the relationship between fragmentation and land loss. The results can be used to predict land loss in the future by using fragmentation as one of the causes. The research also shows that land fragmentation is not the only cause. The land loss pattern change may be caused by human activities (canals and roads) and natural reasons (hurricanes and subsidence). Further studies should focus on testing with more natural and human factors, box size selection, sampling strategies, and increase in the number of samples.

In summary, this thesis research examined the relationship between land loss and land fragmentation in 1996-2010 in the Lower Mississippi River Basin (LMRB). Properly understanding the relationship can hugely benefit coastal land preservation and restoration. The research findings will provide useful insights into the development of strategies to strengthen the protection of highly fragmented coastal land, and in this case, the results imply that land protection might be most effective by prioritizing areas with land patches that have the least fragmentation.

REFERENCES

Allison, M. A., Ramirez, M. T., & Meselhe, E. A. (2014). Diversion of Mississippi River water downstream of New Orleans, Louisiana, USA to maximize sediment capture and ameliorate coastal land loss. Water resources management, 28(12), 4113-4126.

Amos, J. (2014). SkyTruth: Disappearing Mississippi Delta, 1972 - 2014. [online] Blog.skytruth.org. Available at: http://blog.skytruth.org/2014/09/disappearing-mississippi-delta-1972-2014.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+Skytruth+%28SkyTruth%29 [Accessed 20 Apr. 2016].

Barnes, S., Bond, C., Burger, N., Anania, K., Strong, A., Weilant, S., & Virgets, S. (2015, December). Economic Evalua on of Coastal Land Loss in Louisiana. Retrieved May 3, 2016, from http://coastal.la.gov/wp-content/uploads/2015/12/Coastal-Valuation-Executive-Summary.pdf.

Barras, J., Beville, S., Britsch, D., Hartley, S., Hawes, S., Johnston, J., ... & Reed, D. (2003). Historical and projected coastal Louisiana land changes: 1978-2050 (p. 39p). United States Geological Survey.

Baustian, J. J., & Eugene Turner, R. (2006). Restoration success of backfilling canals in coastal Louisiana marshes. Restoration Ecology, 14(4), 636-644.

Bentley, J. W. (1987). Economic and Ecological Approaches to Land Fragmantation: In Defense of A Much-Maligned Phenomenon. Annual Review of Anthropology, 16, 31-67.

Britsch, L. D., & Dunbar, J. B. (1993). Land loss rates: Louisiana coastal plain. Journal of coastal research, 324-338.

Caffey, R. H. (2003). A Case for Subvention of Private Landowners in the Louisiana Coastal Zone. In 2003 Annual Meeting, February 1-5, 2003, Mobile, Alabama (No. 35045). Southern Agricultural Economics Association.

Cai, H., Lam, N. S. N., Zou, L., Qiang, Y., & Li, K. (2016). Assessing Community Resilience to Coastal Hazards in the Lower Mississippi River Basin. Water, 8(2), 46.

Clarke, K. C. (1986). Computation of the fractal dimension of topographic surfaces using the triangular prism surface area method. Computers & Geosciences, 12(5), 713-722.

Cliff, A. D., & Ord, J. K. (1973). Spatial autocorrelation (Vol. 5). London: Pion.

Couvillion, B. R., Fischer, M. R., Beck, H. J., & Sleavin, W. J. (2016). Spatial Configuration Trends in Coastal Louisiana from 1985 to 2010. Wetlands, 1-13.

Davidson, R. A. (1988). Wax Lake Outlet Control Structure, Louisiana; Hydraulic Model Investigation (No. WES/TR/HL-88-23). ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS HYDRAULICS LAB.

Davis-Wheeler, C. (2000, January 7). Louisiana Coastal Land Loss. Retrieved April 15, 2016, from http://www.tulane.edu/~bfleury/envirobio/enviroweb/LandLoss/LandLoss.htm.

Demetriou, D. (2013). The development of an integrated planning and decision support system (IPDSS) for land consolidation. Springer Science & Business Media.

Dijk, T. v. (2003). Scenarios of Central European land fragmentation. Land Use Policy, 20149-158. doi:10.1016/S0264-8377(02)00082-0.

Emerson, C. W., Lam, N. S. N., & Quattrochi, D. A. (2005). A comparison of local variance, fractal dimension, and Moran's I as aids to multispectral image classification. International Journal of Remote Sensing, 26(8), 1575-1588.

Faulkner, S. (2004). Urbanization impacts on the structure and function of forested wetlands. Urban Ecosystems, 7(2), 89-106.

Forman, R. T. (1995). Land mosaics: the ecology of landscapes and regions. Cambridge university press.

Hitch, A. T., Purcell, K. M., Martin, S. B., Klerks, P. L., & Leberg, P. L. (2011). Interactions of salinity, marsh fragmentation and submerged aquatic vegetation on resident nekton assemblages of coastal marsh ponds. Estuaries and Coasts, 34(3), 653-662.

Houck, O. A. (1983). Land loss in coastal Louisiana: causes, consequences, and remedies. Tulane Law Review, 58, 3.

Hudson, B. (2012). Coastal Land Loss and the Mitigation-Adaptation Dilemma: Between Scylla and Charybdis. Louisiana Law Review, 73.

Ingebritsen, S. E., & Galloway, D. L. (2014). Coastal subsidence and relative sea level rise. Environmental Research Letters, 9(9), 091002.

Jaggi, S., Quattrochi, D. A., & Lam, N. S. N. (1993). Implementation and operation of three fractal measurement algorithms for analysis of remote-sensing data. Computers & Geosciences, 19(6), 745-767.

Ju, W., & Lam, N. S. N. (2009). An improved algorithm for computing local fractal dimension using the triangular prism method. Computers & Geosciences, 35(6), 1224-1233.

Khalil, S. M., Finkl, C. W., & Raynie, R. C. (2013). Development of new restoration strategies for Louisiana barrier island systems, northern Gulf of Mexico, USA. Journal of Coastal Research, 2(65), 1467.

King, R., & Burton, S. (1982). Land fragmentation: Notes on a fundamental rural spatial problem. Progress in Human Geography, 6(4), 475–494.

Lam, N. S. N. (1990). Description and measurement of Landsat TM images using fractals. Photogrammetric engineering and remote sensing, 56(2), 187-195.

Lam, N. S. N. (2012). Geospatial methods for reducing uncertainties in environmental health risk assessment: challenges and opportunities. Annals of the Association of American Geographers, 102(5), 942-950.

Lam, N. S. N., & De Cola, L. (1993). Fractal measurement. Fractals in geography, 23-55.

Lam, N. S. N., & De Cola, L. (1993). Fractal simulation and interpolation. Fractals in geography, 56-74.

Lam, N. S. N., Qiu, H. L., Quattrochi, D. A., & Emerson, C. W. (2002). An evaluation of fractal methods for characterizing image complexity. Cartography and Geographic Information Science, 29(1), 25-35.

Lam, N. S. N., Quattrochi, D., Qiu, H. L., & Zhao, W. (1998). Environmental assessment and monitoring with image characterization and modeling system using multiscale remote sensing data. Applied Geographic Studies, 2(2), 77-93.

Lehtinen, R. M., Galatowitsch, S. M., & Tester, J. R. (1999). Consequences of habitat loss and fragmentation for wetland amphibian assemblages. Wetlands, 19(1), 1-12.

McCulloh, R. P., & Heinrich, P. V. (2013). Surface faults of the south Louisiana growth-fault province. Geological Society of America Special Papers, 493, 37-49.

McGarigal, K. (2014). FRAGSTATS help. Pieejams: http://www. umass. edu/landeco/research/fragstats/documents/fragstats. help, 4.

McGarigal, K., Cushman, S. A., & Ene, E. (2012). FRAGSTATS v4: spatial pattern analysis program for categorical and continuous maps. 2012.Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at: the following web site: http://www. umass. edu/landeco/research/fragstats/fragstats. html.

McGarigal, K., & Marks, B. J. (1995). FRAGSTATS: spatial pattern analysis program for quantifying landscape structure.

Mitsch, W. J., & Gosselink, J. G. (1993). Wetlands Van Nostrand Reinhold. New York, 722.

Mostowy, J. (2008). ERDAS IMAGINE fundamentals. Scientific Investigations Report, 10.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & Dubash, N. K. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Penland, S., Roberts, H. H., Williams, S. J., Sallenger Jr, A. H., Cahoon, D. R., Davis, D. W., & Groat, C. G. (1990). Coastal land loss in Louisiana.

Penland, S., Wayne, L., Britsch, L. D., Williams, S. J., Beall, A. D., & Butterworth, V. C. (2000). Geomorphic classification of coastal land loss between 1932 and 1990 in the Mississippi River Delta Plain, Southeastern Louisiana (No. 2000-417).

Peyronnin, N., Green, M., Richards, C. P., Owens, A., Reed, D., Chamberlain, J., ... & Belhadjali, K. (2013). Louisiana's 2012 coastal master plan: overview of a science-based and publicly informed decision-making process. Journal of Coastal Research, 67(sp1), 1-15.

Read, J. M., & Lam, N. S. N. (2002). Spatial methods for characterising land cover and detecting land-cover changes for the tropics. International Journal of Remote Sensing, 23(12), 2457-2474.

Reed, D. J., & Cahoon, D. R. (1992). The relationship between marsh surface topography, hydroperiod, and growth of Spartina alterniflora in a deteriorating Louisiana salt marsh. Journal of Coastal Research, 77-87.

Reyes, E., White, M. L., Martin, J. F., Kemp, G. P., Day, J. W., & Aravamuthan, V. (2000). Landscape modeling of coastal habitat change in the Mississippi Delta. Ecology, 81(8), 2331-2349.

Scaife, W. W., Turner, R. E., & Costanza, R. (1983). Coastal Louisiana recent land loss and canal impacts. Environmental Management, 7(5), 433-442.

Shaffer, G. P., Day, J. W., Hunter, R. G., Lane, R. R., Lundberg, C. J., Wood, W. B., ... & Kandalepas, D. (2015). System response, nutria herbivory, and vegetation recovery of a wetland receiving secondarily-treated effluent in coastal Louisiana. Ecological Engineering, 79, 120-131.

Sorensen, S. G., Faulkner, P. L., Reid, C. S., & Maxit, I. E. (2005). Louisiana comprehensive wildlife conservation strategy (p. 455). Baton Rouge, Louisiana: Louisiana Department of Wildlife and Fisheries.

Tibbetts, J. (2006). Louisiana's wetlands: A lesson in nature appreciation. Environmental Health Perspectives, 114(1), A40.

Turner, R. E. (1987). Relationship between canal and levee density and coastal land loss in Louisiana (No. BR-85 (14)). Louisiana State Univ., Baton Rouge (USA). Center for Wetland Resources.

Tweel, A. W., & Turner, R. E. (2014). Contribution of tropical cyclones to the sediment budget for coastal wetlands in Louisiana, USA. Landscape ecology, 29(6), 1083-1094.

Twilley R.R., Bentley S. J., Chen Q, Edmonds D.A., Hagen S.C., Lam N.S.-N., Willson C. S., Xu K. Braud D., Peele H. 2016. Co-evolution of wetland landscapes, flooding and human settlement in the Mississippi River Deltaic Plain. (Manuscript in Review).

VITA

Weijia Cheng is from Beijing, the People's Republic of China. She earned her bachelor degree in Petroleum Engineering from China Southwest Petroleum University (Chengdu, China) in 2013. During that time, she was greatly influenced by an outstanding faculty member Yu Fu, who played an important role in her decision to pursue an advanced degree.

Weijia entered the graduate program at Louisiana State University in fall 2014, with Dr. Lam serving as her major advisor. During this period, she has learned the knowledge of environmental science and decided to be an environment keeper in the future.

Weijia is a candidate to graduate from LSU with a degree in Master of Science in Environmental Sciences in the summer of 2016.