

8-5-2010

# Geospatial Technology/Traditional Ecological Knowledge-Derived Information Tools for the Enhancement of Coastal Restoration Decision Support Processes

Matthew Bethel  
*University of New Orleans*

Follow this and additional works at: <https://scholarworks.uno.edu/td>

---

## Recommended Citation

Bethel, Matthew, "Geospatial Technology/Traditional Ecological Knowledge-Derived Information Tools for the Enhancement of Coastal Restoration Decision Support Processes" (2010). *University of New Orleans Theses and Dissertations*. 1228.

<https://scholarworks.uno.edu/td/1228>

This Dissertation is protected by copyright and/or related rights. It has been brought to you by ScholarWorks@UNO with permission from the rights-holder(s). You are free to use this Dissertation in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/or on the work itself.

This Dissertation has been accepted for inclusion in University of New Orleans Theses and Dissertations by an authorized administrator of ScholarWorks@UNO. For more information, please contact [scholarworks@uno.edu](mailto:scholarworks@uno.edu).

Geospatial Technology/Traditional Ecological Knowledge-Derived Information Tools  
for the Enhancement of Coastal Restoration Decision Support Processes

A Dissertation

Submitted to the Graduate Faculty of the  
University of New Orleans  
in partial fulfillment of the  
requirements for the degree of

Doctor of Philosophy  
in  
Engineering and Applied Science  
Environmental Science

by

Matthew Byron Bethel

B.S. The University of Tennessee, 1994  
M.S. Murray State University, 1999

August, 2010

Copyright 2010, Matthew Byron Bethel

## ACKNOWLEDGMENTS

First and foremost, I would like to thank the gracious and generous residents of the Grand Bayou, Louisiana community. Without their collaboration and knowledge this research would not have been possible. A huge debt of gratitude is also extended to Dr. Shirley Laska and Rev. Kris Peterson of the University of New Orleans (UNO) for introducing me to the community and providing invaluable guidance and mentoring from the social science perspective.

This study was truly a collaborative effort, and many people contributed resources, their time, and their knowledge to all aspects of this research. In particular, thanks go to Emily Danielson of UNO for all of her efforts on this research and for stimulating me to continually re-examine my methods of data collection and integration from new perspectives, and to Lynn Brien (UNO) for her immeasurable contributions to this study, as well as for invaluable insight and motivational support.

During the course of this study, I received vital aid, insight, and support from Dr. Marco Giardino (NASA-Stennis Space Center), Dr. Mark Kulp (UNO), Dr. Alex McCorquodale (UNO), Dr. Deepak Mishra (Mississippi State University), John Troutman and Bill Boshart of the Louisiana Office of Coastal Protection and Restoration (OCPR), Lauren Bartholomew (Princeton University), Michelle Alcina (UNO), and Sean O'Brien and Luis Martinez (UNO). My gratitude also goes to the late Dr. Shea Penland for giving me the opportunity to pursue a career as an environmental scientist at UNO. In a variety of ways, my parents (Bill and Sandra Bethel), my fiancée (Amanda), and the rest of my family made this work possible.

Funding was provided by the Coastal Restoration and Enhancement through Science and Technology Program, and The National Oceanic and Atmospheric Administration's Gulf of Mexico Coastal Storms Program and the Mississippi-Alabama Sea Grant Consortium.



## TABLE OF CONTENTS

List of Figures .....	vii
List of Tables .....	x
ABSTRACT .....	xi
CHAPTER 1: INTRODUCTION .....	1
Objectives .....	2
References .....	4
CHAPTER 2: BACKGROUND .....	5
Study Area .....	5
Current Coastal Restoration Management .....	11
The CPRA CWPPRA Decision Support Process .....	12
Previous Studies .....	13
References .....	19
CHAPTER 3: HISTORICAL LAND LOSS ASSESSMENT .....	23
Introduction .....	23
Methods .....	24
Quickbird Satellite Data Specifications .....	27
Digital Orthophoto Quarter Quadrangle Specifications .....	28
Scanned Aerial Photograph Specifications .....	28
Pre-classification Image Processing Procedures .....	33
Georectification .....	33
Mosaicking .....	33
Reprojection .....	34
Noise Reduction .....	34
Image Subsetting .....	34
Masking .....	34
Land-Water Classification .....	35
Supervised Classification .....	35
Unsupervised Classification .....	36
Classification Enhancement .....	36
Application of Clump/Eliminate Procedures .....	37
Accuracy Assessment of Land-Water Classifications .....	37
Change Analysis .....	40
Identification of Transitional Zones .....	40
Results .....	41
Accuracy Assessment of Land-Water Classifications .....	42
Results of Change Analysis .....	43
Discussion .....	51
Conclusions .....	56
References .....	59
CHAPTER 4: MAPPING COMMUNITY RESTORATION PRIORITIES AND OBSERVED CHANGE IN THE STUDY AREA USING TRADITIONAL ECOLOGICAL KNOWLEDGE (TEK) .....	61

Introduction.....	61
Collaborative Partnership Development with the Grand Bayou Community .....	62
Methods.....	67
TEK Sample.....	67
TEK Data Collection, Transcription, and Coding .....	68
Codebook Development.....	69
Intercoder Reliability Assessment .....	75
Applying Numeric Codes .....	77
Results.....	81
Discussion.....	85
Conclusions.....	90
References.....	96
CHAPTER 5: ASSESSING, IDENTIFYING, AND MAPPING MARSH AREAS	
VULNERABLE TO LOSS USING SCIENTIFIC DATASETS.....	97
Introduction.....	97
Methods.....	101
Field Data Collection .....	101
Image Calibration.....	106
Estimated Chlorophyll Meter and LAI Map Production .....	109
Producing the Calibrated Vegetation-Only Map .....	110
Vegetation Indices Tested for Correlation with Chlorophyll and LAI Field	
Measurement.....	111
The Normalized Difference Vegetation Index (NDVI).....	111
The Ratio Vegetation Index (RVI) .....	112
The Green Normalized Difference Vegetation Index (GNDVI) .....	113
The Atmospheric Resistant Vegetation Index (ARVI).....	113
The Second Modified Soil Adjusted Vegetation Index (MSAVI2).....	113
The Modified Triangular Vegetation Index (MTVI).....	114
The Wide Dynamic Range Vegetation Index (WDRVI).....	114
Fragmentation Map Production .....	117
Results.....	120
Estimated Chlorophyll Meter and LAI Map Production Results .....	120
Fragmentation Map Results .....	123
Discussion.....	132
Conclusions.....	140
References.....	143
CHAPTER 6: MERGING THE SCIENTIFIC AND TEK DATASETS TO	
SUPPORT COASTAL RESTORATION DECISION-MAKING WITH NEW	
INFORMATION TOOLS.....	146
Introduction.....	146
Methods.....	149
Spatial Cluster Analysis of High Risk Areas.....	149
Overlay of Marsh Vulnerability Map with TEK-derived Maps .....	154
Discussion.....	157
Applicability of Results to Recommendations of the Louisiana Coastal	
Area (LCA) Science and Technology Program .....	158

The CPRA Current Restoration Prioritization Model.....	160
Comparison of Study Results with Proposed Local Restoration Projects Based on Current Decision-Making Process .....	168
Conclusions.....	173
References.....	177
CHAPTER 7: CONCLUSIONS .....	179
Future Research Recommendations.....	186
References.....	188
APPENDIX A: MAPPING PROCESS FLOW CHART.....	190
APPENDIX B: GRAND BAYOU PROJECT DECLARATION OF PRINCIPLES.....	193
APPENDIX C: RESTORATION PRIORITY INDEX .....	197
APPENDIX D: OBSERVED CHANGE INDEX.....	205
VITA .....	215

## LIST OF FIGURES

### CHAPTER 2

1. Map of Southeast Louisiana showing location of Grand Bayou study area .....	6
2. Selected Louisiana Coastal Restoration Projects 2005 map showing geographical relation of projects to Grand Bayou (CWPPRA project map courtesy of <a href="http://www.lacoast.gov">www.lacoast.gov</a> ) .....	9
3. West Pointe a La Hache Siphon (image provided by the Louisiana Department of Natural Resources) .....	10
4. Diagram showing typical spectral reflectance curves associated with various land and water features including vegetation. ....	16
5. Example of how spectral reflectance from remotely sensed imagery has been used successfully in agriculture to identify areas of crop canopy stress .....	17

### CHAPTER 3

1. 11/25/1968 aerial photo mosaic of the study area. ....	29
2. 3/26/1979 aerial photo mosaic of the study area. ....	30
3. 11/5/1991 DOQQ mosaic of the study area.....	30
4. 1/24/1998 DOQQ mosaic of the study area.....	31
5. 1/21/2004 DOQQ mosaic of the study area.....	31
6. 10/27/2005 DOQQ mosaic of the study area.....	32
7. 10/30/2008 DOQQ mosaic of the study area.....	32
8. 11/12/2009 DigitalGlobe Quickbird satellite image of the study area .....	33
9. 11/25/1968 to 3/26/1979 land change analysis map .....	44
10. 3/26/1979 to 11/5/1991 land change analysis map .....	45
11. 11/5/1991 to 1/24/1998 land change analysis map .....	46
12. 1/24/1998 to 1/21/2004 land change analysis map .....	47
13. 1/21/2004 to 10/27/2005 land change analysis map .....	48
14. 10/27/2005 to 11/12/2009 land change analysis map .....	49
15. Actual Land Loss from 11/25/1968 to 11/12/2009 by time period .....	50
16. Graph of Proportion of Total Land to Water Area by time period .....	53
17. Graph of Land Loss in hectares by time period .....	54

### CHAPTER 4

1. Photos showing TEK field data collection between project researchers and community informants .....	65
2. Poster-size map with residents' observations written/drawn for the Grand Bayou map biography .....	66
3. 'Community Perspective' map produced from the map biography .....	67
4. Atlas.ti software is used to organize, derive relationships, and make inferences from the transcribed TEK collected .....	70
5. Example of TEK Data Transcription/Coding using Atlas.ti software .....	71
6. The process for generating intercoder reliability from Hruschka et al. (2004) .....	77
7. Index of Observed Change Map derived from Community-Based TEK .....	83

8. Community-based Restoration Priority Map Derived with TEK .....	84
9. Major themes related to local environmental degradation and land loss and their interrelationships.....	92

## CHAPTER 5

1. Sampling Points to Date Overlaid on November 2008 Aerial Image DOQQ Mosaic.....	102
2. Field data collection with the Ocean Optics USB4000 system .....	104
3. Field data collection using the CM1000 Chlorophyll Meter .....	106
4. The development of a prediction equation from field calibration targets by the Empirical Line Method (Smith and Milton, 1999) .....	108
5. Uncalibrated and calibrated 10/30/2009 image prior to masking of clouds, etc. ....	110
6. Calibrated, vegetation only 10/30/2009 image dataset.....	111
7. Estimated chlorophyll content map .....	120
8. Estimated chlorophyll meter map validation dataset plot.....	121
9. Chlorophyll meter validation plot of predicted versus actual values.....	121
10. Estimated Leaf Area Index map .....	122
11. Estimated LAI map validation dataset plot.....	123
12. LAI validation plot of predicted versus actual values .....	123
13. 1968 Grand Bayou area fragmentation map .....	124
14. 1979 Grand Bayou area fragmentation map .....	125
15. 1991 Grand Bayou area fragmentation map .....	126
16. 1998 Grand Bayou area fragmentation map .....	127
17. 2004 Grand Bayou area fragmentation map .....	128
18. 2005 Grand Bayou area fragmentation map .....	129
19. 2009 Grand Bayou area fragmentation map .....	130
20. Marsh vulnerability map produced using a weighted overlay in ArcGIS .....	132
21. Photo showing marsh condition at sampling site #5 along the Ravine ridge .....	134
22. Photo showing sampling site #11 near siphon.....	135
23. Pictures showing the various marsh conditions observed within the study site .....	137
24. Illustration of the marsh fragmentation and disintegration process by Shea Penland.....	139

## CHAPTER 6

1. Map processes in knowledge integration and priority areas setting (Balram et al., 2004) .....	148
2. The calculation of the Local Moran's I statistic (Anselin, 1995) .....	150
3. Significantly clustered areas of high risk of loss overlaid on the Marsh Vulnerability Map.....	153
4. Significantly clustered areas of high risk in the vicinity of Grand Bayou Village...	154
5. Final map showing clustered High Risk for loss areas that are within areas of any Negative OC and the Most Important RP .....	156
6. Final map resulting from modified criteria that selected only areas around Grand Bayou Village .....	157
7. Southeast Louisiana land loss represented in a USGS map typically used in the restoration project decision-making process (Barras, 2007).....	163

8. Grand Bayou area from map in Figure 7 zoomed in to show differences and similarities with similar datasets produced for this study .....	165
9. Grand Bayou land change map (1/21/2004 to 10/27/2005) produced for this study .....	166
10. Southeastern Louisiana projected land loss map produced by USGS (USGS, 2005).....	167
11. Grand Bayou study area enlarged to show detail from Southeastern Louisiana projected land loss map (USGS, 2005).....	168
12. Lake Hermitage Marsh Creation restoration project (LaCoast, 2010a).....	169
13. Map showing TEK-based restoration priorities and high risk of loss areas for the location of the Lake Hermitage Marsh Creation project.....	170
14. West Pointe a la Hache Marsh Creation restoration project (LaCoast, 2010b) .....	172
15. Map showing TEK-based restoration priorities and high risk of loss areas for the location of the West Pointe a la Hache Marsh Creation project .....	173

## LIST OF TABLES

### CHAPTER 3

1. Imagery Used in Land Change Analysis .....	26
2. Table given by Landis and Koch (1977) for interpretation of Kappa values .....	42
3. Image Classification Accuracy Assessment Results.....	43
4. Land Loss by Time Periods and Hurricanes that passed within 65 miles of study area .....	44

### CHAPTER 4

1. Final codebook.....	72-74
2. Example results of applying numeric codes for Restoration Priority .....	78-79
3. Restoration Priority Index used to create the Restoration Priority Map .....	80
4. Agreement Matrix used for intercoder reliability assessment .....	82

### CHAPTER 5

1. Chlorophyll Meter test dataset for Stepwise Multiple Regression Analysis .....	115
2. LAI test dataset for Stepwise Multiple Regression Analysis.....	116
3. Fragmentation class land loss proportions calculated for each combined image .....	130
4. Results of Duncan's multiple range test of fragmentation class loss risk assessment.....	131

### CHAPTER 6

1. Table showing results of cluster and outlier analysis and selection of significantly clustered high risk areas.....	152
2. Feature dataset table for TEK-based data layer showing results of query.....	156
3. Project benefit scoring criteria for Objective 4 (CPRA, 2009).....	161
4. Qualitative benefit score conversion matrix (CPRA, 2009) .....	162
5. Master Plan metric relative weights (CPRA, 2009).....	162

## **ABSTRACT**

This research investigated the feasibility and benefits of integrating geospatial technology with traditional ecological knowledge (TEK) of an indigenous Louisiana coastal population in order to assess the impacts of current and historical ecosystem change to community viability. The primary goal was to provide resource managers with a comprehensive method of assessing localized ecological change in the Gulf Coast region that can benefit community sustainability. Using Remote Sensing (RS), Geographic Information Systems (GIS), and other geospatial technologies integrated with a coastal community's TEK to achieve this goal, the objectives were (1) to determine a method for producing vulnerability/sustainability mapping products for an ecosystem-dependent livelihood base of a coastal population that results from physical information derived from RS imagery and supported, refined, and prioritized with TEK, and (2) to demonstrate how such an approach can engage affected community residents who are interested in understanding better marsh health and ways that marsh health can be recognized, and the causes of declining marsh determined and addressed.

TEK relevant to the project objectives collected included: changes in the flora and fauna over time; changes in environmental conditions observed over time such as land loss; a history of man-made structures and impacts to the area; as well as priority areas of particular community significance or concern. Scientific field data collection measured marsh vegetation health characteristics. These data were analyzed for correlation with satellite image data acquired concurrently with field data collection. Resulting regression equations were applied to the image data to produce estimated marsh health maps.

Historical image datasets of the study area were acquired to understand evolution of land change to current conditions and project future vulnerability. Image processing procedures were developed and applied to produce maps that detail land change in the study area at time intervals from 1968 to 2009. This information was combined with the TEK and scientific datasets in a GIS to produce mapping products that provide new information to the coastal restoration decision making process. This information includes: 1) what marsh areas are most vulnerable; and 2) what areas are most significant to the sustainability of the community.



Keywords:

Restoration, GIS, Geographical Information Systems, Remote Sensing, TEK, Traditional Ecological Knowledge, Coastal Louisiana, Land Loss, Marsh Health, Community Vulnerability, West Point a la Hache, Grand Bayou, PAR, Participatory Action Research

## **CHAPTER 1**

### **INTRODUCTION**

Louisiana's coastal marshes serve as essential buffer zones between land and water in estuaries and coastal zones; however, they are disappearing rapidly, and those that remain are often in poor health. The most dramatic coastal marsh losses in the United States are in the northern Gulf of Mexico (Turner, 1997), which has 41% of the nation's coastal wetlands. Louisiana's rate of coastal wetland loss reached a peak of 108.4 km<sup>2</sup>/year in the 1970s (Barras et al., 2003). Since the 1980s this peak rate of marsh loss has declined (Britsch and Dunbar, 1993), but the trend of land loss continues. The remaining marsh areas serve as a cushion between coastal communities and the open water of the Gulf, as well as an integral resource for the economic and social viability of these communities. These coastal marshes are also critical physical buffers against the full fury of storm events that impact the more densely populated areas in the Gulf region such as the Greater New Orleans Metropolitan Area. Therefore, coastal community leaders, government officials, and resource managers must be able to accurately assess and predict a given coastal community's sustainability and/or vulnerability as this coastal habitat continues to undergo rapid and dramatic changes associated with natural processes and anthropogenic activities.

The dependency of coastal communities and more populated areas inland on the marshes was clearly illustrated during the 2005 hurricane season as the Louisiana Gulf coast bore the brunt of hurricanes Katrina and Rita. The destructive impact of these storms to coastal communities and populated centers inland was more pronounced after decades of loss of critical

marsh habitat. It is hypothesized that a storm surge approaching New Orleans from the south through existing coastal marshes could have been reduced by 3.7 meters if it had crossed 80 kilometers of marsh before reaching the city (Mitsch and Gosselink, 2007). “In essence, the levees would have encountered less than half of the storm surge caused by hurricane Katrina and society would not have experienced such grief and devastation if the wetlands were not disappearing at a rapid rate” (Bartholomew, 2009). The ability to determine probable effects and impacts of wetland loss to coastal communities will allow more informed decision making in utilizing resources for coastal restoration activities that are crucial to continued viable habitation and sustainability of the region.

## **Objectives**

The primary objective of this study was to develop information tools, based on the properties of a declining marsh habitat that are suitable for coastal management, protection and restoration. The goal was to create tools for integration into and enhancement of the decision-making process used by the Coastal Protection and Restoration Authority of Louisiana, Office of Coastal Protection and Restoration (CPRA). To meet this objective, Remote Sensing (RS) and Geographical Information Systems (GIS) technologies, as well as the Traditional Ecological Knowledge (TEK) of an indigenous population intricately tied to the study area ecosystem were utilized. TEK is a cumulative body of knowledge, practice, and belief which evolves by adaptive processes, is handed down through generations by cultural transmission, and centers on the relationships of humans with one another and with their environment (Berkes et al., 2000).

Historical imagery was acquired and used to conduct land change analyses of the study area. These datasets were complemented by the TEK, which is comprised of indigenous knowledge of historical land loss, natural resource use, and flora and fauna changes in the area based on accumulated observations over time by the residents. A method was developed to

integrate the scientific datasets derived from the RS imagery and other geospatial technologies with the residents' TEK in order to provide a more comprehensive assessment of ecological change that includes affects on local resource utility value and areas of cultural significance that can be used to benefit both ecosystem and human community sustainability. Using RS, GIS, and other geospatial technologies integrated with a coastal community's TEK this research created a detailed assessment of historical land loss in the study area and the evolution of the landscape to its current condition. A method for producing a marsh surface condition map indicating overall marsh health and potential for deterioration was also developed. This map was produced for an ecological livelihood base of a coastal community, and resulted from physical information derived from RS imagery and in situ data, supported by TEK. Finally, this research demonstrated an approach for engaging affected residents and restoration managers in mutual efforts to aid prioritization and decision-making through more comprehensive understanding of marsh health and the ways that marsh health can be recognized, as well as the causes of marsh decline determined.

## REFERENCES

- Barras, J. A., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota, and J. Suhayda. 2003. Historical and projected coastal Louisiana land changes: 1978-2050. *U.S. Geological Survey Open-File Report 03-334*, 39 p.
- Bartholomew, L. 2009. The Impact of Hurricanes Katrina and Rita on Herbaceous Marsh Plant Diversity and Wetland Perseverance in West Pointe a la Hache, Louisiana. *Senior Thesis*, 81 pp., Princeton University, Princeton, New Jersey.
- Berkes, F., J. Colding, and C. Folke. 2000. Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications*, 10(5): pp. 1251-1262.
- Britsch, L. D. and J. B. Dunbar. 1993. Land loss rates: Louisiana coastal plain. *Journal of Coastal Research*, 9:324-338.
- Mitsch, W.J., and J.G. Gosselink. 2007. *Wetlands*, 4<sup>th</sup> ed., John Wiley & Sons, Inc., Hoboken, New Jersey.
- Turner, R. E. 1997. Wetland Loss in the Northern Gulf of Mexico: Multiple Working Hypotheses. *Estuaries*, Vol. 20, No. 1, pp. 1-13.

## CHAPTER 2

### BACKGROUND

#### Study Area

The study area is the ecological livelihood base of the coastal community of Grand Bayou, Louisiana in lower Plaquemines Parish (Figure 1). The residents of Grand Bayou trace their ancestry within this region back two to three hundred years (Manning, 2005). They are self-identified as predominantly Native Americans of the Atakapa tribe with a mix of various other cultures to a lesser degree. Although the Atakapa is a historically recognized Native American tribe indigenous to South Louisiana, the community does not have Federal tribal recognition (Manning, 2005). During the late 18<sup>th</sup> and early 19<sup>th</sup> century, the Atakapa mainly occupied the coastal and bayou areas of southwestern Louisiana and southeastern Texas, however smaller groups of the tribe migrated eastward along the Louisiana coast. Archeological evidence suggests that Native American settlements have existed in this area for at least 2000 years (Texas State Historical Association, 2008). These people have historically sustained themselves by utilizing the natural resources available to them in this coastal environment. For example, Dyer (1917) reports that the Atakapa used Spanish moss (*dendropogen usuecides*) found naturally in the region's swamps and bayous as diapers for their infants. Marine life such as the shark was very important to the Atakapa as it provided meat, oil, and bones, all of which were integral to the everyday life of a coastal tribe (Dyer, 1917). Alligator, which is native to this coastal area, was hunted and utilized for its meat, oil, and hide. They even used the oil of the alligator as an insect repellant (Texas State Historical Association, 2008). This traditional

utilization and dependence on the area's natural resources, specifically marine life, persists in the Atakapa culture today. Grand Bayou is a coastal community where the residents are intricately tied to their surrounding ecosystem and have a long history of adaptation to the challenges that have resulted from persistent change of this ecosystem due to both natural and anthropogenic factors. Like generations before them, they are fishers, hunters, and trappers that depend on the natural resources of the surrounding ecosystem to sustain their way of life. Because of this dependency on their environment, they are actively engaged in issues such as habitat restoration, water quality, and economic development to promote conservation and understanding of this complex and vulnerable ecosystem.

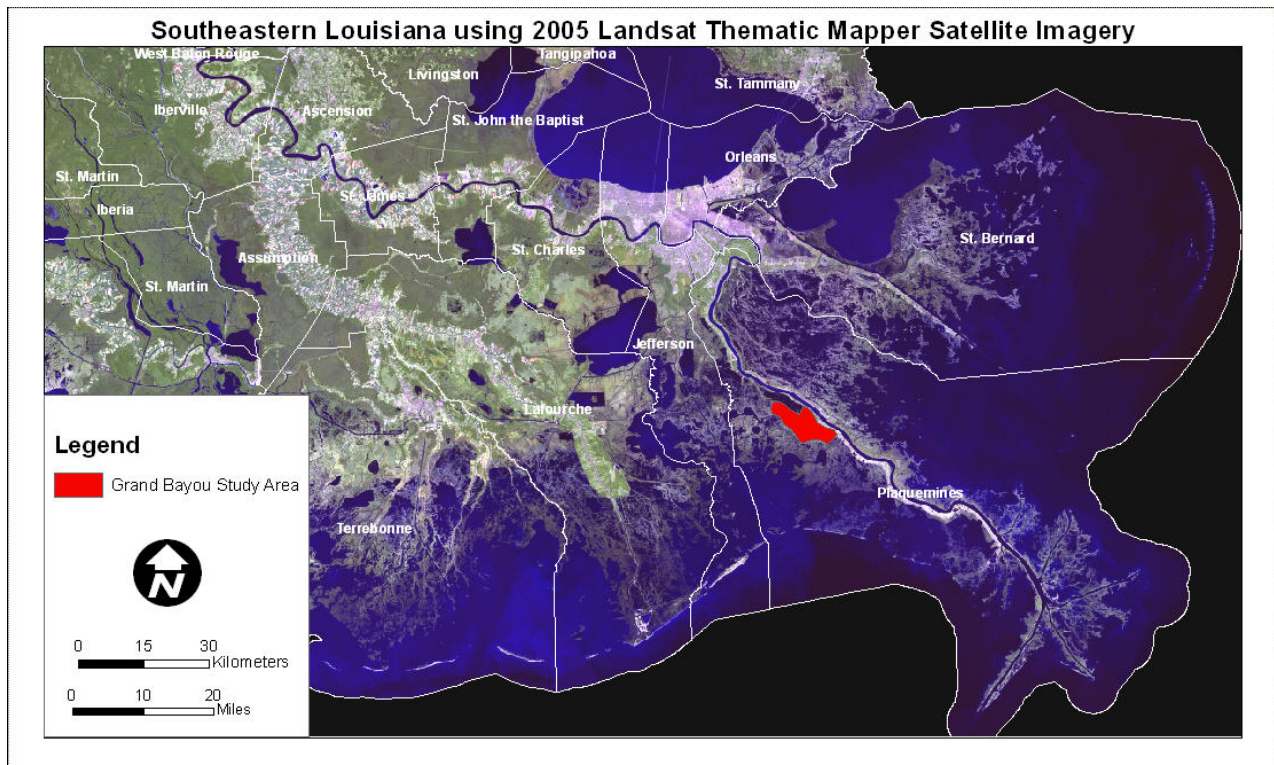


Figure 1. Map of Southeast Louisiana showing location of Grand Bayou study area.

The residents of Grand Bayou utilize the local ecosystem in the seasonal harvest of all commercial species; shrimp, oysters, crab, softshell crab, nutria pelts, alligator, and fish. Most members select from these resources, some utilizing a remarkably large number of different species. Since hurricanes Katrina and Rita, efforts at resource extraction have become increasingly difficult. Because only a few homes have been rebuilt, very few members of the community have been able to fully return to Grand Bayou. The extractors must either live on their boats docked at the Grand Bayou community center or travel from their temporary homes up the river and into other communities north of Grand Bayou. Combinations of these housing/commute patterns have been adopted; they vary according to the resource season and to the price that the harvesters are able to obtain for their catch/harvest. Some community members work fulltime offshore (usually as boat operators) and fit their extraction activities to their time off. The members of Grand Bayou recognize that unless the proposed restoration projects are implemented with speed and with effectiveness, they may be the last generation of Grand Bayou members to be able to successfully undertake commercial resource harvest activities and retain their endemic understanding of this area. If this outcome occurs, then the TEK of the residents will quickly decline and be lost from the science of coastal restoration.

This study has built upon several past National Science Foundation (NSF) and on-going sociological studies of adaptive management at Grand Bayou. These studies have allowed for collaboration among several academic institutions, federal agencies, practitioners, professional organizations, and the residents in Participatory Action Research (PAR). This close relationship and participation has educated the researchers specifically about how the community responds to environmental risks including natural disasters. Reciprocally, the community residents have become more articulate in their knowledge, assessment and appreciation of themselves. Through



these collaborations, scientific knowledge and traditional local knowledge became linked (Laska et al., 2007).

Geographically, Grand Bayou is located within or near several on-going and planned Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) marsh restoration projects that either have affected or will impact the community and its ecological livelihood base (Figure 2). This area has experienced some of the highest rates of land loss in the Louisiana Coastal Zone. The rate of subsidence in some areas of Plaquemines Parish is almost 2 cm/year, which serves to exacerbate the land loss problem when combined with other natural and anthropogenic causes of loss affecting this region (McCorquodale, 2010). In this vicinity, the average rate of marsh land loss was 0.13%/year between 1932 and 1958, 0.37%/year between 1958 and 1974, 0.37%/year between 1974 and 1983, and 0.40%/year between 1983 and 1990 (Dunbar et al., 1992).

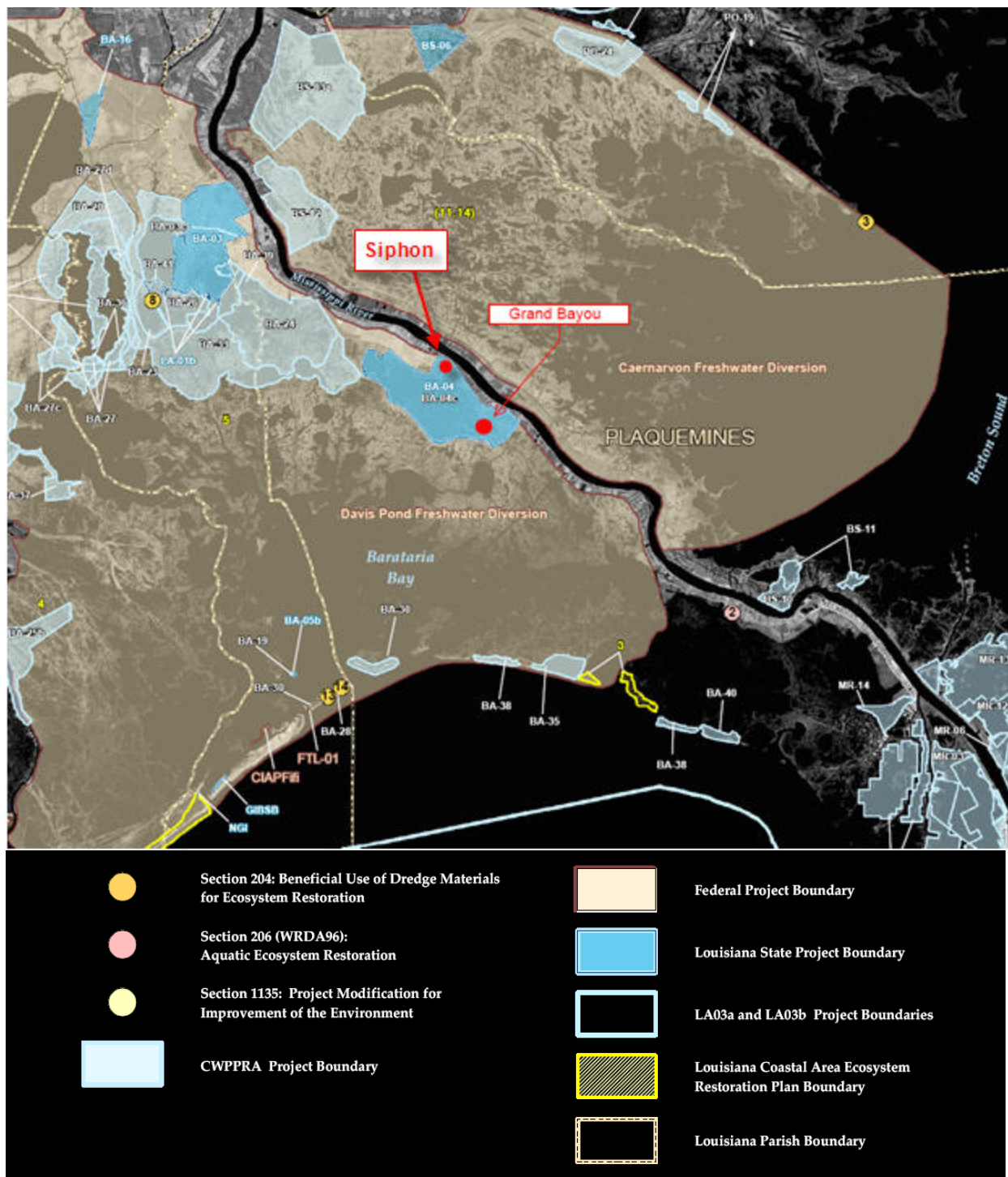


Figure 2. Selected Louisiana Coastal Restoration Projects 2005 map showing geographical relation of projects to Grand Bayou (CWPPRA project map courtesy of [www.lacoast.gov](http://www.lacoast.gov)).

Specifically related to this research are the projects BA-04c – West Pointe a la Hache Outfall Management (Figure 3) and BA-33 – Delta Building Diversion at Myrtle Grove. The status of each of these two CWPPRA restoration projects is detailed on the Louisiana Coastal Wetlands Conservation and Restoration Task Force Web site (LaCoast, 2008), which contains information and links relating to coastal restoration projects in coastal Louisiana. The West Pointe a la Hache freshwater diversion siphons have been operational since early 1993 and divert sediment and freshwater into the surrounding marshes. It is reported on this website (LaCoast) that the effects that the siphons are having on the marsh has not been quantified yet.

The Myrtle Grove project is still in the design phase and will eventually nourish 15,894 acres of brackish marsh in Plaquemines Parish by reintroducing sediment, nutrients, and freshwater. This research aims to provide useful information to the restoration managers of these CWPPRA projects to aid and improve related decision-making processes.



Figure 3. West Pointe a La Hache Siphon (image provided by the Louisiana Department of Natural Resources)

## **Current Coastal Restoration Management**

The Society of Wetland Scientists (2000) defines wetland restoration as actions taken in a converted or degraded natural wetland that result in the reestablishment of ecological processes, and functions. Restoration of a wetland should lead to a persistent, resilient system integrated within its landscape. Current wetland restoration techniques include marsh creation, freshwater diversion, and outfall management. Marsh creation projects replicate the natural land-building process in a controlled fashion by restoring elevation and subsided material.

Freshwater diversion and outfall management are techniques used to regulate the volume of freshwater flow channeled from a nearby river or water body into surrounding wetlands.

“This infusion of water, sediment, and nutrients helps slow saltwater intrusion and promotes the growth of a new marsh” (Department of Natural Resources, 2008). The results of this research are anticipated to benefit restoration efforts by helping to determine whether particular restoration sites are good candidates for marsh restoration/creation. CWPPRA partners could use the integrated information derived from the results of this project to evaluate proposed restoration project sites not only on the basis of good science, but also on the goals and values of the affected local communities.

In planning restoration by marsh creation, CWPPRA project managers must answer questions such as; ‘Why are we building marsh here rather than there? How much marsh do we need? Are we creating a certain kind of habitat? Is there infrastructure that we want our marsh to protect?’ In order to answer these questions “it is becoming increasingly evident that decisions regarding restoration cannot be made solely by using ecological metrics but should involve social and economic considerations and measurements of success as well” (Thayer et al., 2003). This work brought together physical and social scientists, and local community

representatives in an effort to provide restoration managers more comprehensive information to help them arrive at more informed answers to these questions.

### **The CPRA CWPPRA Decision Support Process**

Currently the CPRA uses standard operating procedures that detail how projects are selected for the CWPPRA program as well as for other restoration programs (i.e., Coastal Impact Assistance Program and the Louisiana Coastal Area Program). These procedures begin with the development of supporting information for use by Regional Planning Teams (RPTs) in examining and accepting nominations of projects (Louisiana, 2007). Information on the status of current CWPPRA restoration projects is also included. This supporting information, used to make decisions regarding adaptive management of existing restoration projects and site selection for new projects, includes basin maps produced by the United States Geological Survey (USGS) that indicate regional projected land loss. Once projects are nominated by the RPTs, the process continues through a preliminary assessment phase to ensure project compliance with Coast 2050 strategies (Louisiana, 1998). A Technical Committee then considers project costs and potential wetland benefits of the nominees before selecting candidate projects for assignment to a Federal sponsor for the development of preliminary Wetland Value Assessment data and engineering cost estimates.

CPRA's Quality Management Plan for the CWPPRA Monitoring Program (Steyer et al., 2000) and the Coastwide Reference Monitoring System Standard Operating Procedure Manual (Folse et al., 2008) detail the requirement and use of both aerial and satellite imagery in the initial assessment and monitoring phases of CWPPRA projects. The land loss maps produced by USGS for CPRA typically use Landsat 30-meter resolution images for assessing loss from the regional scale down to projects a few thousand acres in size. These datasets are suitable for

regional assessment of land and water trends, however, they may not be appropriate for small project assessments (Barras, 2008). Higher resolution datasets are available through the USGS (such as aerial or high-resolution satellite imagery) for restoration project planning, but very few of these available datasets are requested by CPRA, mainly due to the perceived benefit versus higher cost and processing time associated with such datasets as compared to Landsat (Barras, 2008).

The proposed research aims to provide CPRA with information tools in the form of GIS maps that incorporate historical and projected marsh loss at a higher spatial resolution than currently utilized. In addition, these data will be integrated with the TEK of an indigenous Louisiana coastal population to assess the impacts of current and historical ecosystem change to community viability. This comprehensive dataset can then be included in a more detailed assessment of a CWPPRA project's 'potential wetland benefits' and the associated Wetland Value Assessment conducted during the CWPPRA decision-making process. USGS land loss datasets developed with Landsat imagery are used as a baseline to estimate any benefit to the CPRA restoration management process gained by including the higher resolution data combined with the TEK information developed in this study. The goal is to determine if there is a significant benefit to incorporating this type of dataset into the current process, which would justify the additional time/cost that currently precludes it from being utilized more frequently.

## **PREVIOUS STUDIES**

Literature about the causes, trends, and impacts of Louisiana coastal marsh decline and loss shows that any current or future marsh restoration plan must include a method for monitoring and identifying vulnerable marsh areas (Bernier et al., 2006; Michot et al., 2004;

Walker et al., 1987; Turner, 1997; and Penland et al., 1996). Site-specific sampling and monitoring efforts often do not properly represent overall trends due to the regional scale of the problem. The use of remotely sensed imagery and other geospatial technologies have the potential to enhance marsh health monitoring, and may provide a timelier, more accurate, and more efficient monitoring approach. Remote sensing offers ecologists and resource managers the potential of directly discerning large-scale processes with repeat measurement that allows for the identification of trends over time (Roughgarden et al., 1991). For example, Lulla (1983) reviewed the use of Landsat MSS satellite imagery for surveying wetlands and coastal ecosystems. Another study by Lee and Lunetta (1996) reviewed methods to detect changes in wetlands, including using remotely sensed datasets and assessing their ability to detect wetland changes. MacDonald (1999) investigated the potential of using remotely sensed imagery for monitoring change in wetland rehabilitation projects, understanding causes of wetland degradation, and prioritizing potential restoration sites.

For studies on land cover change, remotely sensed imagery is often used because of vegetation's unique spectral signature. The spectral signal of vegetation is easily distinguished from the spectral signatures of other types of land cover, such as water and soil. Remotely sensed imagery can be classified using various image classification techniques that are based on grouping pixels into clusters depending on the similarity of their spectral features. In addition to land degradation, remotely sensed imagery can be used to detect vegetation health, biodiversity, and change over time using multiple image datasets.

In order to appreciate how data derived from remotely sensed imagery can be used to monitor marsh vegetative health, it is necessary to understand how spectral reflectance is used to describe the phonological characteristics of a plant canopy (Figure 4). Spectral reflectance data

from remotely sensed imagery have been commonly used to identify vegetation stress and vigor in a variety of applications including agriculture and forestry (Figure 5). Reflectance in the near-infrared wavelengths is sensitive to changes in the leaf structure of plants. Changes in photosynthetic activity can be monitored in the red and blue chlorophyll absorption bands. Additionally, changes due to stress can be detected before they are visible to the naked eye (Lillesand and Kieffer, 1987). Research has shown that various ratios of the near-infrared and red bands are capable of detecting stress in vegetation (Jackson et al., 1983; Tucker, 1979; Carter, 1994). These band ratios, which detect variability in the red and near-infrared wavelengths caused by changes in plant physical properties, are useful in detecting general stress (Lelong et al., 1998), weed infestations (Medlin et al., 2000; Deguise et al., 1999; Richardson et al., 1985; Spectral Visions, 2000), water stress (Wanjura and Upchurch, 1999) and nitrogen stress (Blackmer et al., 1994) in plants. Areas of plant stress identified using imagery may indicate increased insect, pest, or other pressures. Areas of increased plant vigor may contain weeds, or may be experiencing increased nutrient supply for some reason. In this way the resource manager utilizing remotely sensed data may be directed toward problems areas, resulting in more efficient use of time in the field and more confidence that trouble spots have been visited.



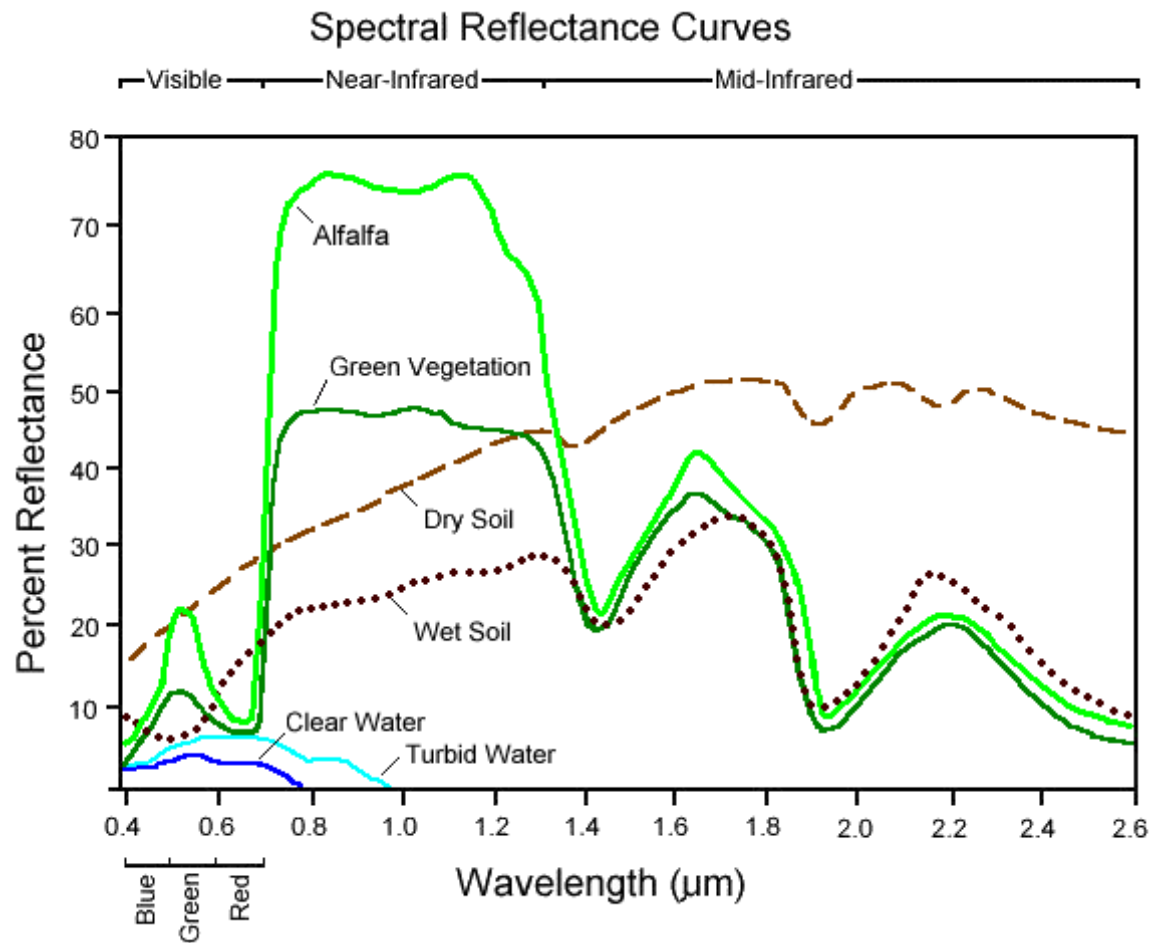


Figure 4. Diagram showing typical spectral reflectance curves associated with various land and water features including vegetation (figure provided by the Institute for Technology Development at Stennis Space Center, MS).

## Soybeans: Early Stress Detection through Remote Sensing

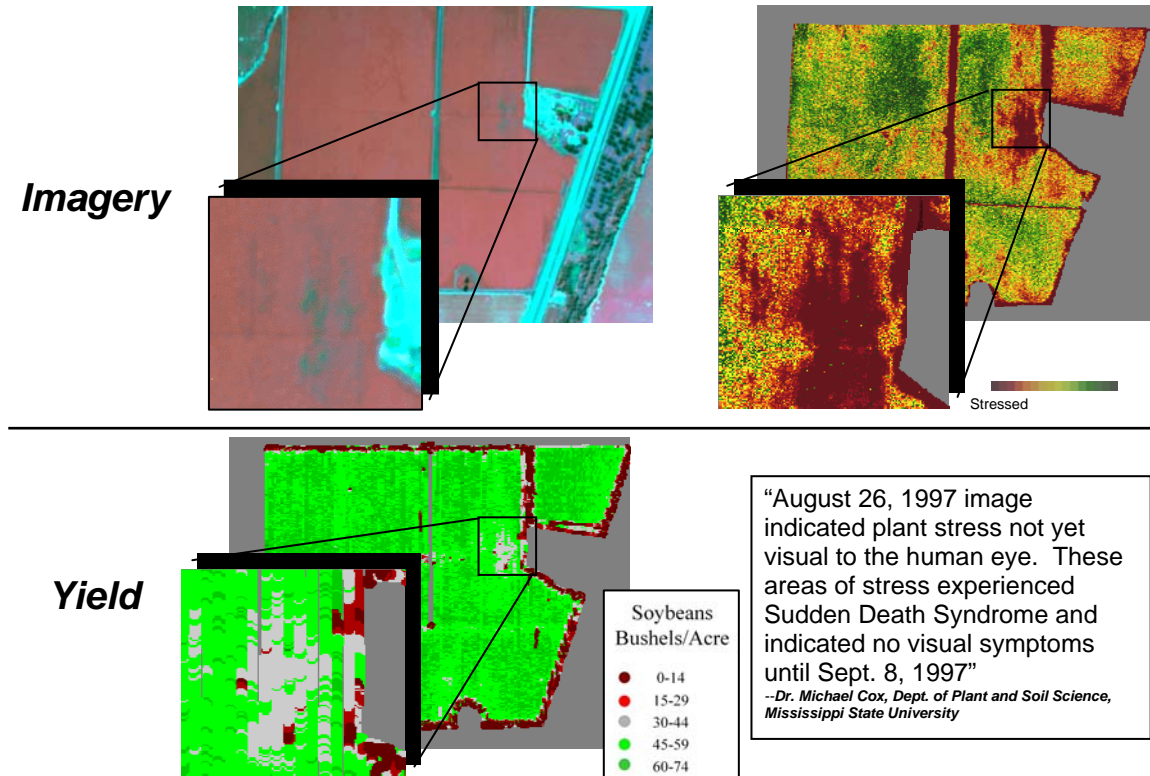


Figure 5. Example of how spectral reflectance from remotely sensed imagery has been used successfully in agriculture to identify areas of crop canopy stress.

Specific examples of determining marsh plant stress using reflectance data are reported in Ewing et al. (1997). The results of this study show that spectral reflectance indices derived from reflectance values responded to changes in a number of environmental variables in Louisiana marshes. These environmental variables included salinity, submergence, and nutrient differences affecting the marsh plant communities studied near Lake de Cade, Louisiana. The authors of the study conclude that with remotely sensed reflectance data, “the basic tools for early detection of sublethal stress are available” for marsh vegetation, and that “what is left is to develop a protocol for their successful application”. Similarly, Hardisky et al. (1986) using field spectroradiometers, reported green biomass, percent live biomass, total biomass, and canopy

height to be significantly correlated with red and near-infrared spectral reflectance of *Spartina alterniflora* and salt hay (*Distichlis spicata*-*S. patens* mixture) communities found in Delaware salt marshes.

The value that remotely sensed imagery and other geospatial technologies can have in a decision support system for planning coastal restoration activities may be enhanced through appropriate integration of this information with TEK of indigenous groups throughout coastal communities. The integration of the physical measurements with the traditional knowledge of the people who are living and working in this rapidly changing environment could give resource managers, community leaders, and other decision makers a more comprehensive understanding of environmental conditions favorable for a healthy and productive marsh habitat, as well as the ability to predict and model changes in the marsh vulnerability pattern over time. This integrated knowledge could have a profound influence on the designs of projects intended to restore wetland resources. Additionally, the active involvement of local communities in conservation decision-making and practice develops legitimacy and secures broad popular support for conservation efforts and restoration activities (Goodwin, 1998).

## REFERENCES

- Barras, J. A. 2008. Personal Communication. Baton Rouge, Louisiana: USGS/CR/BRD National Wetlands Research Center, Coastal Restoration Field Station.
- Bernier, J. C., R. A. Morton, and J. A. Barras. 2006. Constraining Rates and Trends of Historical Wetland Loss, Mississippi River Delta Plain, South-Central Louisiana. In: *Coastal Environment and Water Quality*, pp. 371-382.
- Blackmer, Tracy M., James S. Schepers and Gary E. Varvel. 1994. Light Reflectance Compared with Other Nitrogen Stress Measurements in Corn Leaves. *Agronomy Journal*, 86:934-938.
- Carter, Gregory. 1994. Ratios of Leaf Reflectances in Narrow Wavebands as Indicators of Plant Stress. *International Journal of Remote Sensing*, 15(3); 697-703.
- Deguisse, J. C., K. Staenz and J. Lefebvre. 1999. Agricultural Applications of Airborne Hyperspectral Data: Weed Detection. Fourth International Airborne remote Sensing Conference and Exhibition/21<sup>st</sup> Canadian Symposium on remote Sensing, Ottawa, Ontario, Canada, June 21- 24, 1999.
- Department of Natural Resources (DNR). 2008. Restoration Project Types. URL: <http://dnr.louisiana.gov/crm/background/types.asp>
- Dunbar, J. B., L. D. Britsch, and E. B. Kemp. 1992. Land Loss Rates, Report 3, Louisiana Coastal Plain. *Technical Report GL-90-2*. US Army Engineers District, New Orleans. March 1992. 28 pp. plus app.
- Dyer, J. O. 1917. The Lake Charles Atakapas (Cannibals) Period of 1817 to 1820, Galveston, 1917.
- Ewing, K., K. L. McKee, and I. A. Mendelssohn. 1997. A Field Comparison of Indicators of Sublethal Stress in the Salt-Marsh Grass *Spartina patens*. *Estuaries*, Vol. 20, No. 1, pp. 48-65.
- Folse, T. M., J. L. West, M. K. Hymel, J. P. Troutman, L. Sharp, D. Weifenbach, T. McGinnis, and L. B. Rodrigue. 2008. A Standard Operating Procedures Manual for the Coast-wide Reference Monitoring System-Wetlands: Methods for Site Establishment, Data Collection, and Quality Assurance/Quality Control. *Louisiana Coastal Protection and Restoration Authority, Office of Coastal Protection and Restoration*. Baton Rouge, LA. 191 pp.
- Goodwin, P. 1998. 'Hired Hands' or 'Local Voice': Understandings and Experience of Local Participation in Conservation. *Transactions of the Institute of British Geographers*, New Series, Vol. 23, No. 4: pp.481-499.

- Hardisky, M. A., M. F. Gross, and V. Klemas. 1986. Remote Sensing of Wetlands: Landsat TM, SPOT, and imaging spectrometers will enhance remote sensing research on wetlands. *BioScience*, Vol. 36, No. 7, pp. 453-460.
- Jackson, R. D., P. N. Slater and P. J. Pinter, Jr. 1983. Discrimination of Growth and Water Stress in Wheat by Various Vegetation Indices Through Clear and Turbid Atmospheres. *Remote Sensing of Environment*, 13:187-208.
- LaCoast. 2008. CWPPRA Restoration Status. URL: <http://www.lacoast.gov/reports/rtc/1997/7.htm>
- Laska, S., J. Pine, P. Jenkins, K. Peterson, B. Phillips, B. Kennedy, M. Levitan, H. Mashriqui, E. McNaughton. 2007. An Interdisciplinary Approach to Coastal Vulnerability and Community Sustainability. *National Science Foundation Collaborative Research – Small Grant for Exploratory Research (SGER)*, Final NSF Project Report.
- Lee, K. H. and R. S. Lunetta. 1996. Wetland Detection Methods. In: *Wetland and Environmental Applications of GIS*. Lewis Publishers, New York, pp. 249-284.
- Lelong, Camille C. D., Patrick C. Pinet and Herve Poilve. 1998. *Hyperspectral Imaging and Stress Mapping in Agriculture: A Case Study on Wheat in Beauce (France)*. Elsevier Science, Inc.
- Lillesand T. M. and R. W. Kiefer. 1987. *Remote Sensing and Image Interpretation*, John Wiley and Sons, Inc. New York, 2<sup>nd</sup> edition.
- Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority. 1998. Coast 2050: Toward a Sustainable Coastal Louisiana. Louisiana Department of Natural Resources. Baton Rouge, La. 161 p.
- Louisiana Coastal Wetlands Conservation and Restoration Task Force and Wetlands Conservation and Restoration Authority. 2007. Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) Project Standard Operating Procedures Manual. Revision 13.0. <http://www.mvn.usace.army.mil/pd/CWPPRA-SOP-version13-FINAL-apprbyTC14Mar07.pdf>
- Lulla, K. 1983. The Landsat satellites and selected aspects of physical geography. *Progress in Physical Geography*. 7: pp. 1-45.
- MacDonald, T. A. 1999. Wetland rehabilitation and remote sensing. In: *An International Perspective on Wetland Rehabilitation*. Kluwer Academic Publishers, Boston, pp. 251-264.

- Manning, S. C. 2005. Riding out the Risks: An Ethnographic Study of Risk Perceptions in a South Louisiana Bayou Community. *Master of Science Thesis*, Louisiana State University and Agricultural and Mechanical College, Department of Environmental Studies, Baton Rouge, Louisiana.
- McCorquodale, J. A. 2010. Personal Communication. Department of Civil and Environmental Engineering, University of New Orleans, New Orleans, Louisiana.
- Medlin, Case R., David R. Shaw, Patrick D. Gerard and Falba E. LaMastus. 2000. Using Remote Sensing to Detect Weed Infestations in *Glycine max*. *Weed Science*, 48:393-398.
- Michot, T. C., C. J. Wells, and R. S. Kemmerer. 2004. Spatial and Temporal Distribution of Coastal Marsh Dieback in Louisiana, 2000-2003, as Determined from Aerial Surveys. Report submitted to *Coastal Restoration Division, Louisiana Department of Natural Resources* in partial fulfillment of: DNR Contract Number 2512-05-03.
- Penland, S., I. Mendelssohn, L. Wayne, and D. Britsch. 1996. Natural and Human Causes of Coastal Land Loss in Louisiana. *Coastal Studies Institute and Wetland Biogeochemistry Institute*, Louisiana State University, Baton Rouge, Louisiana.
- Richardson, A.J., Menges, R.M. and Nixon, P.R. 1985. Distinguishing Weed from Crop Plants Using Video Remote Sensing. *Photogrammetric Engineering and Remote Sensing*, vol. pp.1785-1790.
- Roughgarden, J., S. W. Running, and P. A. Matson. 1991. What Does Remote Sensing Do For Ecology?. *Ecology*. Vol. 72, No. 6, pp. 1918-1922.
- Society of Wetland Scientists (SWS). 2000. Position Paper on the Definition of Wetland Restoration. URL: <http://www.sws.org/wetlandconcerns/restoration.html>
- Spectral Visions. 2000. 2000 Year End Report to NASA's Geospace Applications and Development Directorate. Pp. 48-64.
- Steyer, G. D., R. C. Raynie, D. L. Steller, D. Fuller, and E. Swenson. 2000. Quality Management Plan for Coastal Wetlands Planning, Protection, and Restoration Act-Monitoring Program. *Louisiana Department of Natural Resources, Coastal Restoration Division*. Open-File Report 95-01. 112 pp.
- Texas State Historical Association. 2008. Atakapa Indians. URL: <http://www.tshaonline.org/handbook/online/articles/AA/bma48.html>

- Thayer, Gordon W., Teresa A. McTigue, Russell J. Bellmer, Felicity M. Burrows, David H. Merkey, Amy D. Nickens, Stephen J. Lozano, Perry F. Gayaldo, Pamela J. Polmateer, and P. Thomas Pinit. 2003. Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457). *NOAA Coastal Ocean Program Decision Analysis Series*. No. 23, Volume 1. NOAA National Centers for Coastal Ocean Science, Silver Spring, MD. 35 pp. plus appendices.
- Tucker, Compton J., 1979. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. *Remote Sensing of Environment*, 8:127-150.
- Turner, R. E. 1997. Wetland Loss in the Northern Gulf of Mexico: Multiple Working Hypotheses. *Estuaries*, Vol. 20, No. 1, pp. 1-13.
- Walker, J. H., J. M. Coleman, H. H. Roberts, and R. S. Tye. 1987. Wetland Loss in Louisiana. *Geografiska Annaler. Series A, Physical Geography*, Vol. 69, No. 1, pp. 189-200.
- Wanjura, D. F. and D. R. Upchurch. 1999. Remotely Sensed Changes in Crop Water Stress. 1999 ASAE/CSAE-SCGR Annual International Meeting, Toronto, Ontario, Canada. July 18-21, 1999.

## **CHAPTER 3**

### **HISTORICAL LAND LOSS ASSESSMENT**

#### **INTRODUCTION**

A necessary step in determining areas that are most vulnerable to loss within the study area is to map local historical change to better understand the evolution to current conditions. By using repeat measurement, which allows for the identification of trends over time, remote sensing offers ecologists and resource managers the potential of directly discerning large-scale processes as they take place (Roughgarden et al., 1991). Remote sensing has been shown to be effective in monitoring the condition of wetlands, as well as to detect changes in wetlands. This information is essential to understanding the causes of wetland degradation, projecting future land loss trends, and informing restoration decision-making.

“One of the most fundamental measures of ecosystem degradation in coastal Louisiana has been the conversion of land (mostly emergent vegetated habitat) to open water” (Barras et al., 2003). Image datasets that include an infrared band are particularly good for land-water discrimination because of the high absorption by water and high reflectance by vegetation for that part of the electromagnetic spectrum (Braud and Feng, 1998). Historical time-series image datasets show areas of marsh prior to eventual decline and loss followed by transition of that marsh to open water areas. The relatively rapid and extensive degradation and conversion of marsh to open water within the study area provides an opportunity to quantify and spatially



assess recent trends in land change with remotely sensed datasets. These trends can then be used to project future changes.

To conduct this land change analysis, historical image datasets of the study area were acquired and processed according to methods based upon those used by Barras et al. (2003), Barras (2007), Barras et al. (2008), and Bernier et al. (2006). This work resulted in the development of high-resolution land change maps of the study area that detail land loss, land gain, areas that were unchanged, and transitional areas for six different time periods between 1968 and 2009. Historical land-water changes were assessed by comparing changes in the distribution and total area of land and water between selected image dates. Average annual rates of land loss were derived for each period by dividing the total loss in land area by the number of years between observations. These land change maps were instrumental in the development of a model designed to improve understanding of the characteristics related to local land loss and to inform associated restoration management approaches.

## **METHODS**

The historical land loss assessment utilized historical image datasets of the study area covering the time period several decades prior to the beginning of the BA-04 CWPPRA project to the present. These historical datasets include aerial and satellite images acquired from 1968 to 2009 (including Digital Orthophoto Quarter Quadrangles, Digital Globe Quickbird satellite images, and digitized aerial photographs). All images used were acquired during fall through early spring to minimize the presence of floating aquatic vegetation that may have caused confusion in land/water discrimination (Barras, 2003). For comparison purposes, image datasets

having differing spatial resolutions were re-sampled to a common spatial resolution determined by the image dataset having the largest pixel size (in this case, the 2.39 meter Digital Globe Quickbird images). All image datasets used in this study were projected to the Universal Transverse Mercator (UTM) Zone 15 North American Datum (NAD) 83 coordinate system, and georectified to the 2005 dataset to insure uniform georegistration for valid change analyses.

Light Detection and Ranging (LIDAR) is another remote sensing dataset that offers promise for creating detailed elevation maps that could be used in combination with remotely sensed image datasets to map land-water distribution at a very high resolution. LIDAR is similar to RADAR, except it relies on light instead of radio waves. The LIDAR instrument transmits light out to a target; the time it takes for the light to return is used to determine distance. Land elevations are estimated with low-flying aircrafts equipped with LIDAR instruments (Cracknell, 2007).

However, the current lack of readily available public and private data providers, unique data processing software requirements, and high cost of LIDAR datasets prohibited its use in this study. Table 1 summarizes the image datasets processed and used in the historical change assessment.

Table 1. Imagery Used in Land Change Analysis.

Image Date	Image Type	Image Source	Image Resolution
11/25/1968	BW scanned aerial photography	US Army Corps of Engineers New Orleans	1:30,000 (600 dpi)
03/26/1979	CIR scanned aerial photography	NASA/UL Lafayette Regional Application Center	1:65,000 (1,500 dpi)
11/05/1991	Digital Orthophoto Quarter Quadrangles (DOQQ)	USGS Earth Resources and Observation Science (EROS) Center	1 m
01/24/1995	CIR Scanned aerial photography	NASA/UL Lafayette Regional Application Center	1:65,000 (1,500 dpi)
01/24/1998	Digital Orthophoto Quarter Quadrangles (DOQQ)	USGS Earth Resources and Observation Science (EROS) Center	1 m
01/21/2004	Digital Orthophoto Quarter Quadrangles (DOQQ)	USGS Earth Resources and Observation Science (EROS) Center	1 m
10/27/2005	Digital Orthophoto Quarter Quadrangles (DOQQ)	USGS Earth Resources and Observation Science (EROS) Center	1 m
10/30/2008	Digital Orthophoto Quarter Quadrangles (DOQQ)	USGS Earth Resources and Observation Science (EROS) Center	1 m
10/30/2009	Satellite imagery	DigitalGlobe Quickbird	2.39 m
11/12/2009	Satellite imagery	DigitalGlobe Quickbird	2.39 m

ERDAS Imagine 9.3 software was used to process and analyze the imagery. The Digital Orthophoto Quarter Quadrangles (DOQQs) and scanned aerial photos were re-sampled using the Nearest Neighbor method so that all images had a resolution of 2.39 meters. Following re-sampling, image processing methods were applied to create land-water images. These methods included the application of a combination of radiometric or spectral enhancements and/or classification methods. The particular method employed depended on image type and quality prior to performing land-water classification. A threshold procedure was conducted in which

thresholds were applied to the land-water images based on visual identification of the land/water break. Index ranges were derived from these threshold values and used to color code the image into land and water categories and produce a land-water classified map. The accuracy of each land-water classification was verified via comparison with the original images. Area of Interest (AOI) tools and raster fill techniques were used to correct any identified misclassification. Finally, each map was analyzed for change with other image dates. Change analysis was performed on all images to determine the change in land and water area within the study area over the time period studied. Net land loss and average rates of land loss were calculated for time periods given image dataset availability between 1968 and 2009. The resulting values were compared to each other as well as to the net land loss and to the average rate of land loss. Maps depicting the changes for each time period were created using ESRI ArcGIS 9.3 software.

### **Quickbird Satellite Data Specifications**

The Quickbird satellite is privately owned and operated by DigitalGlobe (2010). Each scene covers approximately 16.5 km by 16.5 km at nadir and has a ground resolution of 2.39 meters. However, with single shot tasking orders, as was the case with this study, only an area of interest within a scene can be ordered. The revisit time to capture images of the same location on Earth's surface is dependant upon the latitude of the area of interest and the maximum off-nadir angle desired. "An area of interest at 40 degrees latitude would have a revisit time of approximately 7 days at 0-15 degrees off-nadir, and a revisit time of approximately 4 days at 0-25 degrees off-nadir" (DigitalGlobe, 2010). For the Grand Bayou study area and image data requirements, the revisit time was approximately every 4-5 days at approximately the same local time (10:30am CDT).

The standard image product is geo-referenced, radiometrically calibrated, corrected for sensor and platform-induced distortions, and mapped to a cartographic projection. The multispectral image products used in this study consist of 4 spectral bands, each recording a discrete portion of the electromagnetic spectrum (visible to near-infrared). The specific band spectral characteristics are as follows: Band 1 (Blue) is 450 – 520nm; Band 2 (Green) is 520 – 600nm; Band 3 (Red) is 630 – 690nm; and Band 4 (near-infrared) is 760 – 900nm. Each Quickbird image dataset was delivered and downloaded via Digital Globe's File Transfer Protocol (FTP) site in Tagged Image File (TIF) format and converted to ERDAS Imagine format for processing.

### **Digital Orthophoto Quarter Quadrangle Specifications**

A DOQQ is a digital aerial photograph that includes three or four broad bands (green, red, and near-infrared in the case of the 1991, 1998, 2004, and 2005 datasets used in this study, and blue, green, red, and near-infrared in the case of the 2008 dataset used here). The DOQQs used for this study were acquired from the Louisiana Digital Atlas website (<http://atlas.lsu.edu/>), collaborating OCPR researchers, and directly from the USGS National Wetlands Research Center in Lafayette, Louisiana. Each DOQQ has a ground resolution of 1 meter and covers an area of approximately 4 miles across the top (x direction) by about 4.5 miles on the side (y direction). Each DOQQ was downloaded in either GeoTIF or MrSid format and converted to ERDAS Imagine format for processing.

### **Scanned Aerial Photograph Specifications**

Historical aerial photos of the study area were identified in the archives of these agencies: the U.S. Department of Agriculture's (USDA) Aerial Photography Field Office in Salt Lake City, Utah; the U.S. Army Corps of Engineers' (USACE) New Orleans District Office; and the

NASA/University of Louisiana Lafayette Regional Applications Center (see Table 1 for image date and resolution of each dataset). Each photo was scanned as TIF format and delivered on compact disc (CD) as individual frames along a flight path. Each frame was converted to ERDAS Imagine format, georectified, and projected as indicated previously. The georectified frames were then pieced together as needed to represent the entire study area (or as much of the study area as possible, given the limits of the dataset).

The original image datasets acquired and used in the historical land change analyses for this study are shown in Figures 1-8, with each subset shown to maximum study extent available for image date. It should be noted that the wide range in data quality and image type used in this investigation resulted in the most recent, detailed, and comprehensive inventory of land loss conducted to date for this area. Following these figures is a detailed description of each step in the historical land change analysis process.

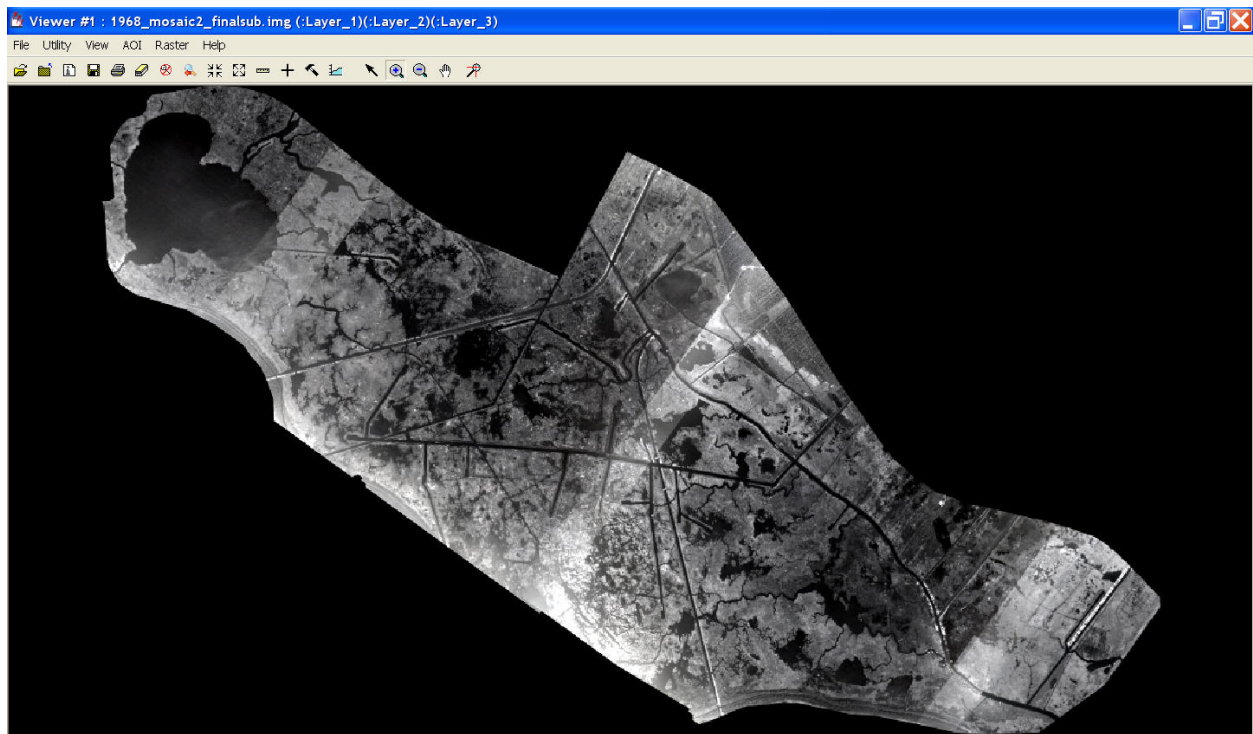


Figure 1. 11/25/1968 aerial photo mosaic of the study area.

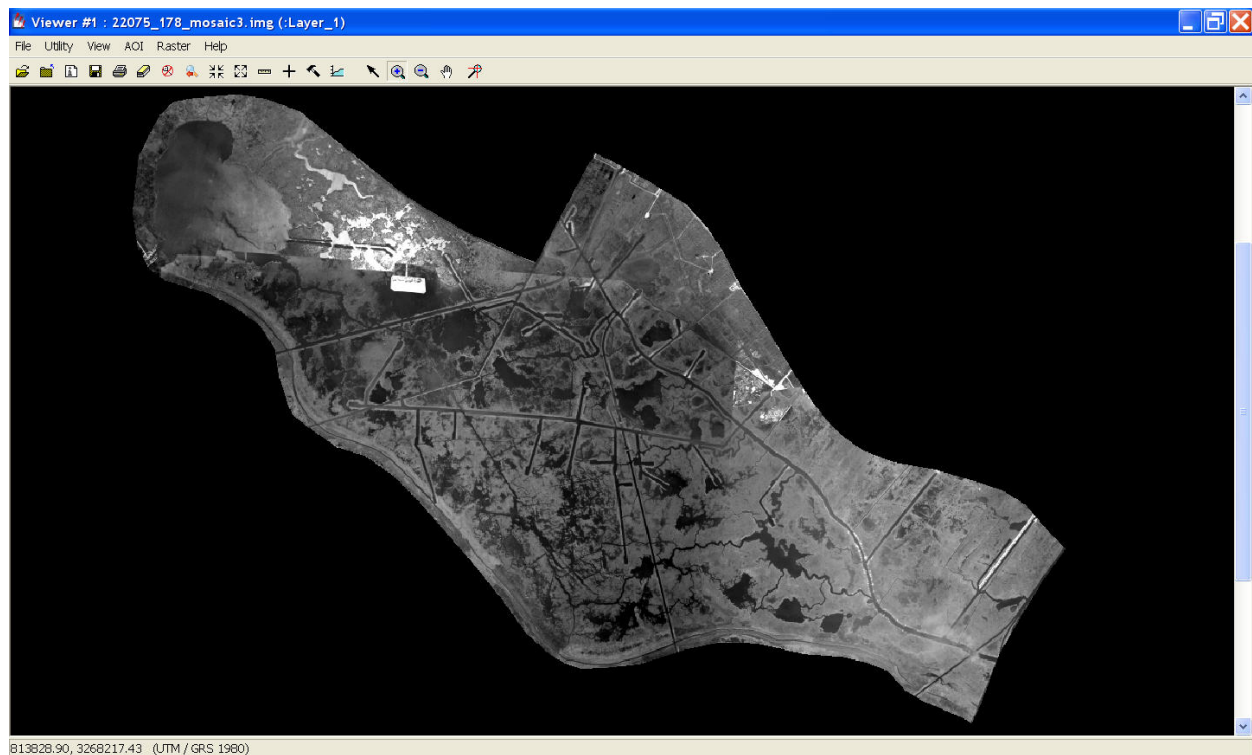


Figure 2. 3/26/1979 aerial photo mosaic of the study area.

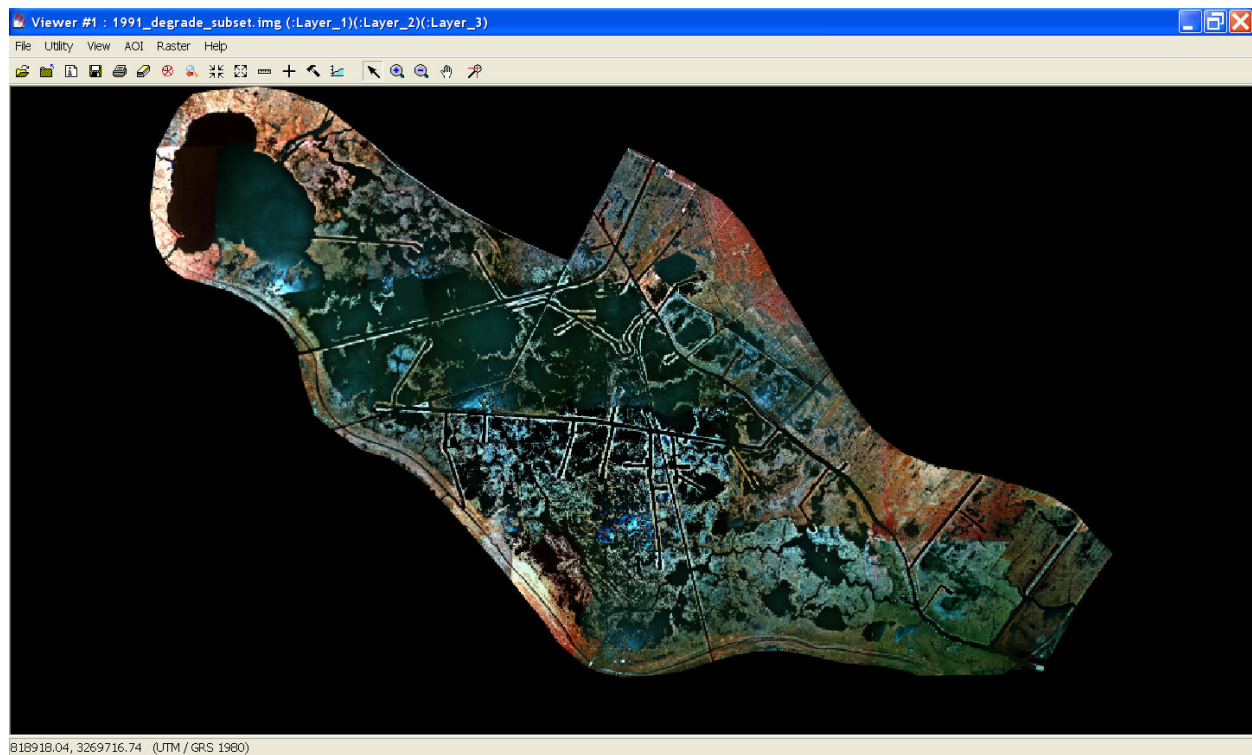


Figure 3. 11/5/1991 DOQQ mosaic of the study area.



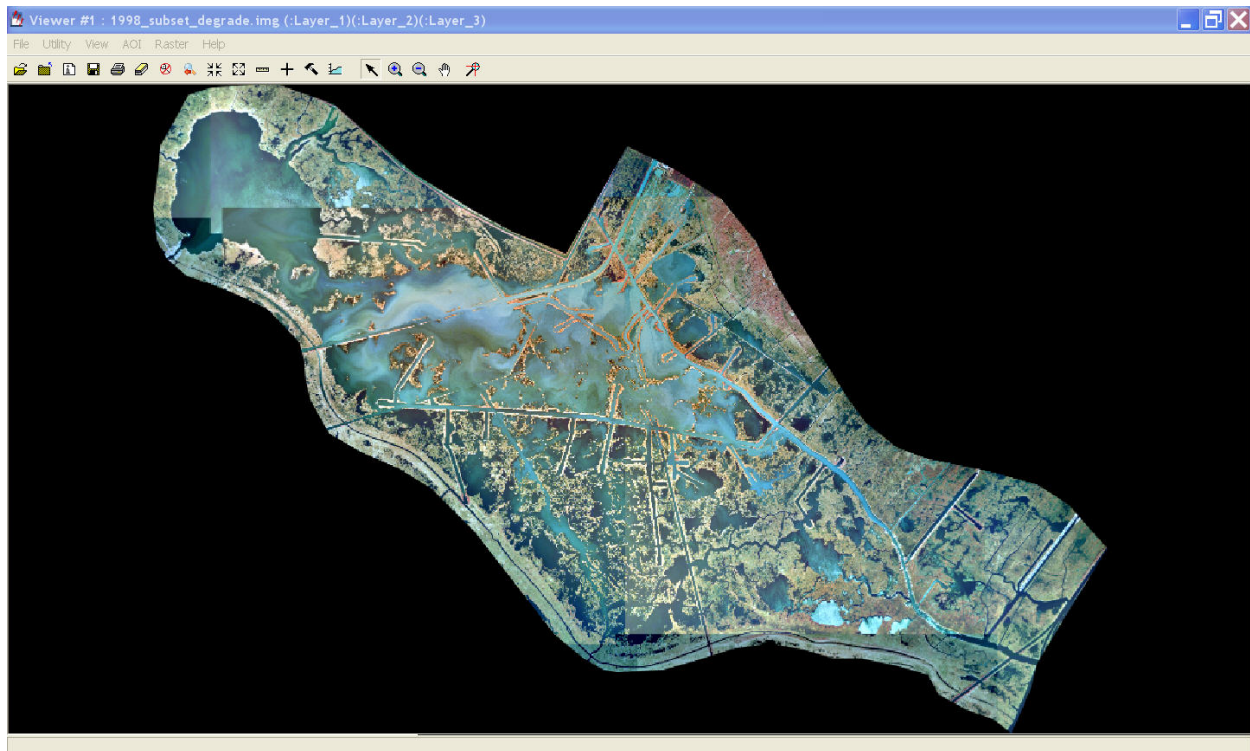


Figure 4. 1/24/1998 DOQQ mosaic of the study area.

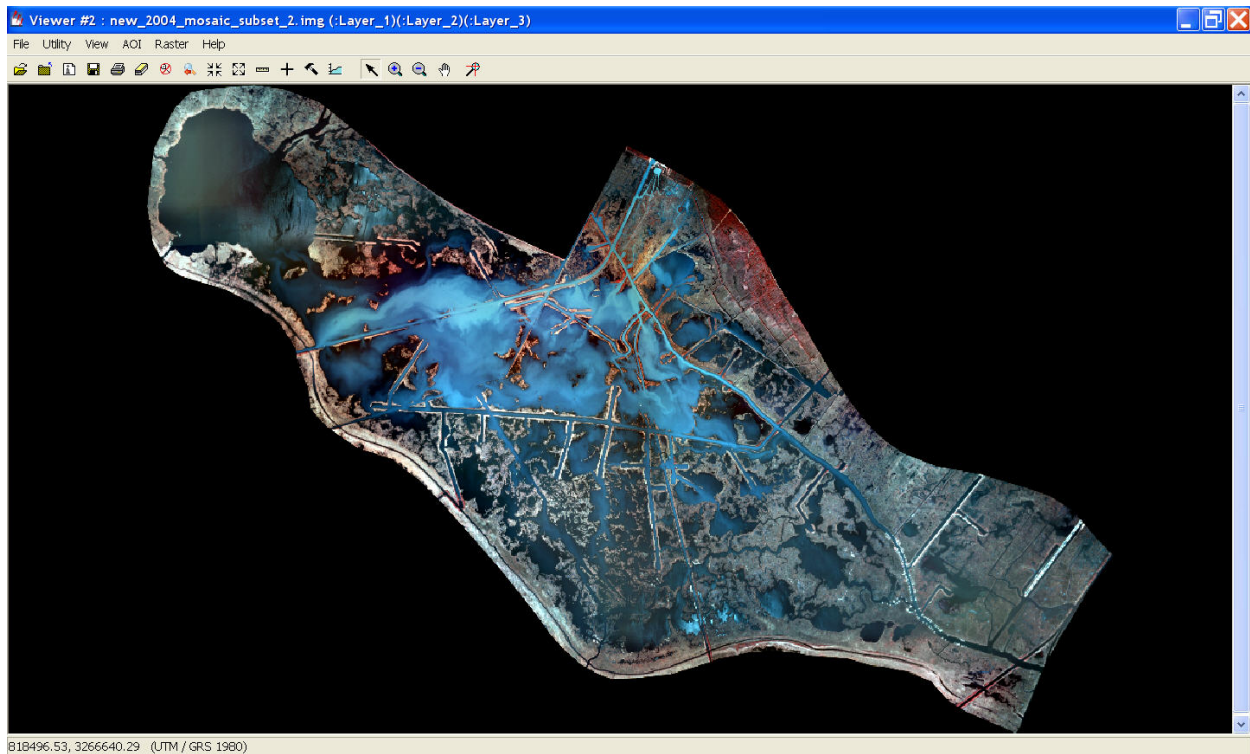


Figure 5. 1/21/2004 DOQQ mosaic of the study area.



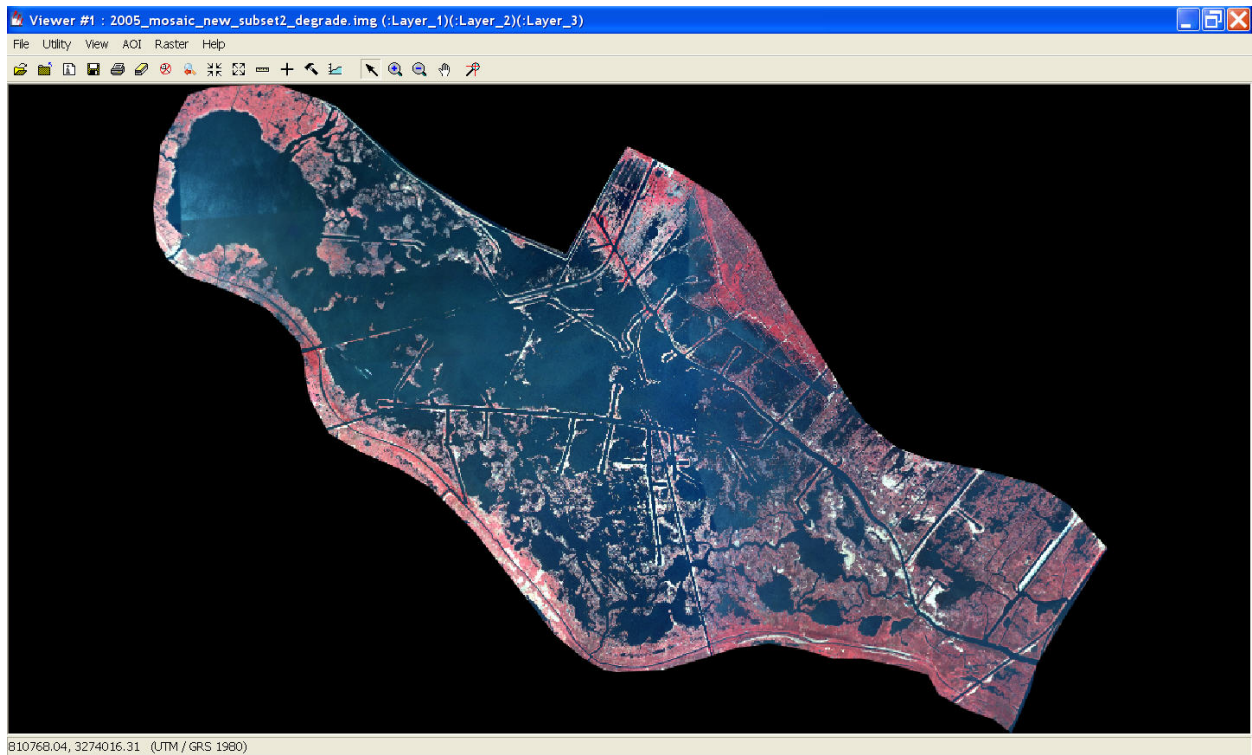


Figure 6. 10/27/2005 DOQQ mosaic of the study area.

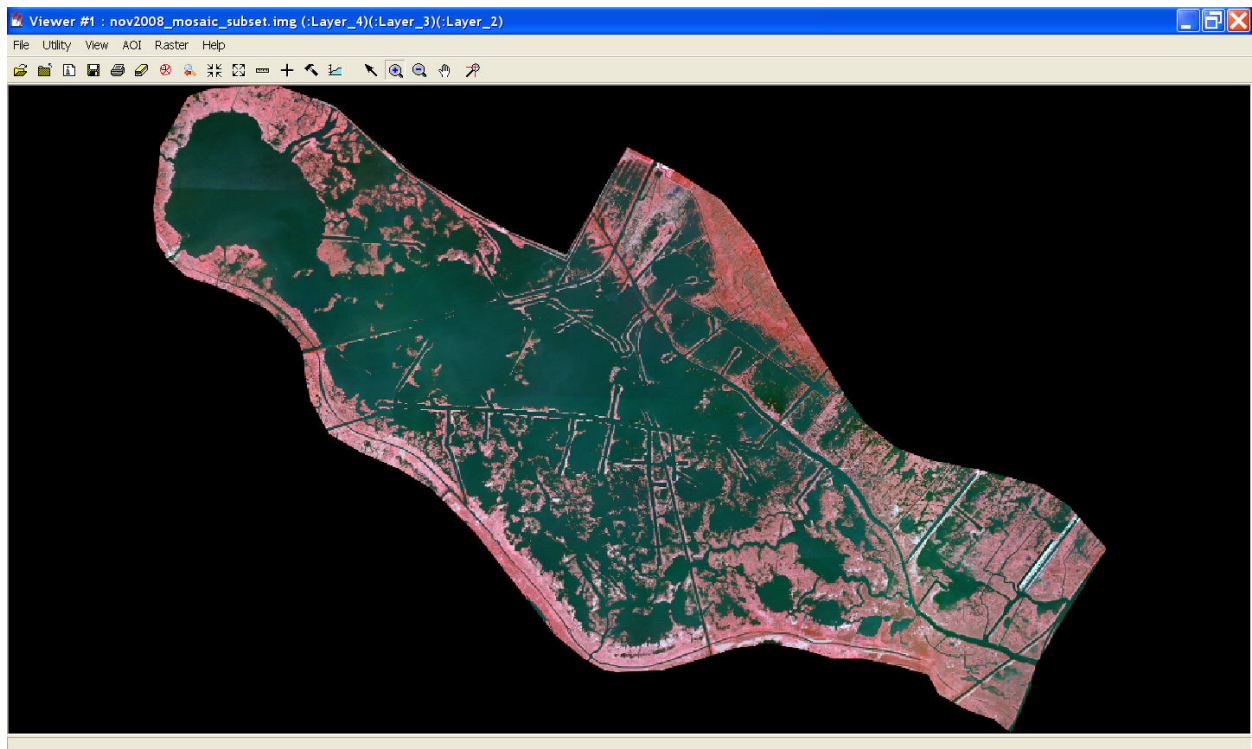


Figure 7. 10/30/2008 DOQQ mosaic of the study area.

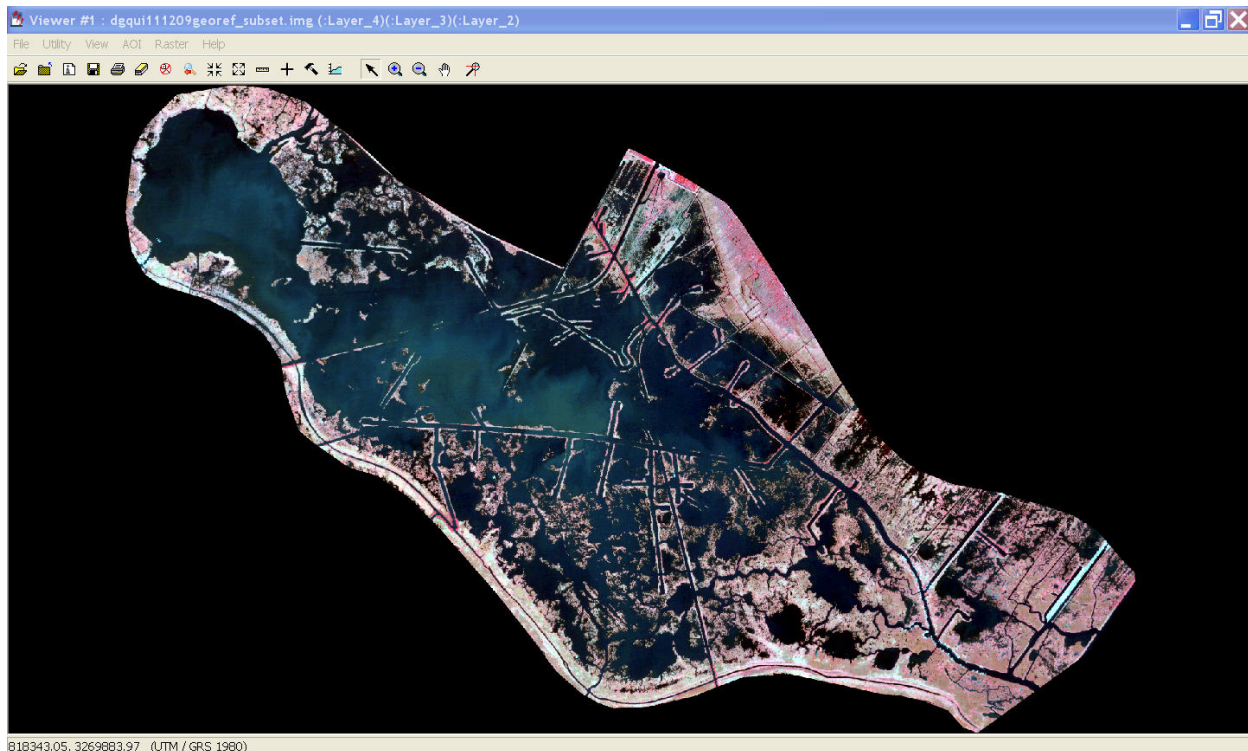


Figure 8. 11/12/2009 DigitalGlobe Quickbird satellite image of the study area.

## **Pre-Classification Image Processing Procedures**

### ***Georectification***

When necessary, images were georectified to the 2005 dataset using a polynomial geometric model with a polynomial order of 1. In each case, a minimum of 15 sets of input and reference points were chosen in the image to image geo-correction, with a resulting RMS error less than 0.5 considered acceptable as the output.

### ***Mosaicking***

Image frames resulting from the scanned aerial photos were mosaicked using an image overlay function with no cutlines. The union of all inputs was specified and the output image was clipped to the study area boundaries.

### ***Reprojection***

When necessary, images were reprojected as follows: UTM GRS 1980 NAD83 South; UTM Zone 15 (Range 96W-90 W); output cell size 2.39 meter by 2.39 meter. The Nearest Neighbor resampling method was used, as was a polynomial approximation with a maximum polynomial order of 3 and a pixel tolerance of 0.100. If the tolerance was exceeded, a continuation of the approximation was specified, rather than a rigorous transformation.

### ***Noise Reduction***

Due to inherent noise resulting from the digitization process of the aerial photos, radiometric enhancement in the form of adaptive filtering noise reduction in ERDAS Imagine 9.3 was applied to the 1968, 1979, and 1995 images prior to classification. This technique preserved the subtle details in the scanned images, while removing noise resulting from the digitization process and manifested by the grainy appearance of features upon close examination.

### ***Image Subsetting***

Where image quality resulted in the same pixel value representing different classes in different areas of an image, subsetting was used during or prior to classification. This technique involved dividing an image into segments based upon unique spectral characteristics apparent in each segment. Common reasons to subset an image prior to classification included: isolating areas of sun glint; accounting for image vignetting; and dealing with the effects of brightness differences along mosaic seamlines. Subsetting was necessary to isolate such problematic areas in the 1968, 1979, 1991, and the 2004 images.

### ***Masking***

Clouds were masked in the 10/30/2009 image by creating a thematic layer that contained pixel values that were unique to the clouds. These pixels were grouped into a 'cloud' class, and

this class was recoded as zeros in the image attributes which indicated excluded areas. This ‘cloud mask’ file was intersected with the original extent of the 10/30/2009 image to mask out the areas obscured by clouds for subsequent analyses.

### **Land-Water Classification**

All pre-processed image datasets were classified using a standardized methodology developed to accurately discern existing land and water conditions at the time of image acquisition within the study area. The methodology is based on level slicing, supervised, and unsupervised classification techniques combined with recoding the resulting thematic image to identify land and water. “Level slicing is a technique that requires visual examination of each discrete level of spectral data to determine whether the pixels contained within the level should be categorized as water or land” (Barras, 2003). A hybrid classification method consisting of both supervised and unsupervised classification procedures was used to derive binary maps.

#### ***Supervised Classification***

In this process, the image analyst selects pixels that represent patterns or features that can be recognized. The result is a set of training signatures that define clusters of pixels or classes (in this case land or water). The computer then identifies pixels with characteristics similar to those of the training samples selected by the analyst.

In the supervised classification, training clusters were chosen in each image using the 8 neighborhood mode that determines which pixels are considered contiguous (similar values) to the selected pixel. The Spectral Euclidian Distance (the spectral distance from the mean of the seed, or selected pixel) was kept as low as possible with the goal of obtaining representative training clusters consisting of a minimum of 25 pixels and with standard deviations of 3 or less. This convention was maintained whenever possible, although it was at times necessary to accept

higher standard deviation values, depending upon image quality. While a minimum of 10 training signatures were obtained for each class, in some images 50 or more training sites were selected to adequately represent the variations within a class. The probabilities of the signatures were normalized prior to the supervised classification, which was based on a maximum likelihood classifier. A distance file was also created in the process. It was used, along with the resulting supervised classified image, to create a threshold image based on a confidence level of 0.050 and Chi-Square of 9.490. The threshold image results from iteratively identifying land and water threshold values with an image raster attribute table based on the original image dataset as reference. Once these class threshold values are determined, all values are recoded as land, water, or no data. For this analysis, the single-band aerial image files were represented as RGB in Imagine 9.3, with the same pixel value representing each band in the RGB signature (corresponding to image brightness).

### ***Unsupervised Classification***

The Iterative Self-Organizing Data Analysis Technique (ISODATA) was used to perform unsupervised classification. ISODATA is a clustering method that uses a minimum spectral distance formula to form clusters or classes of similar spectra for an image dataset.

In the unsupervised classifications, the clusters were initialized from statistics and the number of classes specified varied between 25 and 75, with fewer classes necessary in images exhibiting clear delineation between land-cover classes (i.e., between land and water).

Maximum iterations were set at 100, with the convergence threshold set at 0.950.

### ***Classification Enhancement***

When necessary, an unsupervised classification image was used to classify remaining unclassified or undetermined pixels in a threshold image. This was accomplished by overlaying

the threshold image on the original image and linking it geographically to an unsupervised classification image. In this way, trial and error and careful examination of the images were used to make the best estimates of appropriate classification of remaining undetermined pixels, and thus enhance classification accuracy. In addition, supervised classification was performed on areas of mixed cluster issues resulting from unsupervised classification to better identify land and water pixels for those problem areas. Also, clusters that were not easily labeled were separated from the rest of the image and then the classification algorithm was applied again to obtain additional clusters (Jensen et al., 1987). Each final classified image was recoded for 3 values: unclassified; land; and water.

#### ***Application of Clump/Eliminate Procedures***

To reduce noise inherent in the data, GIS Analysis Clump procedure was used to identify contiguous groups of pixels. The Clump procedure was applied to the recoded classified images using 4 connected neighbors to identify contiguous areas of class values. A GIS Analysis Eliminate procedure was then applied to eliminate “clumps”, i.e., small island classes (or noise) within larger classes, using 4 contiguous pixels or less as the threshold for defining a clump to be eliminated.

#### **Accuracy Assessment of Land-Water Classifications**

Classification accuracy assessment was performed using an error matrix on each land-water classified image to quantify the reliability of the historical land change analyses of the Grand Bayou project. Quantitative accuracy assessment reflects how well the land and water classes are identified from the source imagery for each date processed and classified. The number of accuracy assessment samples is determined based on the goal of insuring that an “adequate number of samples per map class be gathered so that the assessment is a statistically

valid representation of the accuracy of the map” (Congalton and Green, 2009). Typically, early researchers computed the sampling size based on the binomial distribution of their data; however this approach was not designed to work with an error matrix. The multinomial distribution is recommended for use in determining sample size when an error matrix is used for accuracy assessment (Tortora, 1978). When working with remotely sensed images, however, there is typically a very large number of potential samples (e.g. a Landsat TM scene can have over 300,000 pixels), so the traditional ‘rule of thumb’ to use a 2% or 5% sample for accuracy assessment is not practical. Congalton and Green (2009) suggest using a minimum of 50 samples for each map class for maps less than 1 million acres in size and fewer than 12 classes. This guideline was tested using the multinomial equation and was proven to be a good balance between statistical validity and practicality.

The samples for each map class can be adjusted either on the basis of the relative importance of that class for the goals and objectives of the research project or on the inherent variability within each class. Because it is important to select the samples for the accuracy assessment without bias, random sampling was used.

The sampling scheme recommended by Congalton and Green (2009) and used for this study is stratified random sampling. Stratification of the random sampling has the advantage of ensuring that samples are taken from all classes involved, no matter how small. The sampling sizes for each class can also be stratified to be proportional to the area of each class within an image. As with all sampling schemes, however, there are disadvantages to the stratified random sampling scheme. Disadvantages noted by Congalton and Green are the requirement of prior knowledge about the distribution of map classes so that strata can be developed, and the difficulty of finding enough samples in rare map classes.

An error matrix is an array of values in rows and columns that represent samples assigned to particular classes relative to true ‘reference’ values in a classification. The column of values is assumed to be correct and is called the ‘reference’, and the row values are used to display the ‘map labels’ or classified data generated. In this manner, the corresponding values from each sample are compared to one another (Congalton and Green, 2009). The error matrix was developed to evaluate individual categories within a classification scheme for accuracy.

The statistical properties associated with an error matrix are typically: the Overall Accuracy, which is defined as the ratio of the number of validation pixels that are classified correctly to the total number of validation pixels irrespective of the class (Foody, 2002); the Kappa coefficient, which describes the proportion of correctly classified validation sites after random agreements are removed (Rosenfield and Fitzpatrick-Lins, 1986); the commission errors, which are errors of inclusion; and the omission errors, which are errors of exclusion. “A commission error occurs when an area is included in an incorrect category. An omission error occurs when an area is excluded from the category to which it belongs” (Congalton and Green, 2009). For example, in the land-water classifications produced for this study, an error of commission for the land class might be a shallow inlet that was classified as ‘land’ but is actually ‘water’. That same shallow inlet that was classified as ‘land’ would represent an error of omission for the water class in the error matrix. The overall accuracy level of 85% was adopted as representing the minimum value for acceptable results (Anderson et. al, 1976).

Each land-water classification map was assessed for accuracy based on the creation of 150 stratified random points, with a minimum of 50 points representing each class. The accuracy assessment samples were analyzed using the overall classification accuracy reported, as well as the Kappa statistic, which is a measure of the agreement of the classified map with the



reference data and the chance agreement that is indicated by the row and column totals in an error matrix. Numerous papers have been published recommending this analysis technique (Congalton and Green, 2009). Overall classification accuracy and overall Kappa statistics were computed for each land-cover classification map.

### **Change Analysis**

Changes in land-water distribution between 1968 and 1979, and then for each subsequent date (with the exception of 10/30/09) were detected using post classification pixel by pixel comparisons of the land-water images. This process produced change maps for each pair of land-water images. These change maps identified areas that did not change or that converted to either land or water during the time period covered by the input datasets. Any given pixel in the change map may be classified as: 1) land to land = land (no change); 2) water to water = water (no change); 3) land to water = land loss; 4) water to land = land gain. Based on the resulting matrix of possible changes (or no change) for each pixel in a resulting image, categorical maps depicting and quantifying land, water, land loss, and land gain were created for each land-water image pair.

### **Identification of Transitional Zones**

Examination of the change maps representing different time periods indicated the existence of areas where changes were impermanent and reversible and possibly cyclical. These areas were characterized as transitional zones. Identification of transitional zones was accomplished by comparing successive land-cover change maps. For example, the 1968-1979 change map was compared to the 1979-1991 change map, resulting in a change map showing land, water, actual land loss, actual land gain, and transitional classes. Areas that were classified

as land loss in 1968-1979, but land gain in 1979-1991, were classified as transitional. Likewise, areas that were land gain in 1968-1979 but were classed as land loss in 1979-1991 were also considered transitional, and were thus separated from areas that consistently exhibited land loss or gain throughout the time period analyzed. This method of combining several years of observations as a means of discriminating permanent land loss or gain from transitory loss or gain resulting from episodic events such as hurricanes is consistent with methods used by Barras et al (2008).

Once these transitional areas were identified in the change maps, field investigation was conducted to determine possible causes of these features. The 2005-2008 transitional change map was loaded into a handheld computer equipped with GPS to navigate to several locations where transitional zones were mapped. The results of this investigation indicated that these areas tended to be shallow submerged bare land or marsh vegetation that would be emergent during low tidal conditions, and thus would be highly influenced by meteorological (such as wind setup/set down effects) and tidal conditions at the time of image acquisition.

## **RESULTS**

The water to land ratio was calculated for each land-water classification date. The results show that the proportion of land to water in the study area consistently decreased from 1968 (when there was 2.62 times more land than water) to 2009. The results are as follows (in proportion of total land to total water in the study area): 2.62 in 1968; 1.57 in 1979; 0.79 in 1991; 0.71 in 1998; 0.65 in 2004; 0.61 in 2005; and 0.48 in 2009.

## Accuracy Assessment of Land-Water Classifications

Accuracy of the land-water classifications was limited by areas of irremovable cloud cover and sun glint in some images, as well as by image interpretation difficulties experienced by the researcher. If overall classification accuracy for an image was less than 85%, image processing techniques, such as subsetting and selection of additional training samples for subsequent reclassification of problem areas, were implemented. Accuracy assessment was then performed on the revised land-water classification to determine any improvement. This process was repeated, when necessary, until overall classification accuracy above 85% and a Kappa statistic greater than 0.60 were achieved. Kappa values above 0.60 indicate substantial agreement between the image classification and reference dataset, as indicated in Table 2 (Landis and Koch, 1977). Overall classification accuracy and all Kappa statistics computed for each final land-water map are reported in Table 3.

Table 2. Table given by Landis and Koch (1977) for interpretation of Kappa values.

$\kappa$	Interpretation
$< 0$	No agreement
0.0 — 0.20	Slight agreement
0.21 — 0.40	Fair agreement
0.41 — 0.60	Moderate agreement
0.61 — 0.80	Substantial agreement
0.81 — 1.00	Almost perfect agreement

Table 3. Image Classification Accuracy Assessment Results.

Image Date	Image Type	Classification Type	Overall Classification Accuracy	Overall Kappa Statistics
11/25/1968	BW scanned aerial photography	Land/Water	93.33%	0.8454
03/26/1979	CIR scanned aerial photography	Land/Water	91.33%	0.8083
11/05/1991	DOQQs	Land/Water	90.00%	0.7985
01/24/1995	CIR scanned aerial photography	Land/Water	92.67%	0.8526
01/24/1998	DOQQs	Land/Water	92.67%	0.8540
01/21/2004	DOQQs	Land/Water	91.33%	0.8209
10/27/2005	DOQQs	Land/Water	91.33%	0.8199
10/27/2005	DOQQs	Debris/Non-debris	96.00%	0.8933
10/30/2008	DOQQs	Land/Water	95.33%	0.9031
10/30/2009	DG Quickbird satellite imagery	Vegetation/Non-veg	92.67%	0.8374
11/12/2009	DG Quickbird satellite imagery	Land/Water	98.00%	0.9564

## Results of Change Analysis

Six final change maps were produced that include the transitional area class, as well as actual land loss and actual land gain classes. For each of these maps, the total area in hectares (and acres) was calculated for each class. Net land loss and the average land loss per year were then calculated for each time period represented. The results for each composite map are shown in Table 4 below and in Figures 9-14 following. Figure 15, also following, depicts actual land loss by time period.

Table 4: Land Loss by Time Periods and Hurricanes that passed within 65 miles of study area.

Time Period	Actual Land Loss	Actual Land Gain	Hurricane Event	Net Land Loss	Average Land Loss Per Year
11/25/1968 – 03/26/1979 (~10yr 4m)	711 ha (1758 ac)	148 ha (367 ac)	Camille	563 ha (1391 ac)	69 ha (170 ac)
03/26/1979 – 11/05/1991 (~12yr 7 m)	1042 ha (2574 ac)	148 ha (367 ac)	Bob, Florence	894 ha (2208 ac)	83 ha (205 ac)
11/05/1991 – 01/24/1998 (~6yr 3m)	392 ha (969 ac)	243 ha (600 ac)	Danny	149 ha (369 ac)	63 ha (155 ac)
01/24/1998 – 01/21/2004 (~6 yr)	288 ha (711 ac)	167 ha (413 ac)	Georges	121 ha (298 ac)	48 ha (119 ac)
01/24/2004 – 10/27/2005 (~1yr 9 m)	343 ha (848 ac)	199 ha (491 ac)	Ivan, Cindy, Katrina	144 ha (357 ac)	196 ha (484 ac)
10/27/2005 – 11/12/2009 (~ 4yr)	397 ha (980 ac)	62 ha (154 ac)	Gustav	335 ha (826 ac)	99 ha (245 ac)

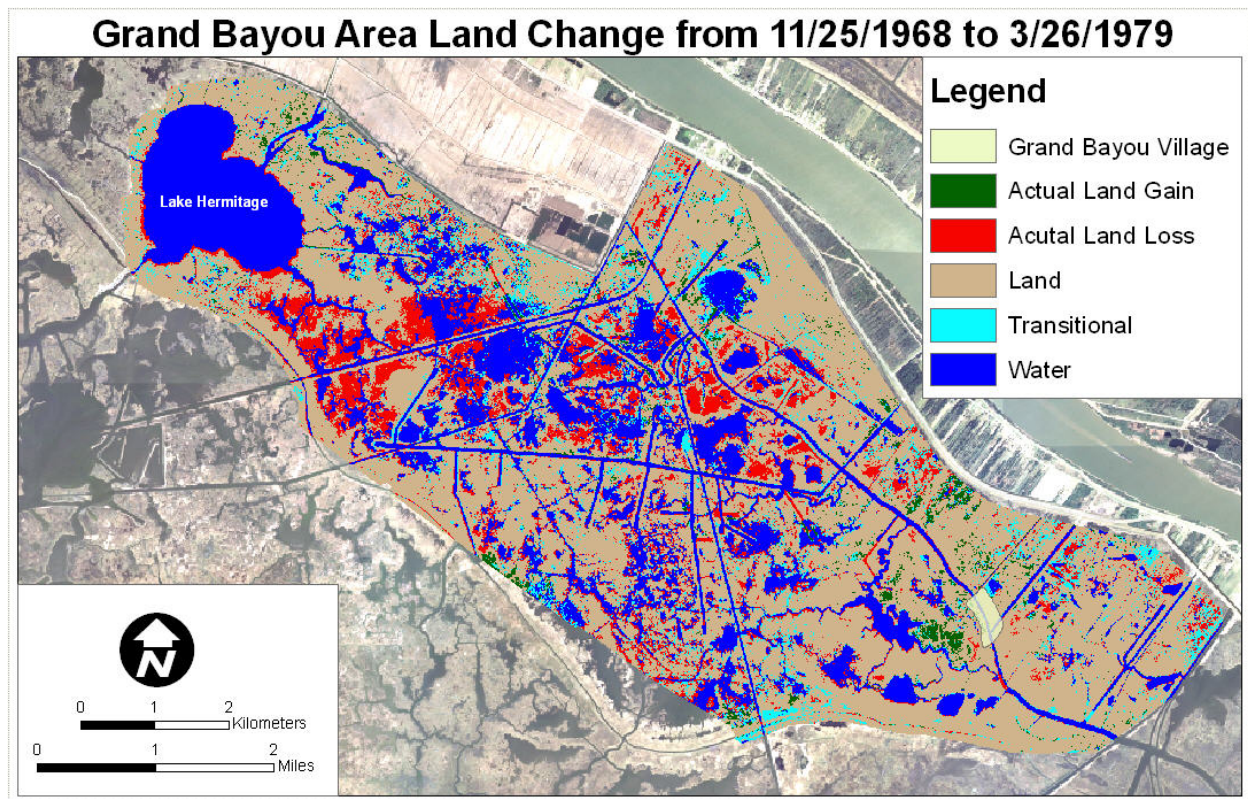


Figure 9. 11/25/1968 to 3/26/1979 land change analysis map.



For the approximately 10 year, 4 month period from 11/25/1968 to 03/26/1969, net land loss totaled 563 ha (1391 ac), averaging 69 ha (170 ac) per year. Land loss was concentrated in core marsh areas near cut canals and near new canals built during this time. Erosion of edges of some lakes contributed significantly to the loss as well, most notably along the western and southern edges of Lake Hermitage. Transitional areas accounted for 7% of the total area.

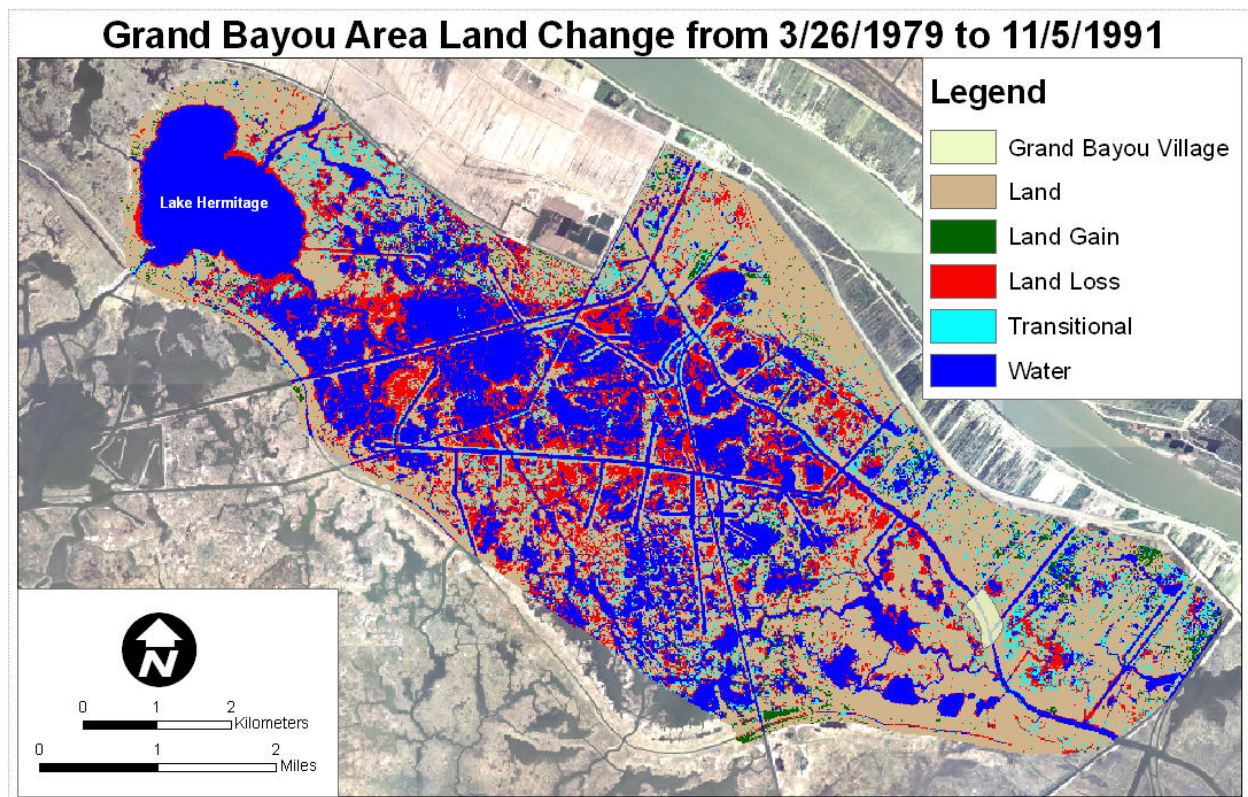


Figure 10. 3/26/1979 to 11/5/1991 land change analysis map.

For the approximately 12 year, 7 month period from 03/26/1979 to 11/05/1991, net land loss totaled 894 ha (2208 ac), averaging 83 ha (205 ac) per year. Average yearly land loss increased during this time period. With the exception of the later periods characterized by significant storm activity (i.e., hurricanes Katrina, Rita, and Gustav), this period represents the most widespread land loss observed. Significant land loss occurred in previously fragmented

areas, at the edges of lakes and ponds (most evident around Lake Hermitage), near canals, and in areas adjacent to previous land loss. Transitional areas accounted for 7% of the total area.

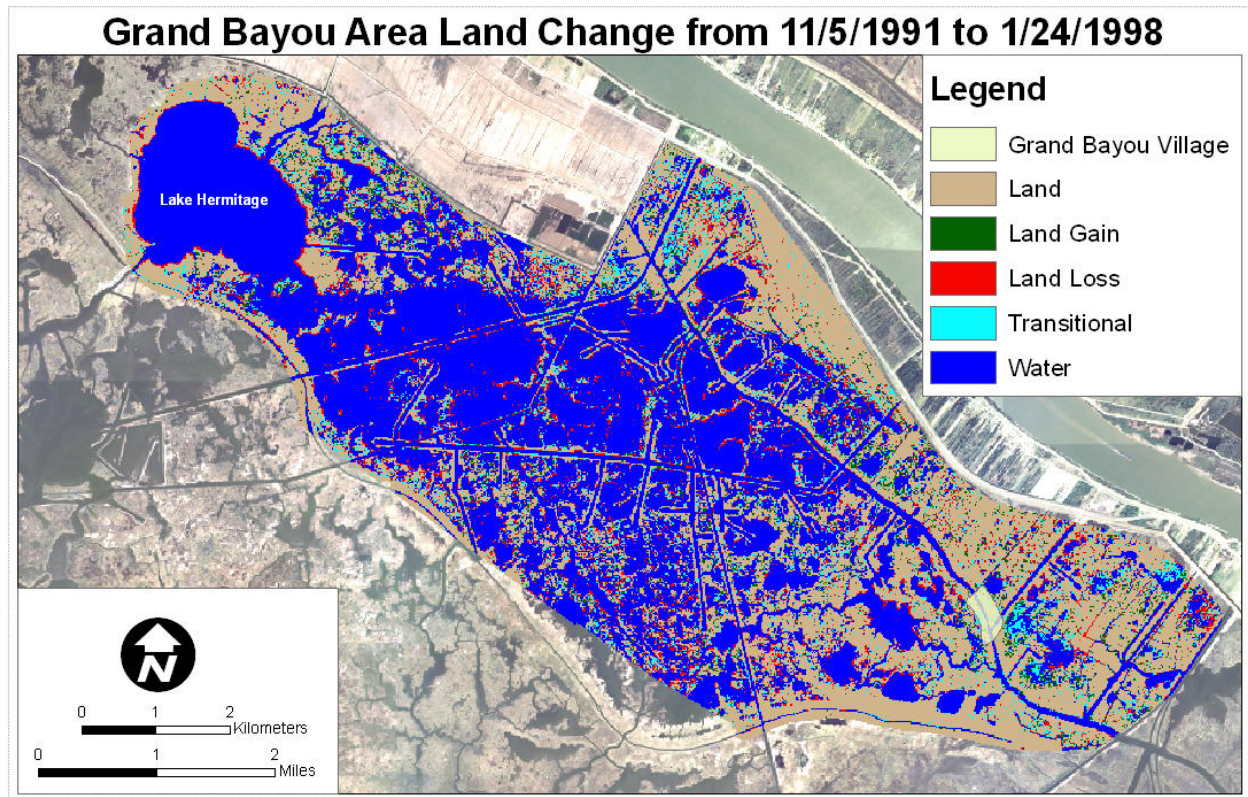


Figure 11. 11/5/1991 to 1/24/1998 land change analysis map.

For the approximately 6 year, 3 month period from 11/05/1991 to 01/24/1998, net land loss totaled 149 ha (369 ac), averaging 63 ha (155 ac) per year. This period is characterized by a dramatic decline in land loss compared with the average yearly land loss observed during the previous (1979 to 1991) time period. Land loss is evident in the continued erosion of lake edges and is concentrated in patchy marsh areas which survived the extensive land loss of the previous period. Transitional areas accounted for 5% of the total area.



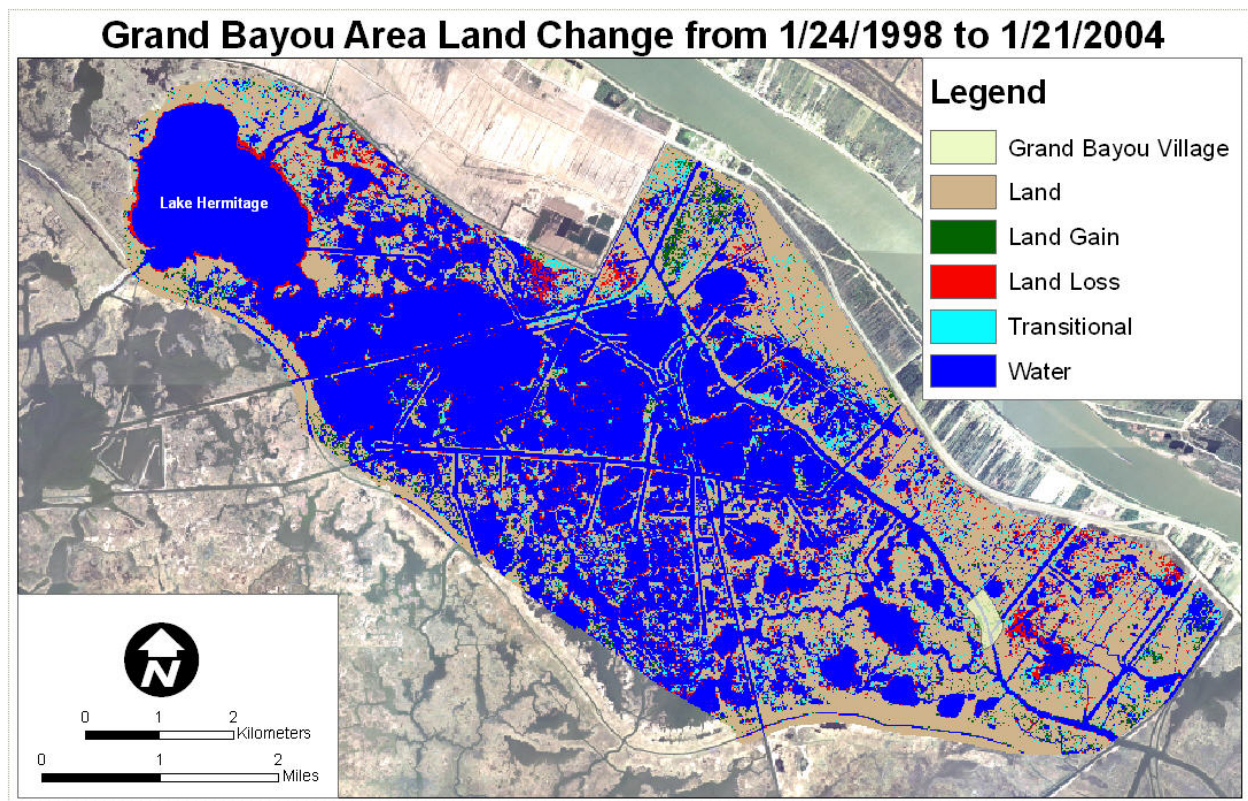


Figure 12. 1/24/1998 to 1/21/2004 land change analysis map.

For the approximately 6 year period from 01/24/1998 to 01/21/2004, net land loss totaled 121 ha (298 ac), averaging 48 ha (119 ac) per year. Land loss again declined during this period but continued around the edges of Lake Hermitage, as well as in patchy marsh areas on the fringe of previous land loss. Land loss ‘hotspots’ are clustered in the east near Grand Bayou Village. ‘Hotspot’ clusters are also evident in the north along a back levee which protects farmland and Highway 23 from storm surges. Transitional areas accounted for 4% of the total area.



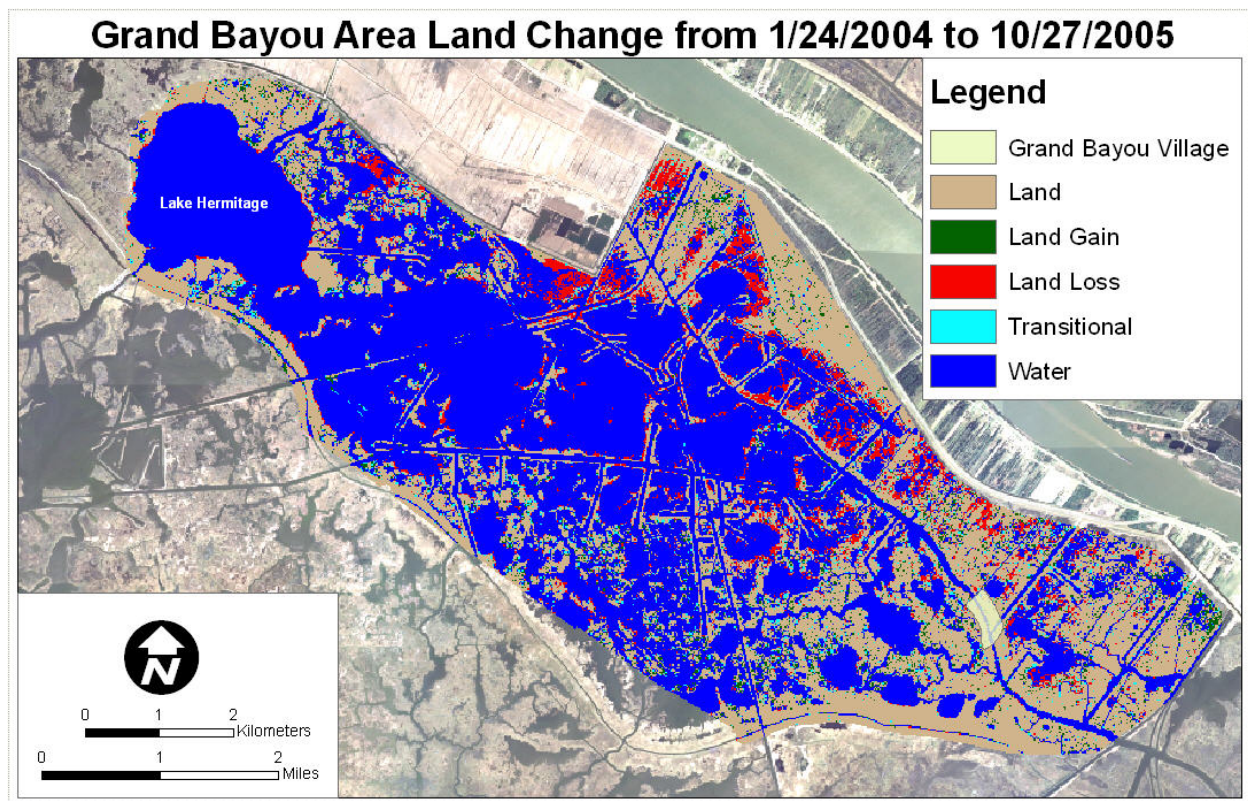


Figure 13. 1/21/2004 to 10/27/2005 land change analysis map.

For the approximately 1 year, 9 month period from 01/21/2004 to 10/27/2005, net land loss totaled 144 ha (357 ac), averaging 196 ha (484 ac) per year. Extensive land loss occurred as a result of hurricanes Ivan, Cindy, Katrina, and Rita which affected the area during this short time period. Most losses occurred in the northern and eastern parts of the study area. Land loss trends affecting patchy marsh areas which were noted during previous time periods (i.e., 1991 to 1998 and 1998 to 2004) continued during this period, but on a much larger scale. In contrast, relatively minor land loss was observed around the edges of Lake Hermitage, suggesting that the land loss noted there during this period is not the result of severe storm events, but is due rather to ongoing long-term natural erosion processes. Transitional areas accounted for 2% of the total area.

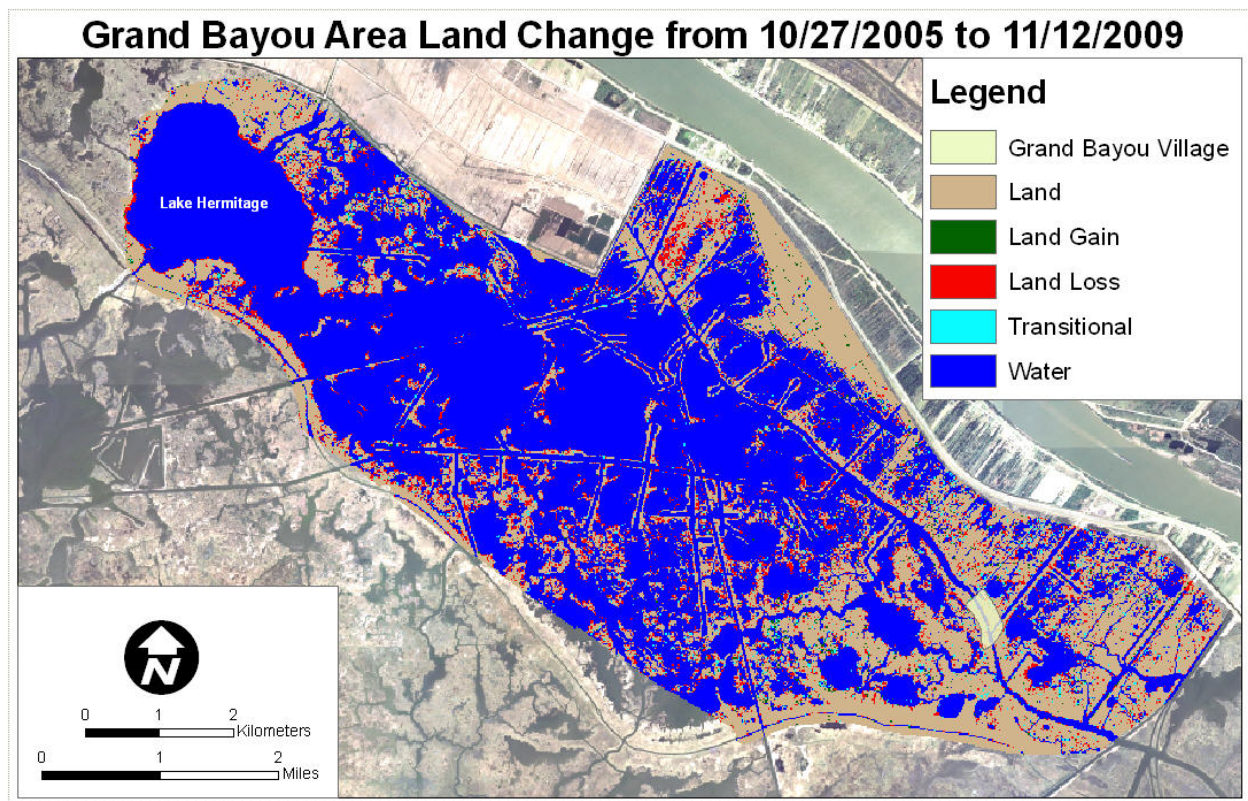


Figure 14. 10/27/2005 to 11/12/2009 land change analysis map.

For the approximately 4 year period from 10/27/2005 to 11/12/2009, net land loss totaled 335 ha (826 ac), averaging 99 ha (245 ac) per year. The yearly rate of land loss for this time period declined dramatically from the previous (2004 to 2005) time period. However, the rate remained well above pre-Katrina/Rita levels, likely due to the impact of hurricane Gustav. During this period, land loss was concentrated in the northern part of the study area around the siphon, as well as throughout the fragmented marsh areas in the south. Transitional areas accounted for 2% of the total area.



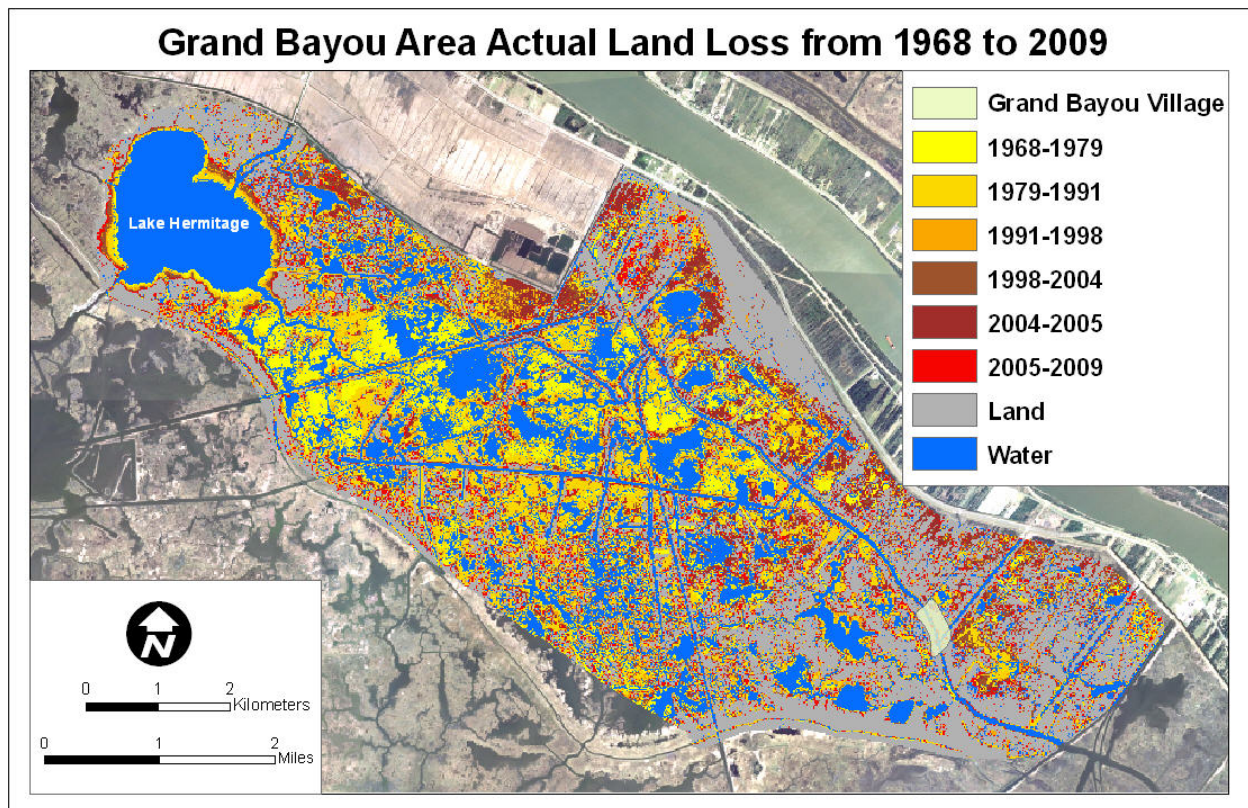


Figure 15. Actual Land Loss from 11/25/1968 to 11/12/2009 by time period.

In this study, land loss which persists over time and appears permanent and irreversible is classified as actual land loss. Figure 15 depicts actual land loss by time period. Land loss was first concentrated along the edges of lakes and in core marsh areas near cut canals. Over time, land loss gradually spread outward from the core areas towards the perimeter of the study area. Earlier land loss generally occurred primarily in areas adjacent to previous land loss and generally in relatively close proximity to cut canals. More recent land loss continues this trend, but is also evident in previously uninterrupted stretches of marsh, as for example, in the southeastern and northwestern portions of the study area. The greatest concentrations of recent land loss are evident in the north central portion of the study area near the siphon, and continuing both to the east, near a forced drainage system levee, and west in the vicinity of Lake Hermitage.

## DISCUSSION

The land loss analysis method reported by Barras et al. (2003) for which this study was based on, uses edge enhancing and level slicing of Landsat band 5 to identify land and water on a per scene basis. The method used in this study differs from Barras' method in that it is a hybrid classification approach that utilizes a combination of supervised and unsupervised classification techniques using multiple band image datasets, as well as a level slicing technique similar to that used by Barras et al. (2003). This hybrid approach was necessary to obtain accurate, comparable land-water classifications using remotely sensed images with varying quality from different sources. Given these different land loss analysis approaches, the pattern of land change indicated by the land change analysis in this study is generally consistent with the overall Barataria Bay area land change pattern determined by Barras et al., (2003) and Boshart and Cook (2004). This study found a decrease in the rate of land loss during the time period 1991 to 1998, as compared with the period 1979 to 1991. This is consistent with the Barras et al (2003) report that the land loss rate in the LCA Subprovince, which includes this study area, decreased significantly from 1990 to 2000 in relation to the historical land loss rates from 1978 to 1990. Similar conclusions were reported in the *2004 Operations, Maintenance, and Monitoring Report for West Pointe a la Hache Siphon Construction* (Boshart and Cook, 2004) in that "aerial photography analysis indicated that land loss still occurred in the project area [same extent as this study area] from the period 1991 through 1999", however "this land loss decreased in relation to historical loss rates". Furthermore the dramatic increase in land loss rates observed in this study resulting from the impacts of hurricanes Katrina and Rita are also noted by Barras et al., (2008) and Barras (2007). Barras (2007) concludes that "the combined impacts of Katrina and Rita on land area changes

(identified by using Landsat TM imagery from 1983 to the present) exceeded impacts from other hurricanes in coastal Louisiana (including Andrew)". Similarly, this study found that during the 2004 to 2005 time period of less than 1 year (pre to post-hurricanes Katrina and Rita), the average land loss rate exceeded all other previous time periods combined!

Of great interest is the magnitude of land loss observed in this study and occurring as a result of Hurricanes Ivan, Cindy, Katrina, and Rita (2004 to 2005 time period). It is doubtful that this extensive land loss was caused by events other than these powerful storms, which were characterized by record storm surges and winds. Barras (2007) estimated that the two storms created 46.6 km<sup>2</sup> of new water areas in the Barataria Basin. Furthermore, the National Wetlands Research Center detected significant erosion (possibly caused by Katrina's winds) in central Barataria Basin (Barras, 2007). The extensive folding of marsh substrate along Katrina's track, east of the study area, contributed to the erosion (Cahoon, 2006). The exceptionally high level of land loss clearly indicates the severity of hurricane Katrina.

The results of this study indicate that the rate of land loss remained relatively high from 2005 to 2009 in relation to land loss rates observed prior to 2005. The higher rate is likely the result of drastic marsh fragmentation that occurred with the 2005 hurricane season. Marsh areas that survived the impacts of the 2004-2005 storms were degraded so that natural erosion processes were likely more effective at removing sediment, thus contributing to greater than normal land loss.

Prior to 2005, the highest rate of land loss observed in this study occurred during the 1979 to 1991 time period (an average of 83 hectares per year). Moreover, the decrease in the total land to water ratio in the study area was greatest during this time (1968 to 1991). This trend of rapidly decreasing land to water proportions generally slowed after 1991 to present.

Hurricane Andrew (a category 5 storm in 1992 which passed just west of the study area) did not affect land loss rates to the extent that the 2004-2005 hurricanes did. However, Andrew may account for the higher rate of land loss from 1991 to 1998 than was observed in the time period from 1998 to 2004 when there was a lack of major storms affecting the area. As Andrew moved inland, it brought a 2 to 6 meter storm surge with it, inundating marshes in Plaquemines Parish with saltwater. Moreover, marsh substrate was scoured and “marsh balls” or spherical clumps of marsh were formed (Penland et al., 1999). These land loss trends are evident in the graph of proportion of total land area to total water area over time (Figure 16), and the graph of land loss in the study area over time (Figure 17).

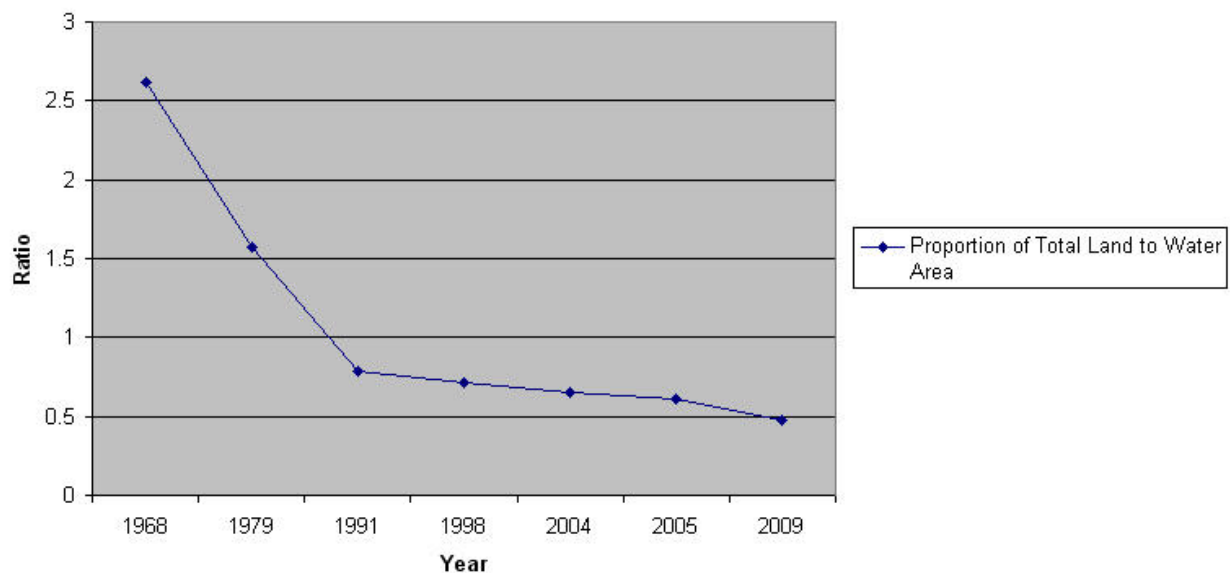


Figure 16. Graph of Proportion of Total Land to Water Area by time period.

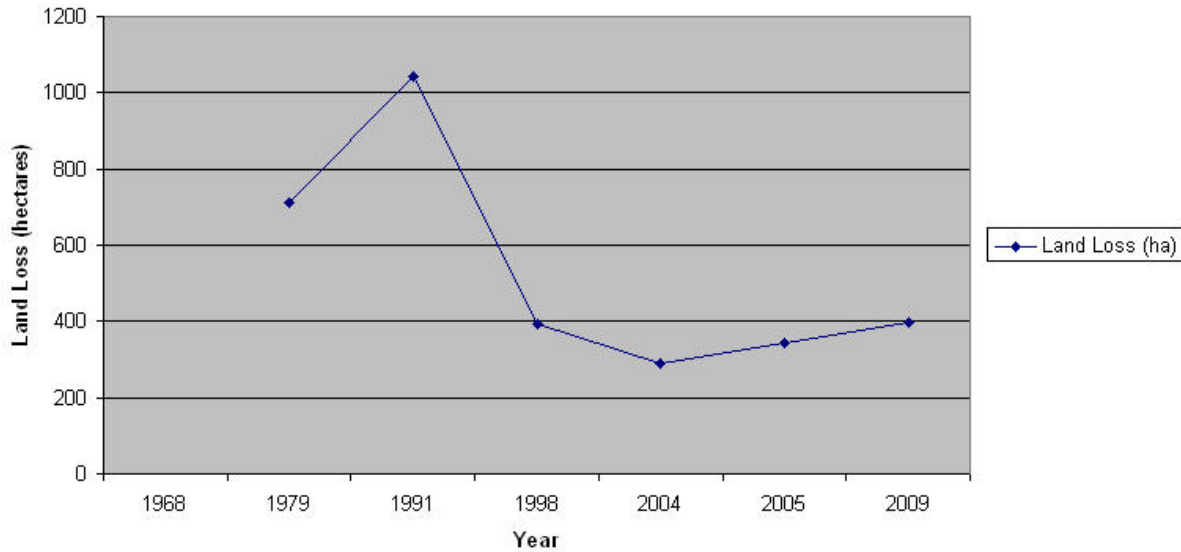


Figure 17. Graph of Land Loss in hectares by time period.

While the results of this study are generally consistent with previous studies, there are some notable inconsistencies. Barras et al. (2008) reports a “significant decrease in rates of land loss after 1978” for the Deltaic Plain, whereas the results of this study show a significant increase in rates of land loss from 1979 to 1991. Furthermore, Britsch and Dunbar (1993) also indicate a general trend of decreasing land loss in Louisiana’s Coastal Plain after 1978, at rates even greater than those reported in Barras et al. (2008). These conflicting results may be explained by the different scales at which the land loss rates are reported. Barras et al. (2008) and Britsch and Dunbar (1993) are reporting average land loss rates across a region that encompasses the central and southeastern portions of coastal Louisiana, which includes the study area. Areas outside of the study area included in calculating average land loss rates across the Deltaic Plain may have experienced the most land loss prior to 1978 and subsequently significantly influenced the averaged results for the region. This may very well be the case with areas included in the region that are closer to the open water of the Gulf, and therefore more

exposed at earlier time periods to storm surges and effects of wave action that cause land loss than was the Grand Bayou study area. Other factors could have contributed to differences in the land loss rates reported on a regional scale by Barras et al. (2008) and the results of this study such as the timeframe in which the areas across this region were developed for oil and gas exploration, and other anthropogenic activities that result in accelerated land loss rates.

In fact, Britsch and Dunbar (1993) cite a previous study (May and Britsch, 1987) that mapped land loss and accretion throughout the deltaic plain for the 1930's to 1983, which "illustrates that land loss is not evenly distributed throughout the coast; rather, it is concentrated in specific areas". Moreover Britsch and Dunbar (1993) report land loss rates for areas defined by each USGS 15-minute topographic quadrangle map representing a part of their study area along coastal Louisiana, as well as averaged for the entire coastal plain. Looking at the land loss rate trends by quadrangle map, it is apparent that land loss rates vary significantly throughout coastal Louisiana. Britsch and Dunbar (1993) conclude that "in general, this variability reflects differences in the geologic setting of individual quadrangles and differences in the factors contributing to land loss". The land loss rate trends according to quadrangle maps associated with the Grand Bayou study area (i.e., Fort Livingston, Pointe a la Hache, and Empire) show that the area restricted to the vicinity of and including Grand Bayou experienced relatively higher land loss rates from 1974 to 1983 than in the 1954 to 1974 time period (Britsch and Dunbar, 1993). However, when averaged across the whole study area, Britsch and Dunbar (1993) conclude that land loss rates peaked in 1974, and declined through 1990.

Direct comparisons of land loss rates observed in this study with the results obtained by Barras et. al. (2008) are further complicated by differences in the spatial scale of the image datasets used in the analyses. The minimum detectable spatial resolution of the Landsat TM



imagery used by Barras et al. (2008) to calculate land changes is 30 meters. Therefore, “to accurately detect shoreline erosion...the erosion must be in excess of 50 to 60 meters between the two dates at which the images are acquired” (Barras et al. 2003). The significantly higher resolution (2.39 meters) used to calculate land change for this study may have identified significant areas of land loss within the study area that were not detectable with the coarser resolution datasets used by Barras et al. (2008). Still, general trends would be expected to be comparable if results were reported specifically for the Grand Bayou area.

## **CONCLUSIONS**

1. Land loss continued through all time periods observed. The average land loss per year increased dramatically for the time period 1979 to 1991, as compared with 1968 to 1979, and then decreased during the time period 1991 to 1998, a trend which continued during the 1998 to 2004 period. Average land loss per year increased more than 400% during the time period 2004 to 2005 as compared to the immediately preceding time period, due to the enormous impacts of Hurricanes Cindy and Katrina in particular, as well as Ivan and Rita (though Ivan and Rita by-passed the study area much farther to the east and south respectively). While land loss declined following these storm events, it remained high during the time period 2005 to 2009, exceeding the average rate of land loss during each of the other periods except 2004 to 2005. This continuation of the relatively high rate of land loss can be attributed to the ongoing impact of hurricane Katrina which uprooted vegetation and formed areas of broken marsh. The new inlets and expanded waterways allowed saltwater intrusion and tidal action to reach inland, which created a stressful habitat for the freshwater vegetation. The lack of

vegetation cover further contributed to wetland loss by facilitating erosion (Weller, 1994). Thus, weaker marsh areas eroded more easily with regular tidal action or occasional tropical storm activity. As an example, in 2008, hurricane Gustav (a minimal category 2 hurricane) affected the area and contributed to land loss observed in the 2005 to 2009 change map. The 2008 satellite imagery was acquired before Gustav occurred, and analysis of the 2005 to 2008 land loss indicates a much lower level of land loss in the study area prior to that storm event (an average of 67 hectares per year lost).

Prior to the anomalous spike in land loss rates as a result of the 2005 storm season, average land loss rates in the Grand Bayou study area were highest from 1979 to 1991. Rates of land loss dropped dramatically after 1991 and remained relatively stable through 2004. Interestingly, this timeframe of relatively low land loss rates corresponds to a period of relatively few significant storm impacts to the area. Only hurricanes Danny (category 1) and Georges (category 2) came within 65 miles of the study area during this 12 year span. These land loss results and correlation with historical episodic storm events show that the frequency and intensity of hurricane impacts to the area, or the lack thereof, significantly influence land loss rates. Following the 2005 storms, the land loss rates dropped, but remained relatively high indicating that the extensive marsh degradation caused by Katrina, in particular, to the area may have pushed remaining marsh areas past a ‘tipping point’ in which minor storms and natural erosion processes cause losses that would have previously not resulted in significant land loss.

2. The pattern of land loss over the entire time period studied shows early land loss to be widespread around the edges of lakes, ponds, and man-made canals, as well as significant

interior core areas of previous land. These areas tend to be more concentrated near areas of man-made canals. Over time these once intact core areas fragment and continue to decline until converted completely to open water, leaving only narrow strips of land which are the spoil banks of the man-made canals (which were built up to higher elevation than the surrounding marsh). Periodic hurricane events are indicated by sheared ponds, fragmented areas that were once solid marsh, and the deposits of wrack material (marsh vegetation, soil, and debris) on the fringes of ponds and lakes.

3. There are small areas of land gain throughout the timeframe studied. This land gain is most likely due to sediment reworking during storm events and the deposits of the wrack material as previously mentioned which fill up small ponds and previously shallow submerged areas. As noted earlier, there are also errors with land-water classifications, resulting from sun glint and image data quality issues, which likely contribute to some misclassification of land gain. These results are consistent with land loss observations made by Barras et al. (2003) for areas in Lower Plaquemines Parish.

## REFERENCES

- Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witner. 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. *USGS Professional Paper 964*. 28 pp.
- Barras, J. A., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota, and J. Suhayda. 2003. Historical and projected coastal Louisiana land changes: 1978-2050. *U.S. Geological Survey Open-File Report 03-334*, 39 p.
- Barras, J. A. 2007. Land area changes in coastal Louisiana after Hurricanes Katrina and Rita, in Farris, G. S., Smith, G. J., Crane, M. P., Demas, C. R., Robbins, L. L., and Lavoie, D. L., eds., *Science and the storms: the USGS response to the hurricanes of 2005*: U. S. Geological Survey Circular 1306, p. 98-113, <http://pubs.usgs.gov/circ/1306/pdf/c1306>
- Barras, J. A., J. C. Bernier, and R. A. Morton. 2008. Land area change in coastal Louisiana-A multidecadal perspective (from 1956 to 2006): U. S. Geological Survey Scientific Investigations Map 3019, scale 1:250,000, 14 p. pamphlet
- Bernier, J. C., R. A. Morton, and J. A. Barras. 2006. Constraining Rates and Trends of Historical Wetland Loss, Mississippi River Delta Plain, South-Central Louisiana, in *Coastal Environment and Water Quality*, Water Resources Publications, LLC, Highlands Ranch, CO, p. 371-382.
- Boshart, W. M. and V. Cook 2004. *2004 Operations, Maintenance, and Monitoring Report for West Pointe a la Hache Siphon Construction (BA-04)*, Louisiana Department of Natural Resources, Coastal Restoration Division, New Orleans, Louisiana. 18pp.
- Braud, D. H., and W. Feng. 1998. Semi-automated construction of the Louisiana coastline digital land/water boundary using landsat thematic mapper satellite imagery. Department of Geography and Anthropology, Louisiana State University. Louisiana Oil Spill Research and Development Program, OSRADP Technical Report Series 97-002. [http://www.osradp.lsu.edu/1997\\_Deliverables/Braud97/Braud97.htm](http://www.osradp.lsu.edu/1997_Deliverables/Braud97/Braud97.htm).
- Britsch, L. D., and J. B. Dunbar. 1993. Land loss rates: Louisiana Coastal Plain. *Journal of Coastal Research*, 9(2), pp. 324-338.
- Cahoon, D. 2006. A review of major storm impacts on coastal wetland elevations, *Estuaries and Coasts*, 29 (6A), 889-898.
- Congalton, R. and K. Green. 2009. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices, 2<sup>nd</sup> edition. Taylor & Francis Group, LLC. Boca Raton, FL. 177 pp.

- Cracknell, A. P. 2007. *Introduction to Remote Sensing* (2 ed.). London: Taylor and Francis.
- Digital Globe. 2010. Standard Quickbird Satellite Imagery. URL: <http://www.digitalglobe.com>
- Foody, G. 1992. On the compensation for chance agreement in image classification accuracy assessment. *Photogrammetric Engineering and Remote Sensing*. Vol. 58, No. 10, pp. 1459-1460.
- Jensen, J. R., E. W. Ramsey, H. E. Mackey Jr., E. J. Christensen, and R. R. Sharitz. 1987. Inland wetland change detection using aircraft MSS data. *Photogrammetric Engineering and Remote Sensing*, Vol. 53: pp. 521-529.
- Landis, J. R. and G. G. Koch. 1977. The measurement of observer agreement for categorical data. *Biometrics*. Vol. 33, pp. 378-382.
- Lee, K. H. and R. S. Lunetta. 1996. Wetland Detection Methods. In: *Wetland and Environmental Applications of GIS*. Lewis Publishers, New York, pp. 249-284.
- Lulla, K. 1983. The Landsat satellites and selected aspects of physical geography. *Progress in Physical Geography*. 7: pp. 1-45.
- MacDonald, T. A. 1999. Wetland rehabilitation and remote sensing. In: *An International Perspective on Wetland Rehabilitation*. Kluwer Academic Publishers, Boston, pp. 251-264.
- May, J. R., and L. D. Britsch. 1987. Geological Investigation of the Mississippi River Deltaic Plain, Land Loss and Land Accretion. *Technical Report* GL-87-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.
- Penland, S., C. Zganjar, K.A. Westphal, P. Conner, J. List, and S.J. Williams. 1999. Impact of Hurricane Andrew on the Timbalier Islands, Terrebonne Parish, Louisiana, poster, US Geological Survey.
- Rosenfield, G. and K. Fitzpatrick-Lins. 1986. A coefficient of agreement as a measure of thematic classification accuracy. *Photogrammetric Engineering and Remote Sensing*. Vol. 52, No. 2, pp. 223-227.
- Roughgarden, J., S. W. Running, and P. A. Matson. 1991. What Does Remote Sensing Do For Ecology?. *Ecology*. Vol. 72, No. 6, pp. 1918-1922.
- Tortora, R. 1978. A note on sample size estimation for multinomial populations. *The American Statistician*. Vol. 32, No. 3. pp. 100-102.
- Weller, M.W. (Ed.). 1994. *Freshwater Marshes: Ecology and Wildlife Management, Wildlife Habitats Ser.*, vol. 1, 3rd ed., University of Minnesota Press, Minneapolis, Minnesota.

## CHAPTER 4

### MAPPING COMMUNITY RESTORATION PRIORITIES AND OBSERVED CHANGE IN THE STUDY AREA USING TRADITIONAL ECOLOGICAL KNOWLEDGE (TEK)

#### INTRODUCTION

Methods for documenting and analyzing TEK derive from the social sciences and include the *Semi-Directive Interview*, *Analytical Workshop*, and *Collaborative Field Work* (Huntington, 2000). Established social science methods such as these provide a framework from which to develop particular techniques that best meet the needs of the researchers and community participants, as well as best fit the circumstances of the research. *Collaborative Field Work* methods were employed in this study to acquire and analyze TEK, since they have been shown to be an excellent means of interacting with a community for an extended period (Huntington, 2000). *Collaborative Field Work* methods generally include recording observations made in the field. This technique allows for a more descriptive and complete account of individual and group memory of environmental change as opposed to having a pre-planned survey of questions such as is the case with other social science methods (Manning, 2005). Additionally, the information gained over long-term relationships, and multiple site visits is much richer and more detailed than that collected during a single interview. For the purposes of this study, the observations recorded included: changes in the flora and fauna over time; changes in other environmental conditions such as observed land loss and degradation of natural resources; a

history of man-made structures and impacts to the area; and priority areas of particular community significance or concern.

The Native American tradition of oral history, evident in most indigenous communities where the population has a long history of being intricately tied to the surrounding ecosystem, encouraged the researchers to be patient in our listening and collection of TEK. Thus the collection of TEK was an ongoing process, accomplished via site visits, frequent phone calls, and social interactions. As a result, throughout the course of this study, the process was both dynamic and responsive to changing environmental conditions.

All TEK collected was fully transcribed and a qualitative analysis was carried out using the Atlas.ti program (Cologne, Germany) by a collaborating social scientist with the Center for Hazards Assessment, Response and Technology (CHART) at the University of New Orleans. A total of 53 hours of field note transcripts were imported into the Atlas.ti software. Coding was carried out through a line-by-line review of the transcripts, and categories were created from the data with the aim of identifying underlying concepts evident in the data (Castillo et al., 2005). Categories were linked in order to derive relationships among the codes, and these linkages were used to develop themes that emerged from the TEK regarding aspects of the local landscape. Direct quotations from the transcribed datasets were used to support and illustrate the categories and to construct a codebook from which indices of observed change and community priorities were then developed. These indices related to features or locations within the study area that were subsequently mapped with associated attributes derived from the TEK coding process.

### **Collaborative Partnership Development with the Grand Bayou Community**

The researchers were introduced to the people of Grand Bayou by a CHART Urban Studies Ph.D. candidate who had been working closely with the community for six years.

The research team engaged in a proper *entrée* procedure (West et al., 2008) led by social scientists with CHART, in which the researchers developed a relationship of respect with the community with the goal of achieving a trustful working process. This effort included introducing the community to the geospatial technology used for the project, and collaborating on a document of principles, ethics, and expectations which ensured equitable relationships, so that no harm would come to the community as a result of this work (see Declaration of Principles, Ethics and Expectations in Appendix X). The *entrée* process was continual and ongoing throughout the study period as researchers met additional community members and worked to establish increased trust and stronger relationships with all involved. As part of *entrée* the researchers attended community meetings and learned some of the history of academic exploitation of this community. Resulting guidelines established for our presence in the community included these stipulations: outsiders who want to help must not be self-interested, must be genuine, kind, and respectful; outsiders must commit to transparency and communications with everyone involved, “their heart must be in the right place”. The residents expressed concern that historically outsiders (including researchers) have harmed the environment and betrayed the community’s trust. It was clear that this must not happen again. In addition to this formal meeting, researchers spent significant time socializing and getting to know the people at the meetings.

The following is a direct quote from one of the informants (P) that exemplifies why they decided to partner with the researchers on this study:

We’re glad to help, you know, and this is interesting to us too. We like to see how they improve it and everything. We see the destruction coming around and everything, fading away all the time. We can help someone who can stop it, slow it down some, that’s the main thing. It’s moving fast right now.



During this phase the community assisted researchers in identifying a primary TEK informant for interview/field work who has the expertise and in-depth understanding of the study area as it relates to the project objectives. The researchers accompanied the primary informant in the field numerous times to obtain a first-hand understanding of the study area. As the primary informant became more comfortable with the researchers and more familiar with the scientific methods employed in this study, he made recommendations for additional community informants with comparable project related knowledge of the study area. These recommendations were supported by other community members through statements such as: “Oh yeah, D--- will tell you everything there is to know about the marsh.” and “R--- been around to see a lot of change, a whole lot of change.” All TEK data collection occurred either at a resident’s home or boat, and one map biography was completed at a nearby community center. However, the majority of the data was gathered while out in the field accompanied by 1 to 3 residents at a time. Each field trip to collect TEK data lasted approximately 5 to 8 hours. This TEK field data collection campaign utilized the *Collaborative Field Work* methods and was modeled after previous research where TEK was used in scientific studies (Huntington, 2000) to locate study sites, obtain specimens and data, and interpret field observations and results. Figure 1 shows the project researchers and community TEK informants in the field recording data.



Figure 1. Photos showing TEK field data collection between project researchers and community informants.

Map biographies of the local residents were determined to be useful (Calamia, 1999; and Ferguson et al., 1997) within the ongoing collaboration, especially when choosing sites and working with maps (Figure 2). For these map biographies, a poster-size (32"x46") printed map of the Grand Bayou study area was produced from acquired satellite and aerial imagery and used to establish a relative timeline of observed ecosystem changes and to document those changes by plotting them directly onto the map. The printed map was also used to record traditional community names for features and to identify 'sensitive areas' or areas of particular concern to the local peoples such as cultural sites (i.e. burial grounds) and marine or mammal 'eco-zones' (i.e. fish or animal breeding/spawning areas of particular importance to the community, traditional trapping/fishing areas, areas of unique plant populations that are traditionally utilized by the community, etc.). A 'community perspective' map was produced that includes the information gained during these interviews (Figure 3). This map was updated as new TEK was integrated into the project through subsequent map biographies. Copies of all maps produced were provided to the community.

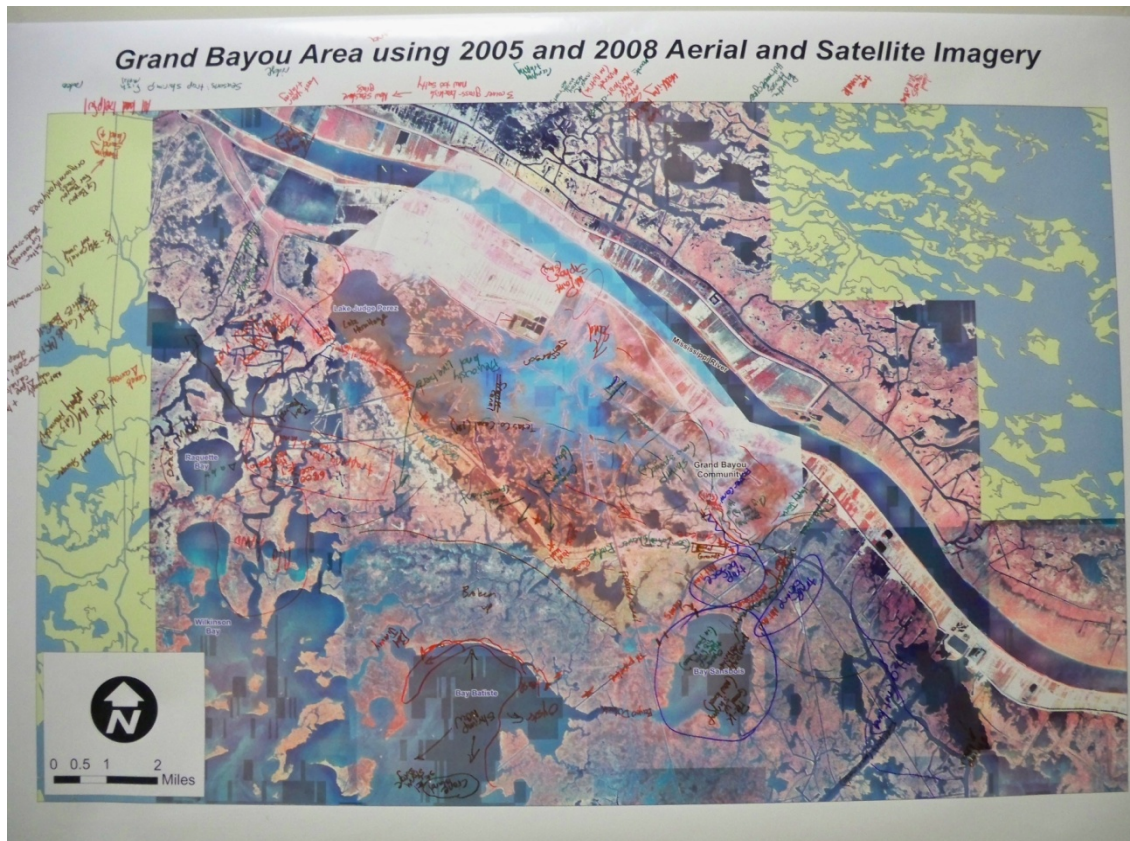


Figure 2. Poster-size map with residents' observations written/drawn for the Grand Bayou map biography.



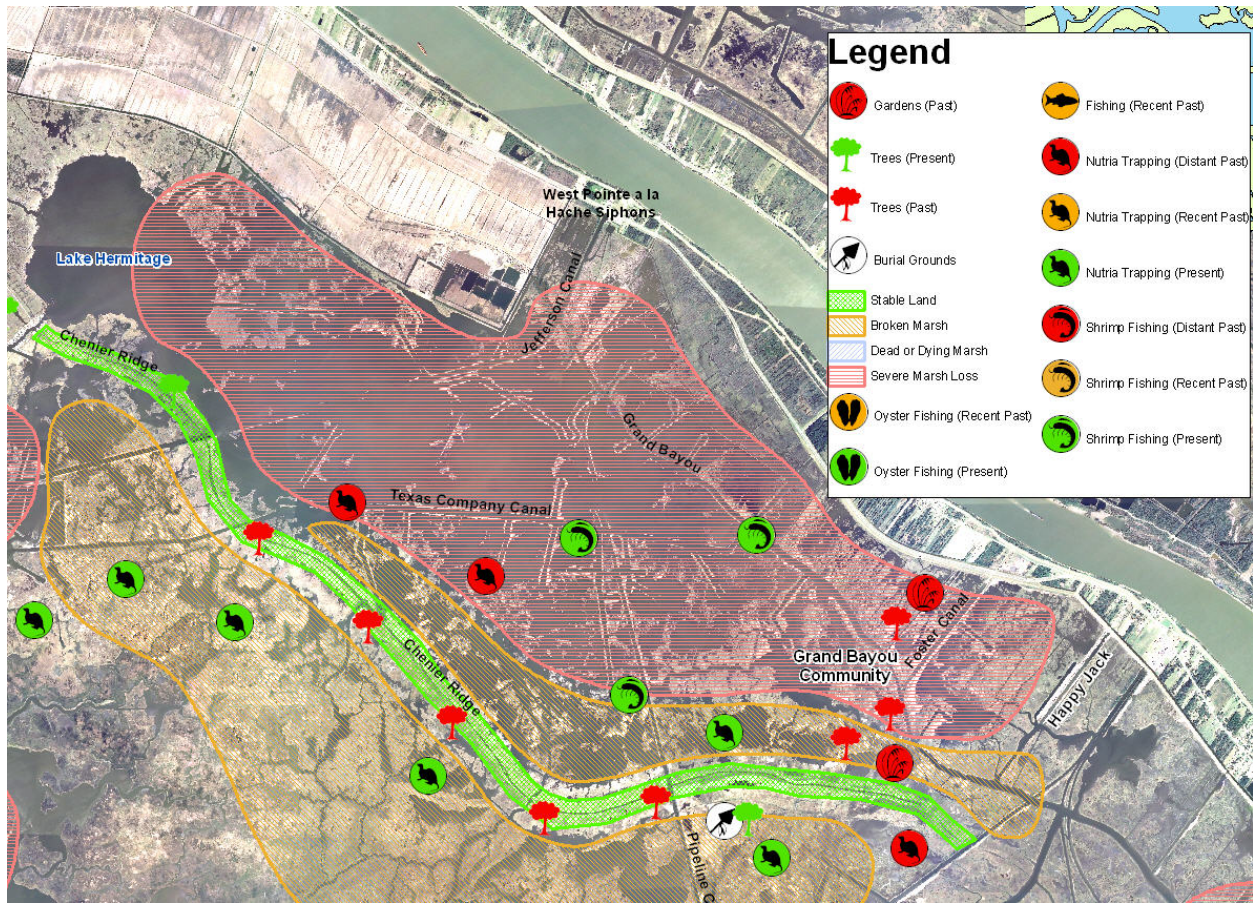


Figure 3. An example of a ‘Community Perspective’ map produced from the map biography.

## METHODS

### TEK Sample

Five Grand Bayou resident fishers/trappers participated in the study as TEK informants. Following identification of the primary informant, the others were chosen using a snowball sampling method (Patton, 1990). That is, the primary informant referred the researchers to the other informants. TEK informants were selected based on their knowledge of the study area

through resource harvesting activities such as trapping and fishing. All informants identified as Native American, specifically of the Atakapa tribe, and had been raised in the village.

### **TEK Data Collection, Transcription, and Coding**

At the beginning of field sampling, TEK collection, or TEK verification activities, the academic researchers requested verbal permission from all present to tape record conversations. It was explained that the recording would be transcribed by the collaborating social scientist and that individuals would remain anonymous. Once verbal approval by all present was obtained, the tape recorder was turned on. Often over the course of data collection other community members would approach. In these instances either the researchers or more often collaborating community members would notify the approaching party that audio recording was in session. Verbal permission over written forms was chosen because some of the collaborating informants have a low level of English literacy and are more comfortable with verbal communication. A battery powered RCA 256M Digital Voice Recorder was used. The tape recorder remained on for the full duration of the trip. The microphone was sufficient to capture all conversations except those which occurred while the outboard motor was running. This produced hours of recorded conversation each field trip. During approximately 5-10% of this time conversation was obscured by the noise of the boat motor. This was judged acceptable because conversations were limited while traveling by boat due to the noise, wind, and need to concentrate on navigation.

Immediately after returning from field work all digital voice files were uploaded into a password protected folder on the collaborating social scientist's computer. Transcriptions were performed as soon as possible after the recording time. The social scientist, who was present for all conversations, conducted all of the transcriptions, inserting her field notes about the setting,

people present, activities, and other observations as recommended by Norris-Raynbird (2009).

Sections of motor noise were played in their entirety and any audible conversation snippets were recorded. Once transcripts were complete all names were changed to protect the anonymity of informants. The social scientist retained the knowledge of the informants' real names.

Transcripts were saved on the social scientist's computer in a password protected folder and the original voice files on the hand-held recorder were deleted. Transcripts were uploaded to Atlas.ti qualitative data analysis software (<http://www.atlasti.com/>) and coded using inductive coding (Crabtree and Miller, 1992). Researchers' comments and reactions were noted and codes were linked to in-field photos and maps used in the field work to provide visual representation of relationships.

### **Codebook Development**

The codes developed to identify themes within the context of the transcribed TEK data were organized and used to create a codebook. Procedures for developing a formal codebook were based on methods outlined by Kurasaki (2000). These methods included annotating the transcribed text, sorting the annotation list, labeling thematic categories, and refining the theme list. Annotations generally consisted of brief notes that summarized the main points expressed throughout the transcribed dataset. These annotations were used to derive themes that emerged during this process. Using the Atlas.ti software, excerpts of the raw data were linked to these annotation themes to serve as examples of each annotation in the list. The annotations were then sorted into categories based on similarity of content. For each theme category, a descriptive label was developed to represent the meaning of each theme. The list of descriptive labels subsequently became the theme list for the codebook.

Atlas.ti software was used to organize and derive relationships among the codes and themes developed from the TEK collected. Coding and relating information with this software allowed inferences to be developed from each transcribed dataset (Figures 4 and 5). The results were verified/validated with the contributing informants in a format that could be easily assessed for accuracy (i.e. maps and verbal summaries as opposed to the complete coded transcriptions).

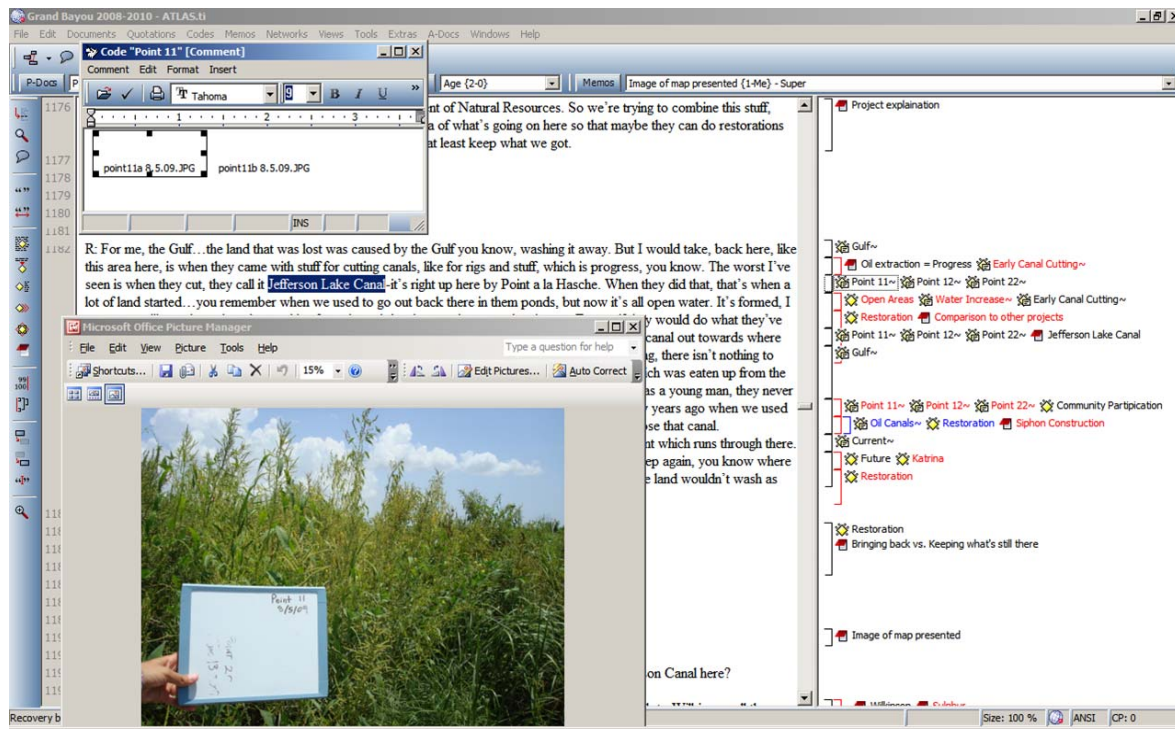


Figure 4. Atlas.ti software is used to organize, derive themes, and make inferences from the transcribed TEK collected.



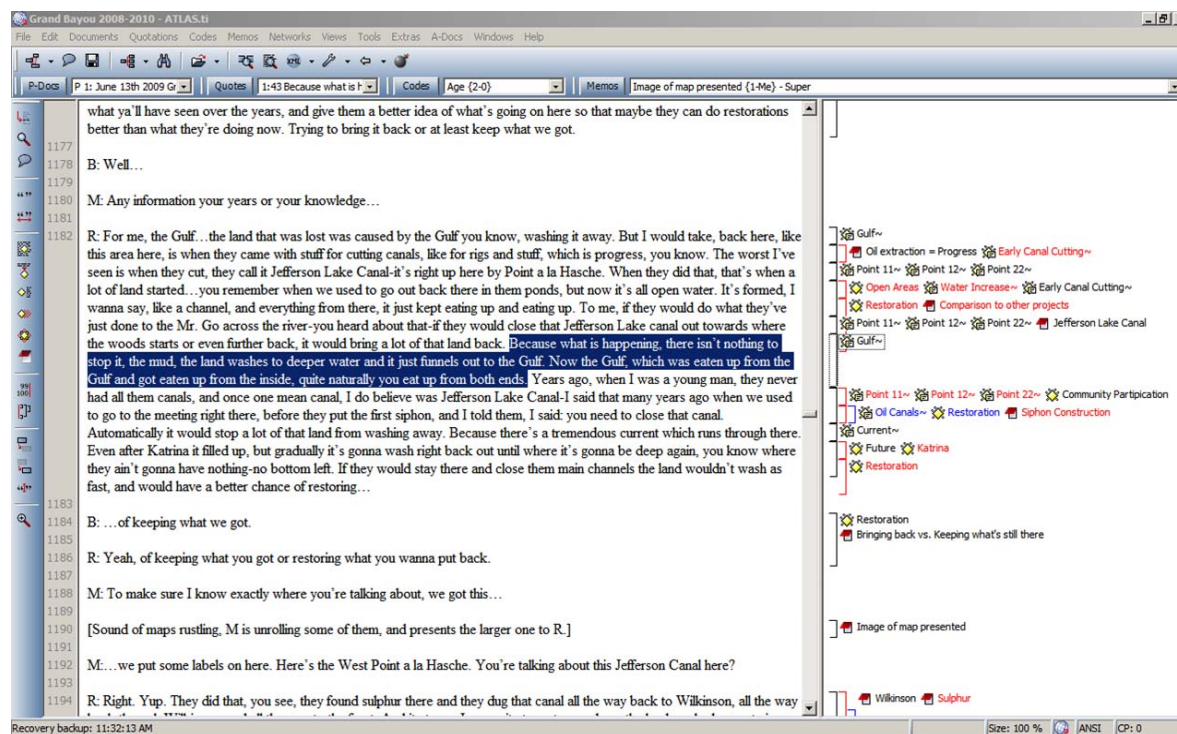


Figure 5. Example of TEK Data Transcription/Coding using Atlas.ti software.

For the purposes of synthesis with mapping practices, the social scientist's codebook was organized into groups according to:

- 1) Mappable Locations - areas which could be depicted on a map (as with the Community Perspective Map in Figure 3).
- 2) Social science TEK codes of the ecosystem users' observations: Marsh Conditions – descriptor variables which can be used to characterize attributes associated with mappable locations and which can result in a community prioritization scale relative to limited restoration resources; Specific Events – events which represent contributing factors to the decline of the marsh, and which, from the community perspective, inform the project as background information to the mapping product and/or other project deliverables. Events also provided a historical backdrop for the current state of the marsh that researchers



observed. Examples include Hurricane Betsy in 1965, the cutting of the first oil canals (in the late 1950s to early 1970s), and Hurricanes Katrina and Rita (2005); Work, Quality of Life, and Cultural Significance – areas which can be designated as “Sensitive Areas” and which should be mapped as the highest ranking priority for community sustainability.

Certain codes from this group are also listed as mappable locations and, like Specific Events, can inform the project in ways that are different from codes that are unmappable.

The final codebook is shown in Table 1, and includes physical locations and features identified in the TEK collected, as well as the associated social science codes derived from themes that emerged from the TEK during the coding process and that were used to assign attributes to the locations and features.

Table 1. Final codebook.

<b>GRAND BAYOU 2008-2010</b>
<b>PHYSICAL SCIENCE/GEOGRAPHIC CODES</b>
Bay Batiste
Bay Roquette
Bay Sambois
Bayou Traverre
Chenier
Crane Island
Four Bayou Pass
Freeport Canal
Grand Bayou Pass
Grand Isle
Grand Lake
Myrtle Grove Canal
Jefferson Lake
Area with the pink spoonbills
Lake Hermitage
Foster's Canal

(Table 1 continued)

Shell Canal	
Tennessee Pipeline	
Texas Company Canal	
Wilkinson Bay	
Frank Canal	
Old evacuation spot	
Trappers Camp	
Bayou Stephan	
Area around the Siphon	
Back Levee	
Pond behind the school	
Bayou Lafourche	
Port Sulphur Canal	
<b>SOCIAL SCIENCE CODES</b>	
Age	Of informant or the age of person they are speaking of. Usually used as a historical point of reference
Beach	A specific, important beach along the Gulf-- a holiday gathering spot and a point of reference
Betsy	Hurricane Betsy (1965)
Boat transportation	Frame of reference for environmental conditions- usually changes in transportation time
Burns	Controlled grass burns, usually to remove dead grass (referred to as "debris")
Change	General changes-- specific word
Community participation	Community members' roles in this research project
Cultural significance	The importance of something to the community's indigenous heritage and culture
Current	Word specific
Dams	Word specific
Early canal cutting	References to the first canals cut in the area
Farming	References to agriculture
Future	General anticipations or expectations
Generations	References to previous or future generations
Gulf	Gulf of Mexico
Hunting and trapping	Word specific
Indian Mounds	Native American burial grounds on the Chenier Ridge
Katrina	Hurricane Katrina (2005)
Land gain	Accumulation of soil/land
Land height	As measured from the surface of the water

(Table 1 continued)

Land leasing/Land ownership	Community members' leasing land for hunting, trapping and oystering from property owners
Land loss	Square footage of solid land decreasing
Legal action	Community initiated
Marsh stability	Softness/hardness of land, what it can support, how broken it is
Mississippi River	Word specific
Money	Word specific
Oil canals	Canals specifically cut by oil companies to lay pipelines (referred to as "canals" "pipelines" and/or "channels")
Open areas	References to areas that contained land and are now all open water
Oysters	Word specific
Political response	Either politicians/government response to change or community actions (top down)
Political action	Community initiated political involvement (bottom up)
Restoration	Environmental
Resource extraction	Oil, gas and sulfur (not seafood or vegetation)
Sediment/Dirt/Soil	Word specific
Shoes and boots	Used to explain changes in land and marsh stability
Shrimp	Word specific
Siphon	Freshwater siphon at West Point a la Hache (completed in 1992)
Speed	Rate of change
Sport fishermen	Non-permanent, non-indigenous property owners in the area (includes references to "sport camps")
Storms	General tropical storms and hurricanes (those not identified by specific names), includes preparations and evacuations
Subsidence	Decreasing land height
Tides	Word specific
Time	References to time past, time it takes to travel or to complete a task
Trash/Debris	Referring to dead grass and vegetation usually created/moved by storms (not litter)
Vegetation	Grasses, plants and trees
Water increase	Increases in the amount of water in the area
Water salinity	Salt content in the water (fresh, brackish, salt)
Wildlife	Animal life in the area
Work	Community members' employment/daily sustaining activities (includes shrimping, fishing, oystering or working outside the community-- off shore, tug boats, etc. Does not include hunting and trapping as that is no longer practiced for profit.)

## **Intercoder Reliability Assessment**

Intercoder reliability is a measure of agreement between multiple coders with regard to how codes are applied to the data (Kurasaki, 2000). Different coders may vary in their interpretation of the transcribed TEK. Consequently, comparison of the results of a consistently applied systematic coding process by multiple coders, with those results used to revise the codebook, is desirable. Following this procedure can lead to more reliable and therefore replicable results than those obtained when individual coders use their own idiosyncratic coding processes. “To achieve acceptable levels of reliability, the process of coding the TEK involves several steps: segmentation of text, codebook creation, coding, assessment of reliability, codebook modification, and final coding” (Hruschka et al., 2004). This assessment was necessary to ensure that coder bias or random error is minimized when making judgments regarding the themes and categories that emerge from complex qualitative datasets.

Intercoder agreement is demonstrated when separate coders can independently replicate each other’s work of assigning codes to the TEK datasets to an acceptable degree (judged by a quantitative measurement of agreement such as a Cohen’s kappa value or a coefficient of agreement). “High intercoder agreement or intercoder reliability strengthens confidence among the scientific community that the theoretical conclusions drawn from text data analysis are valid” (Kurasaki, 2000). The procedures used to determine intercoder reliability for this study generally followed recommendations by Hruschka et al. (2004) shown in Figure 6 and Kurasaki (2000) that included: 1) familiarizing an additional CHART social scientist with the Grand Bayou project and associated TEK collected; 2) having the original coder present a second coder with approximately 10 pages of randomly selected textual “idea units” from the TEK collected (the second coder was not given the entire TEK dataset as suggested by Hruschka et al. (2004)

due to the volume of TEK data collected and time constraints for intercoder reliability assessment); 3) having the second coder code these pages independently; 4) comparing the results from the two independent coders and calculating agreement; and 5) revising the codebook as necessary until an acceptable overall agreement value is achieved.

To calculate intercoder reliability agreement for the coded transcripts, 20 different lines per coded page were randomly selected, and for each randomly selected line the codes of the two coders were checked for agreement using five lines above or below the randomly selected line. The reason for including five lines above or below the selected is to accommodate the variation expected to occur in how each of the coders identified excerpts of TEK data that related to specific codes (Kurasaki, 2000). Because of the conversational nature of the interviews, it was common to find peripheral text surrounding more substantive, codable text. In coding an excerpt of transcribed data, a more inclusive coder might bind the entire text as one text unit, while a less inclusive coder might begin coding the text excerpt with different bounds.

An agreement matrix was subsequently developed. A 1 in the agreement matrix indicated that a code had been applied to the randomly selected line (or any line within five lines above or below the randomly selected line), and a 0 indicated that the code had not been applied. Agreement between the two coders for each of the themes was calculated by a ratio of agreements to total random excerpts for each codebook theme. An overall agreement across all the themes was calculated by averaging the agreements obtained for each theme (Kurasaki, 2000).

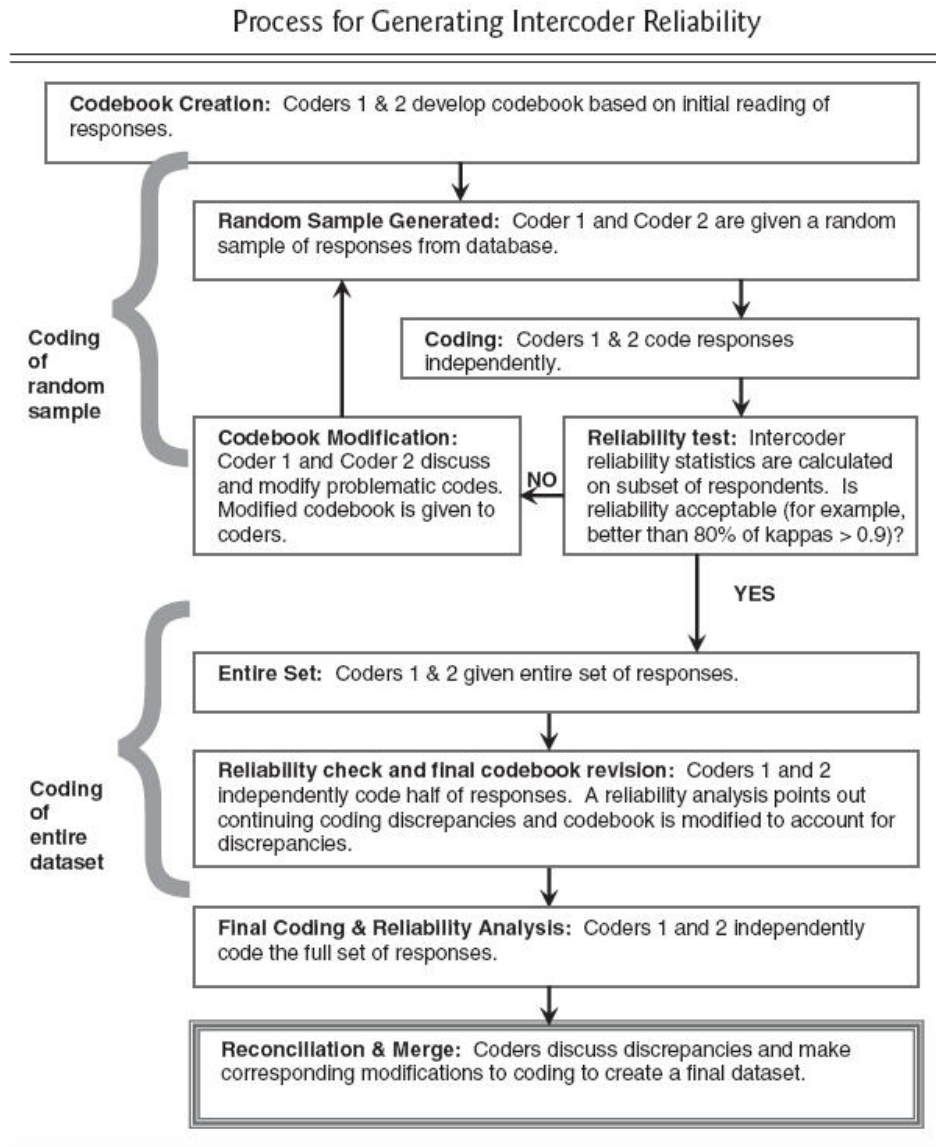


Figure 6. The process for generating intercode reliability from Hruschka et al. (2004).

## Applying Numeric Codes

Once acceptable intercode reliability was established and a codebook finalized, Atlas.ti, was used to investigate the passages related to the Marsh Condition codes in the transcribed documents in reference to the Mappable Locations. Based on the TEK information associated with each of these Marsh Condition codes, an attribute value of +1, -1, or 0 was assigned each Mappable Location. For the community assessment of restoration priority a value of +1

indicated that an area is important/urgent to restore, a value of -1 is relatively not important/not urgent for restoration, and a value of 0 indicates that the location/feature was mentioned during TEK data collection but was inconclusive. For assessment of observed change, a value of +1 indicated a location/feature having a positive or stable condition over time in the context of the natural resources used by the community at that location, a value of -1 represented a location or feature that has undergone negative change or degradation in the resources over time, and a value of 0 indicates that the TEK information was inconclusive for a particular Mappable Location/Feature. Calculation of the Restoration Priority Index (RP) and the Index of Observed Change (OC) was as follows:

$$I=(a-b)/x$$

*I= Index*

*a= number of codes with value of +1*

*b= number of codes with value of -1*

*x= total number of codes*

The following are some examples of the results of applying numeric codes for Restoration Priority:

Table 2. Example results of applying numeric codes for Restoration Priority.

<b>Mappable Location</b>	<b>Attribute</b>	<b>Assigned Value</b>	<b>Restoration Priority Index Calculation</b>
Lake Hermitage	Restoration	+1	RI = 1/13 = 0.07692
	Hunting and trapping	+1	
	Wildlife	0	
	Land ownership/Land leasing	-1	

(Table 2 continued)

Mississippi River			RI = 0
Myrtle Grove Canal	Hunting and trapping	+1	RI = 1/13 = 0.07692
Old evacuation spot	Storms Hunting and trapping Cultural significance Restoration Generations	+1 +1 +1 +1 +1	RI = 5/13 = 0.38462
Pond behind the school	Restoration Hunting and trapping Cultural significance Burns	+1 +1 +1 +1	RI = 4/13 = 0.30769
Port Sulphur Canal	Hunting and trapping	+1	RI = 1/13 = 0.07692
Ravine	Restoration Cultural significance Generations Storms Hunting and trapping Wildlife	+1 +1 +1 +1 +1 +1	RI = 6/13 = 0.46154
Shell Canal			RI = 0
Siphon	Political Action Legal Action Oysters Money Restoration	-1 -1 -1 -1 -1	RI = 5/13 = -0.38462

A sample of the Restoration Priority and Observed Change Indices derived from this information and used to produce the TEK-based Maps is shown in Table 3. The full numeric coded datasets are included in Appendices D and E.



Table 3. Restoration Priority Index used to create the Restoration Priority Map.

Physical Places	$a_{VI}-b_{VI}$	Observed Change	$a_{RP}-b_{RP}$	Restoration Priority
Bay Batiste	-1	-0.045454545	2	0.153846154
Bay Roquette	-7	-0.318181818	3	0.230769231
Bay Sonwa	-7	-0.318181818	0	0
Bayou Traverre	1	0.045454545	0	0
Beach	-2	-0.090909091	2	0.153846154
Chanier	-1	-0.045454545	7	0.538461538
Crane Island	-3	-0.136363636	1	0.076923077
Freeport Canal	2	0.090909091	0	0
Foster's Canal	-2	-0.090909091	3	0.230769231
Grand Bayou Pass	-1	-0.045454545	0	0
Grand Bayou Village	-3	-0.136363636	11	0.846153846
Grand Lake	-3	-0.136363636	0	0
Green Island	-2	-0.090909091	1	0.076923077
Gulf	-6	-0.272727273	0	0
Indian Mounds	3	0.136363636	8	0.615384615
Jefferson Lake	-4	-0.181818182	5	0.384615385
Lake Hermatage	-4	-0.181818182	1	0.076923077
Mississippi River	1	0.045454545	0	0
Texas Company Canal	-5	-0.227272727	1	0.076923077
Shell Canal	1	0.045454545	0	0
Siphon	1	0.045454545	-4	-0.307692308
Wilkinson Bay	-7	-0.318181818	2	0.153846154

The results of this analysis were used to create community-based maps that not only show location of features identified in the TEK, but also prioritization of these locations for restoration based on attributes related to the community perspective of these features. These maps were presented to the TEK informants for verification and validation of the results. Any discrepancies in the TEK information represented on the maps and what was indicated by the informants was corrected for the final map products.

## **RESULTS**

The intercoder reliability assessment for the coded transcripts resulted in a 98% overall agreement between the two coders in assigning codes to 20 randomly selected text segments from the transcribed TEK datasets. This assessment represents average agreement across 8 of the codes used in the final codebook that were used for at least one of the selected text segments for this analysis. The agreement matrix is shown in Table 4 (blank spaces represent text segments selected that did not contain codes assigned by either coder). This finding strengthens the validity of the coding results and conclusions based on the coded text data, and demonstrates that subjectivity in the coding process was minimized.

Table 4. Agreement Matrix used for intercoder reliability assessment.

Line #	Coder #	Land Loss	Open Areas	Vegetation	Change	Time	Wildlife	Age	Indian Mounds
1	1		1						
	2	1							
2	1								
	2								
3	1								
	2								
4	1								
	2								
5	1			1					
	2			1					
6	1			1	1				
	2			1	1				
7	1					1			
	2					1			
8	1		0						
	2		1						
9	1					1			
	2					1			
10	1								
	2								
11	1				1		0		1
	2				1		1		0
12	1								
	2								
13	1								
	2								
14	1							1	
	2							1	
15	1								
	2								
16	1								1
	2								1
17	1								
	2								
18	1								
	2								
19	1								
	2								
20	1								
	2								
% Agreement		19/20 = 95%	20/20 = 100%	20/20 = 100%	20/20 = 100%	19/20 = 95%	20/20 = 100%	19/20 = 95%	20/20 = 100%
<b>Overall Agreement</b>	<b>98%</b>								

The TEK analysis based on the coded TEK was used to create an index for Observed Change (to include, but not restricted to land loss) as shown in Figure 7. The coded TEK transcripts were also used to determine values for an index of Restoration Priority which was then used to weight areas based on community importance (Figure 8). These indices were created in order to increase accessibility of this TEK data to restoration decision makers. Following input from collaborating OCPR scientists, it was determined that a visual representation of observed land loss and priority restoration areas would be more likely utilized in the current restoration process than similar information in text format. The researchers were

privileged to witness elaborate, multi-dimensional storytelling, much of which comprised the TEK collection. We do not propose to represent this traditional practice of storytelling or encompass the complete wealth of TEK collected within these maps, but rather to bridge the gap between the restoration decision making process and TEK by representing two important community-based attributes (Observed Change and Restoration Priority) about features and locations that emerged from the TEK.

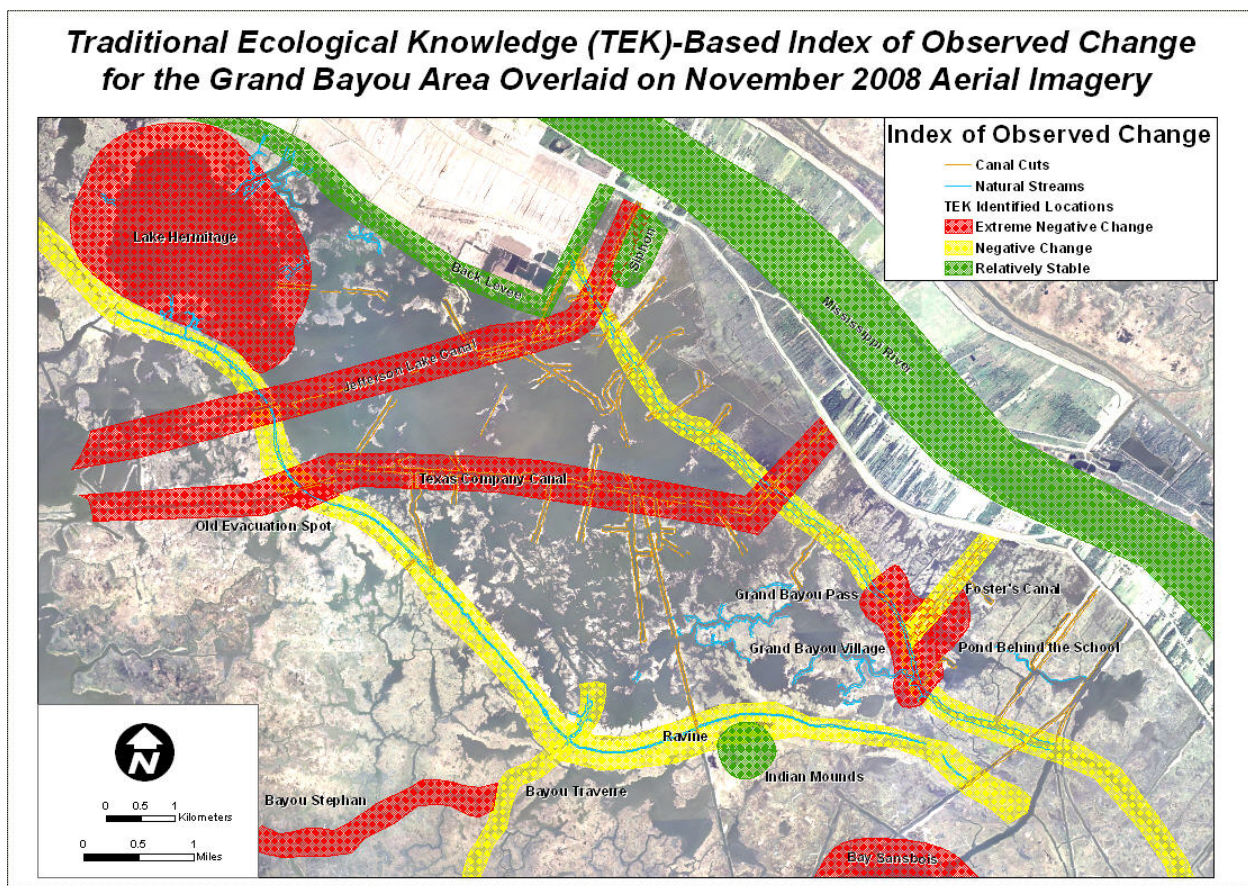


Figure 7. Index of Observed Change Map derived with Community-Based TEK.



Nearly all values of observed change were negative as there are no examples of land gain that community members identified. Even relatively stable locations (with values closer to 0) were accompanied with a warning that they are still degrading, if a bit slower.

According to R:

It's all open. You can just about shoot across it, you know. And before, well, if you didn't stay in the channel you couldn't make it. They had sandbars and land. Right now, no-if you don't know you're gonna get stuck or you cut right across... I mean, it's bad, but I'm still making a living off of it. Which...I would rather see the land. I would rather see the land there. Even when I'm on the road, I go different places, I see the land there and it's nice, you know, but it's not like it used to be. Places that I used to go, matter of fact right down the Bayou, used to have lemon trees, peach trees, I mean towards the Gulf or whatever, persimmon trees. They don't have it anymore. It's not there. And you can't even grow it, put it that way.

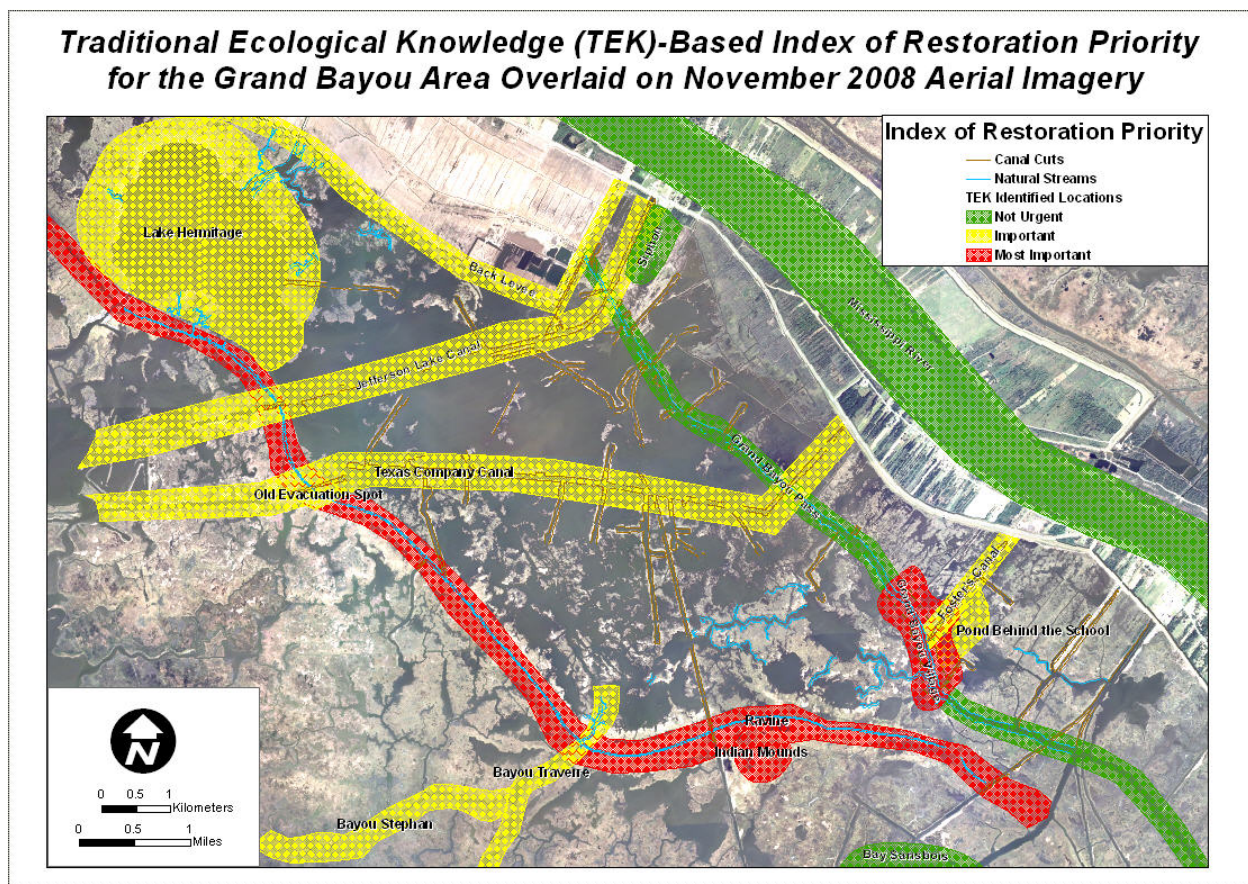


Figure 8. Community-based Restoration Priority Map Derived with TEK.

Identifying specific areas of concern was difficult for some informants as they emphasized that the whole area was vital and contributed to their safety and lifestyle sustainability. Specifically they rely on the health of the entire marsh for protection during hurricanes and tropical storms and as their primary means of sustaining themselves through shrimping, oystering, and fishing. It was emphasized that every area is important to restore as the whole ecosystem works together. Therefore, the reader should not assume that a low-priority (green) area should not be addressed. The entire location represented on the map and beyond has been identified by the community as in need of restoration. However, within that guideline researchers ranked locations (for both the RP and OC indices) given the context of informants' responses using the numeric coding process described previously assuming limited resources available for restoration. It was then concluded that the areas the community could not live without—their village and their sacred burial site, would represent the upper limit. The resulting TEK-based maps were presented to the informants to ensure the TEK information was represented properly. In this manner, the maps were validated as accurate representations of the TEK.

## **DISCUSSION**

The construction of the canals (primarily for oil extraction) in the study area from the 1950s to the 1970s emerged as the most frequently mentioned cause of the land loss observed when analyzing the TEK. The informants accept that some land loss is due to natural processes, such as wave and tidal action, and that it also results from episodic storm events. However, they have observed that the average rate of land loss due to these natural erosion processes was

greatly accelerated by the construction of the canals. An informant in his fifties gives the following account:

...the damage started with the oil, and I believe the canals because it ate into...I mean, they would dig a canal, say we would have a bayou, a little bayou from here to the post right there [~20ft.] for the rig location. Within a year or two or three after, that location ate into this little bayou and this little bayou's got a tremendous amount of current and the next thing you know it got bigger and bigger and bigger-it was gone, it was honestly gone. They would come and try and put a levee and close, but they wouldn't do a good enough job, I don't think. They don't care. They get what they want. When you take something from the bottom, the top sinks.

Other informants voiced similar conclusions when describing why they felt this land was being lost at such a high rate. The following are some of their responses:

An informant explains,

For me, the Gulf...the land that was lost was caused by the Gulf you know, washing it away. But I would take, back here, like this area here, is when they came with stuff for cutting canals, like for rigs and stuff, which is progress, you know. The worst I've seen is when they cut, they call it Jefferson Lake Canal-it's right up here by Point a la Hache. When they did that, that's when a lot of land started...you remember when we used to go out back there in them ponds, but now it's all open water. It's formed, I wanna say, like a channel, and everything from there, it just kept eating up and eating up. To me, if they would do what they've just done to the Mr. Go across the river-you heard about that-if they would close that Jefferson Lake canal out towards where the woods starts or even further back, it would bring a lot of that land back. Because what is happening, there isn't nothing to stop it, the mud, the land washes to deeper water and it just funnels out to the Gulf. Now the Gulf, which was eaten up from the Gulf and got eaten up from the inside, quite naturally you eat up from both ends. Years ago, when I was a young man, they never had all them canals, and once one mean canal, I do believe was Jefferson Lake Canal-I said that many years ago when we used to go to the meeting right there, before they put the first siphon, and I told them, I said: you need to close that canal. Automatically it would stop a lot of that land from washing away. Because there's a tremendous current which runs through there. Even after Katrina it filled up, but gradually it's gonna wash right back out until where it's gonna be deep again, you know where they ain't gonna have nothing-no bottom left. If they would stay there and close them main channels the land wouldn't wash as fast, and would have a better chance of restoring...

Another informant comments,

You know what, I honestly got to say that the reason why the storms now are affecting us more with the land is because the foundation has been taken away with the oil company and stuff, you know. And it don't take much of a storm now to take this marsh away because you can't even step into it. There's no more bottom.

These results are consistent with the findings by Manning (2005) in which the Grand

Bayou residents blame the region's oil and gas industry for land degradation. In fact, Manning reports that "in observations and interviews, few questions or comments evoked a much stronger response than their accounts about the oil and gas industry".

Throughout the discussions with the informants, they frequently offer local restoration and mediation proposals that they feel could reverse the land loss trends in the area. The following are some of their suggestions:

One informant says,

To be honest with you, if they'd have took that money, like I said, just blocking off Jefferson Lake Canal, even pumping sand, the land would have been there. What they talking about, raising cows or planting flowers-you would be able to do it today. But they never did it, they just kinda left and gone. They took what they wanted, which they state, they always got the right of way you know like that, they took what they wanted and after they took it just left it alone. And then it don't happen right just then, throughout the years, like right now, that's when you notice. I mean marsh right here, we used to go walking right through the woods, you can't do it anymore, you just can't. Because it's eating up from this end and from that end you know, sooner or later they're going to meet together. I told that to the president who, I forgot his name, he's dead and gone, Lu Prezivitch, and he said "My boy, don't worry about a nothing. We gonna get this land back and more." But I ain't seen the first grass yet.

Another informant suggests,

The money they spent on that they could have spent closing some of the canals and stuff, that they should have did, it wouldn't be as bad as it is now. They spending money and doing projects and doing things-they already know what needs to be done. Why are you just putting band-aids on things. They put the band-aids on something that needs to be done right.



He goes on to say,

But I honestly believe, and I guess I'm gonna believe this till I die, if they would go and close up the main channels, where the land...you know where, like closer to the levees, like Lake Hermitage in this area, I really think you gotta find out where it's eaten from and you stop that. Gradually you can either build back from the river, or anywhere you're gonna put something, it's gonna stay there. It doesn't really matter if you start from the levee; it's still eating here from the Gulf. If you have a project where you got to stop, you come back and say 'Hey, I know I was this far but it's gone again.' So I honestly believe, you stop it out here, the back part is going to come, it's going to do for itself. Eventually it's gonna do for itself.

R agrees with the previous statement and further states that:

Yeah, yeah, that too. I mean you gotta close that whole area. You go by the woods, I would start by the woods by Jefferson Lake canal...I'll bet you anything you want. I ain't talking about no hundreds of millions of dollars, you go far a Jefferson Lake canal and block that off good. Right there by the Texas Company canal, and block that off. Four, five years, you gonna see the difference, you ain't gonna be able to ride with an outboard motor out there. That land's gonna build back up.

A conversation ensues between the informants (R, H, and B) regarding restoration recommendations as follows:

B: No, but it's not there anymore. I'm not saying that it couldn't be that good but you would have to restore it. Me, I believe that they got enough sand and whatever you want right there in that river. Take a suction dredge and pump it out here like Fosters Canal they pump for miles and miles, almost a mile of sand and they fill it up, what, like overnight. H: They could fill it right by the school there, no problem.

R: Oh yeah. I would go and honestly say, the deepest parts, that's the ones you gotta close up.

B: Where they got more current. R: Right, the deepest with the most current. Right, you see, the deepest part is the one that pulls, it draws everything out. R: But if I would have anything to do with this, that's the first place I would go, Jefferson Lake Canal, Texas Company Canal, block them areas up, fill that in, phew, you can't imagine what you would see.

B: I would be a big difference.

R: Oh yeah. Big difference, because the water is just coming over...everything. It comes up, nothing to stop it. But you know, the reason why I'm saying that too, you see the grasses coming back, automatically the land is gonna stay. Because what holds the land?

B: And like I said, that little cut right here, just close this up. Forget about the siphon it's never gonna close that way over here. Come out here and dam it off or something, you know. Dam it off and then the country is gonna fill up, it's gonna fill. But as long as you leave it open like that it's gonna get bigger and bigger. The siphon's just a waste of money-a million dollars there the invested in that there."

Furthermore the residents suggest ways that the oil companies that dug the canals could help with the land loss problem that was accelerated by their actions. Specifically, one informant suggests, "Everything was all dammed up. The oil rigs. See someone needs to make these companies come back and fill these waterways back in, close all these waterways. Fill them with dirt. And then put a dam."

The residents' accounts show that they do believe that the rate of land loss can be slowed, and they have hope of reversing some of the damage done to the local ecosystem that they depend on, however there is little belief in the current restoration policies and programs of authorities. The main reason for this skepticism is that the residents suggest that scientists and restoration managers currently do not listen to them and consider their suggestions and knowledge when planning and implementing local restoration projects. As Manning (2005) reports, "the [government] agencies that rely on their 'expert' knowledge usually end up implementing 'understudied and under-funded' projects that seem to only compromise the community further".

The informants recognize that restoration activities could have a negative effect on certain aspects of their lives, such as oyster harvesting where oyster bed locations have adapted to the changes in water salinity over the past few decades and have become more easily accessible to the Grand Bayou residents. However, they do acknowledge that these negative impacts to their livelihoods from restoration activities are secondary to the primary concern of

restoring the land which takes precedence as a consideration in restoration objectives. As an informant states,

But this is where the community is at, right here now, if you want to do something the first thing I would start is on the community side, to fill all this in here, and then you move, then work on the barricades around it. These people need it, and need it bad. Need to stop the water from going in their houses, and land erodes, and it hurts the fishing.

Manning (2005) also explains the importance of the land to the Grand Bayou residents, and how “the local knowledge of residents provides them with an understanding of their natural and cultural environment and what the loss of one would mean for the other”. As a Grand Bayou informant in the Manning study states, ‘without the land...the people could not survive’.

The residents realize that their traditional way of life at Grand Bayou will be unsustainable if local land loss rates observed over the past several decades continue to occur. As a result, they have concluded that they must use the agency gained from collaborating on studies such as this, educating the public and government officials to their situation, share their knowledge and suggestions on how to improve restoration practices, and learn more about the science and engineering technologies being used to make the restoration decisions that affect their lives.

## **CONCLUSIONS**

1. Researchers must make every effort to include community members who are accountable to their community and their environment. Simply living in a place or being of a certain ethnicity does not ensure this accountability. Hiring, or taking the word of someone who is not held as a community advocate can be very harmful and create rifts not only between

community members and researchers but also within the community itself. Great pains must be taken during entrée procedures to recognize and identify individuals who are held up as leaders, organizers, and preservationists within the community. In the case of biological and ecological research there must be clear methods of identifying individuals who are the most knowledgeable about, and accountable to the local environment.

The identification of such individuals can take the form of mass referrals, as in the case of this study, in which a significant number of community members identified a primary informant as a key individual in the community who holds strong, correct, long-lasting ecological knowledge both from oral tradition and personal experience. Appropriate individuals may also be identified based upon professional experience since those who work daily in sustainable ways within the study environment have day-to-day knowledge of the changes over time and often have the greatest investment in preserving the area. Similarly, place of residence can be used to identify primary community informants since permanent residents within the study area witness change first hand and are usually invested in preserving their immediate environment. Also, because older community members have often seen and experienced greater change first hand, age can be used to help identify appropriate community informants. At the same time, the information gained from younger community members can also be substantial, based on their knowledge of community history/oral tradition and their profession. Finally, the interests of community members can be used to identify them as appropriate informants, since those who pursue hobbies or recreational activities within the study area are often more interested and invested in exploring new ways in which to understand their area.

2. Qualitative methods and analysis revealed a variety of themes or findings from the TEK collected. The major themes related to local environmental degradation and land loss noted by the informants are detailed in a diagram produced for this study that conceptualizes the interrelationships of these themes in Figure 9.

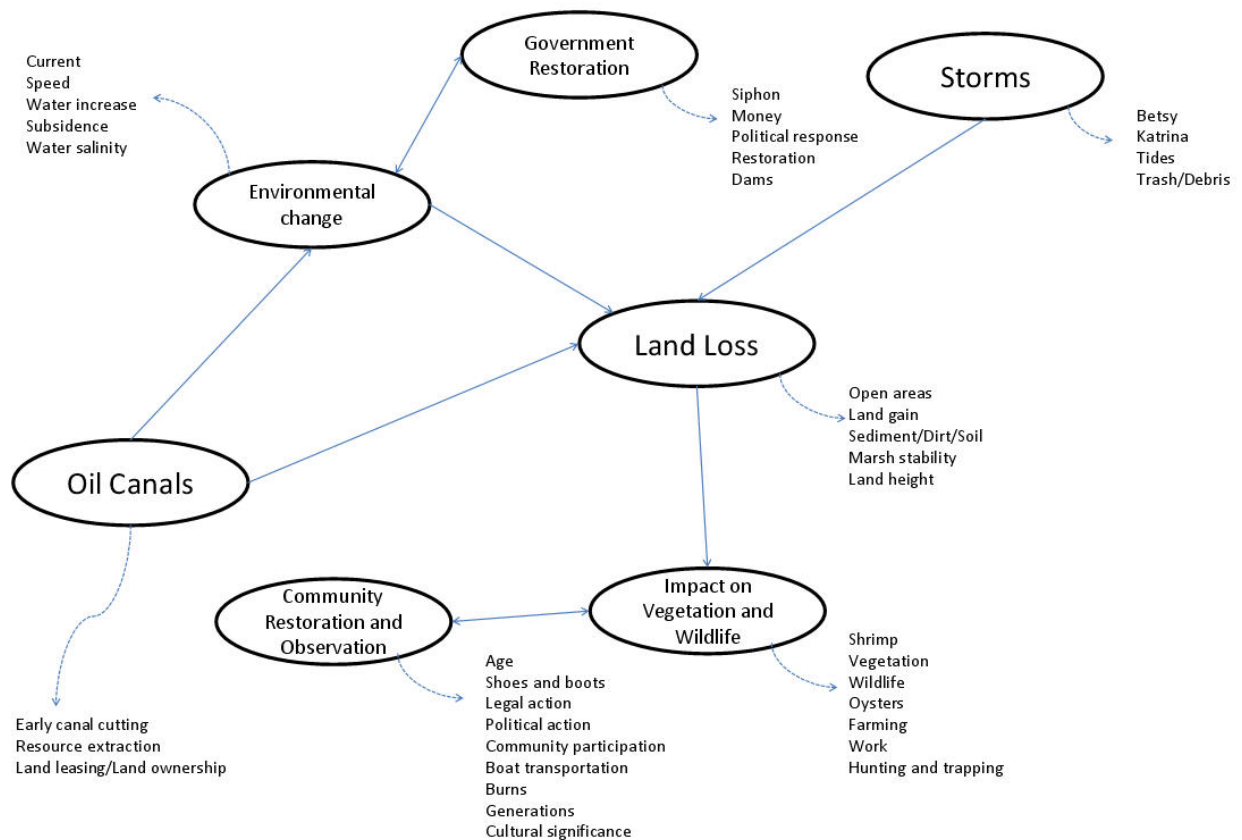


Figure 9. Major themes related to local environmental degradation and land loss and their interrelationships determined from TEK collected for this study (themes are within the circles, the codes within those themes are in small text pointed to by respective themes).

3. Community-based indices that are calculated from numerically coded TEK themes provide a dataset that can be used to create a GIS to map locations and features and to represent their associated attributes as derived from TEK. This TEK mapping method allows for a straightforward verification by the informants of how the TEK was used in this study in a format that facilitated easy assessment. The map format is also conducive to inclusion and

4. Consistent change and adaptation to that change have been a part of the Grand Bayou community's identity and way of life. However, the rate of local land loss has outpaced the residents' ability to adapt to the constant change in the last half century. As a result, the residents have begun to do something that they have never had to do before – work and share knowledge with outsiders to solve this problem. Because they feel that the land loss risk is usually managed beyond their control, they have formed agency that networks with outsiders to import expert knowledge, while exporting and diffusing their local knowledge. As Manning (2005) concludes; “by actively working with researchers, experts, and politicians the community residents are empowered to continually fight for their land”.
5. Traditional ecological knowledge is not limited to indigenous communities. There are many communities with long histories of living in one specific area which can be compatible with similar research studies. There are many communities of various ethnic and cultural backgrounds that are very mindful of the natural environment and have immense knowledge of systems at play. The researchers for this study did not choose Grand Bayou as a partner

community simply based on their indigenous heritage, but rather on their wealth of knowledge and understanding of the study area. There are very complex ecological, social, cultural, and spiritual ties which bind these people to Grand Bayou. Residents have refused to re-locate even in the face of devastating hurricanes, rapid land loss, and recently the threat of toxic crude oil. Thus, they are much more concerned about environmental decline in their area than are more mobile communities. They have a two-hundred year history of caring for and monitoring their environment through traditional practices and have taken political and professional steps to adapt this commitment to societal influences at large. This includes pressuring legislative bodies for appropriate restoration priorities, accepting (often low paying) environmental jobs, and choosing to partner with university researchers in order to increase their knowledge base and garner support.

6. The collection of TEK requires additional time and resource commitments by scientists that are not normally factored into traditional scientific studies. With few precedents that quantitatively show a significant improvement in research results from utilizing TEK, a scientist will typically not go ‘outside-the-box’ and incur additional project costs and time requirements if he/she does not understand a benefit to doing so. Also, scientists may be reluctant to use data collected in less formal ways (such as TEK) due to how conventional scientists are trained and the nature of the scientific method itself. Specifically, conventional scientists are trained in rigorous sampling design and standardized data collection and verification/validation methods. Typically, TEK is what is learned from experiences and observations of an area collected over years of living there, though not recorded or organized in a formal manner. Despite the many benefits of including TEK in scientific studies, there is

significant skepticism among many scientists in TEK acquired from local peoples on the grounds that it is biased to reflect the views and experiences of the informants.



## REFERENCES

- Calamia, M. A. 1999. A methodology for incorporating traditional ecological knowledge with geographic information systems for marine resource management in the Pacific. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin*, No. 10: pp. 2-12.
- Castillo, A., A. Torres, A. Velazquez, and G. Bocco. 2005. The use of ecological science by rural producers: a case study in Mexico. *Ecological Applications* 15(2):745–756.
- Crabtree B. F. and W. L. Miller. 1992. *Doing Qualitative Research*, Newberry Park, CA: Sage.
- Ferguson, M. A. and F. Messier. 1997. Collection and Analysis of Traditional Ecological Knowledge about a Population of Arctic Tundra Caribou. *Arctic*, Vol. 50, No. 1: pp. 17-28.
- Hruschka, D. J., D. Schwartz, D. C. St. John, E. Picone-Decaro, R. A. Jenkins, and J. W. Carey. 2004. Reliability in Coding Open-Ended Data: Lessons Learned from HIV Behavioral Research. *Field Methods*, Vol. 16, No. 3: pp. 307-331.
- Huntington, Henry P. “Using Traditional Ecological Knowledge in Science: Methods and Applications” *Ecological Applications*, 10(5), 2000, pp. 1270-1274.
- Kurasaki, K. S. 2000. Intercoder Reliability for Validating Conclusions Drawn from Open-Ended Interview Data. *Field Methods*, Vol. 12, No. 3: pp. 179-194.
- Manning, S. C. 2005. Riding out the Risks: An Ethnographic Study of Risk Perceptions in a South Louisiana Bayou Community. *Master of Science Thesis*, Louisiana State University and Agricultural and Mechanical College, Department of Environmental Studies, Baton Rouge, Louisiana.
- Norris-Raynbird, C. 2009. Personal Communication. Bemidji, Minnesota: Center for Environmental, Earth and Space Studies, Economics and Sociology, Bemidji State University.
- Patton, M. Q. 1990. *Qualitative evaluation and research methods*. 2nd ed. Newbury Park, CA: Sage.
- West, J., K. Peterson, M. Alcina and S. Laska. 2008. Principles of Participation and Issues of Entry for Participatory Action Research (PAR) in Coastal Community Resiliency Enhancement Collaboration. *Journal for Community Engaged Research and Learning Partnerships* 1 (1): <http://www.manifestationjournal.org/>

## **CHAPTER 5**

# **ASSESSING, IDENTIFYING, AND MAPPING MARSH AREAS VULNERABLE TO LOSS USING SCIENTIFIC DATASETS**

## **INTRODUCTION**

Studies of the location and historical rates of land losses in coastal Louisiana are often limited to their change in spatial extent; however, prioritization of future restoration efforts requires additional information regarding marsh condition in terms of biophysical characteristics and spatially dependent relationships of the landscape. Marsh biophysical characteristics include the distribution of chlorophyll content, leaf area index, vegetation fraction, and biomass. These biophysical characteristics are indicators of the physiological status of marsh vegetation. Monitoring these characteristics through remotely sensed imagery can aid in the inference of the overall health of these areas so that more informed restoration management strategies may be implemented. Spatially dependent relationships refer to the patterns of change related to the configuration and connectivity of land cover types within a landscape. Prediction of future change can be aided through better understanding of the spatial relationships of land cover types for a given area.

It is well documented that most physiological stress in plants will reduce the concentration of photosynthetic pigments, and as a result stressed plants are known to have different spectral reflectance characteristics compared to healthy ones (Nilsson, 1995). Various vegetation indices can serve as indicators of plant health and chlorophyll pigment loss. For

instance, Vigier et al. (2004) reported that plant damage was associated with the chlorophyll absorption in reflectance and normalized vegetation indices, showing a loss of chlorophyll pigment compared to healthy plants. Carter and Spiering (2002) determined specific wavelengths that are most sensitive to chlorophyll concentration in an effort to better understand the relationship between leaf optical properties and chlorophyll content. A CM1000 Chlorophyll Meter was made available to this study by NASA, and calculates a chlorophyll index value (0-999) from the measured ambient and reflected light data of a target. “This index value is a measure of the relative greenness of the leaf” (Fieldsout, 2008). Therefore, relative chlorophyll content was used as a biophysical parameter to assess marsh health variability for this study.

Leaf area index (LAI) is the ratio of total upper leaf surface of vegetation divided by a given surface area of the land on which the vegetation grows. Because LAI most directly quantifies the plant canopy structure, it is highly related to a variety of canopy processes, such as water interception, evapotranspiration, photosynthesis, respiration, and leaf litterfall. LAI “is a critical variable for understanding the biological and physical processes associated with vegetated land surfaces” (Wang et al., 2004). Non-destructive techniques of estimating LAI have been developed using optical ground and remote sensors that measure radiation interception or absorption by plant canopies. These LAI measurements represent the proportion of ground obscured by foliage in a vegetative canopy (Chen and Black, 1992). Given that LAI has been shown to be important in understanding many aspects of plant canopy development, growth, and management, it was the second biophysical parameter, along with chlorophyll content, used in this study.

The quantification of landscape pattern allows for the identification of interactions among spatial patterns and ecological processes. Because land cover maps derived from remotely

sensed imagery only indicate the location and type of land cover, further processing is needed to quantify and map land cover fragmentation (Turner and Gardner, 1991; Gustafson, 1998).

Practical applications of landscape pattern quantification include: describing how a landscape has changed through time; making future predictions regarding landscape change; and evaluating alternative land management strategies in terms of the landscape patterns that may result. The calculation of landscape pattern metrics is necessary to rigorously describe landscape patterns (Gergel and Turner, 2003). The purpose of a landscape fragmentation analysis is to map the types of fragmentation present in a land cover type (i.e. marsh). Turner et al. (2003) define fragmentation as the “breaking up of a habitat or cover type into smaller, disconnected parcels”. Fragmented land cover is typically classified into 4 main categories: patch; edge; perforated; and core. These fragmentation types are defined by ESRI (2010) as:

- Perforated – pixels along the edge of an interior gap in a land cover that are degraded by ‘edge effects’
- Edge – pixels along the exterior perimeter of a land cover that are degraded by an ‘edge effect’
- Patch – small isolated fragments of a land cover that are completely degraded by ‘edge effects’
- Core – land cover pixels that are not degraded by ‘edge effects’

Fragmentation type is determined by proximity to fragmenting features (such as water in this case). Originally, fragmentation analysis was developed for use on forest land covers but can be applied to any land cover of interest (ESRI, 2010).

The initial TEK data collection for this study indicated that there were two main driving factors related to land loss in the study area; 1) marsh vegetation health and 2) marsh

fragmentation (or broken marsh versus solid marsh as the residents would say). The biophysical and fragmentation parameters tested and related were based on this TEK information.

A goal of this study is to successfully correlate remotely sensed image data to specific plant characteristics indicative of plant vigor. Based on the relationship between field data and image data, this study produced maps estimating the variability of marsh vegetative vigor within the study area using two measures of marsh biophysical characteristics (chlorophyll content and leaf area index). Landscape pattern was recognized as an important variable indicative of areas vulnerable to eventual loss through the TEK collected for this study. As a result, another goal of this study is to assess historical land loss trends identified during the historical land loss image assessment with regard to local patterns of marsh fragmentation. This was accomplished by producing historical marsh fragmentation maps depicting various landscape spatial characteristics as unique classes corresponding to fragmentation type. The historical land loss patterns were compared with the marsh fragmentation maps, and statistical analysis was performed to determine if certain fragmentation classes were more likely to be lost to open water over time. Knowledge of fragmentation is beneficial because it permits some inference about the probable impacts of fragmentation, even without detailed knowledge of all of the ecological processes that might be affected (O'Neill et al., 1997). Fragmentation results combined with the marsh vegetative vigor results from the biophysical measurements were used to identify and prioritize areas that are most vulnerable to loss.

## **METHODS**

The marsh health assessment relied upon four-band multispectral imagery acquired at 2.39 meter resolution by DigitalGlobe's Quickbird satellite. The image was acquired on October 30, 2009 to coincide as closely as possible to field data collected on October 28, 2009 and November 2, 2009.

### **Field Data Collection**

Preliminary identification of possible sample sites for this research study was based on surveys performed in the field with the Grand Bayou resident guides and on existing Louisiana Department of Natural Resources (LDNR) data collection sites (Figure 1). LDNR has maintained data collection sites within the study area since 1992 to monitor environmental changes associated with the West Point a la Hache freshwater diversion siphons. Salinity (ppt), specific conductance ( $\mu\text{siemens/cm}$ ), and water temperature ( $^{\circ}\text{C}$ ), all measured at the surface and bottom of the water column, as well as water depth (ft) have been measured monthly at these 17 stations throughout the project area since May 28, 1992. In some instances in 1992, data were collected weekly or bi-weekly then averaged to obtain a monthly mean for each station. In addition, salinity, specific conductance, water temperature, and water level were recorded hourly at five stations (stations 7, 10, 17, 55, and 56) beginning January 8, 1993. These data were recorded with either Hydrolab Datasonde 3, YSI Model 6000 or 6920 continuous dataloggers. Discrete salinity was monitored monthly at 17 stations from 1992 to 2004. Salinity data will continue to be collected through 2012. When feasible, several of these sites were chosen as sampling sites for this research based upon the wealth of historical data associated with their

locations. Such data was expected to prove useful in correlating the results obtained in this study with existing historical data.

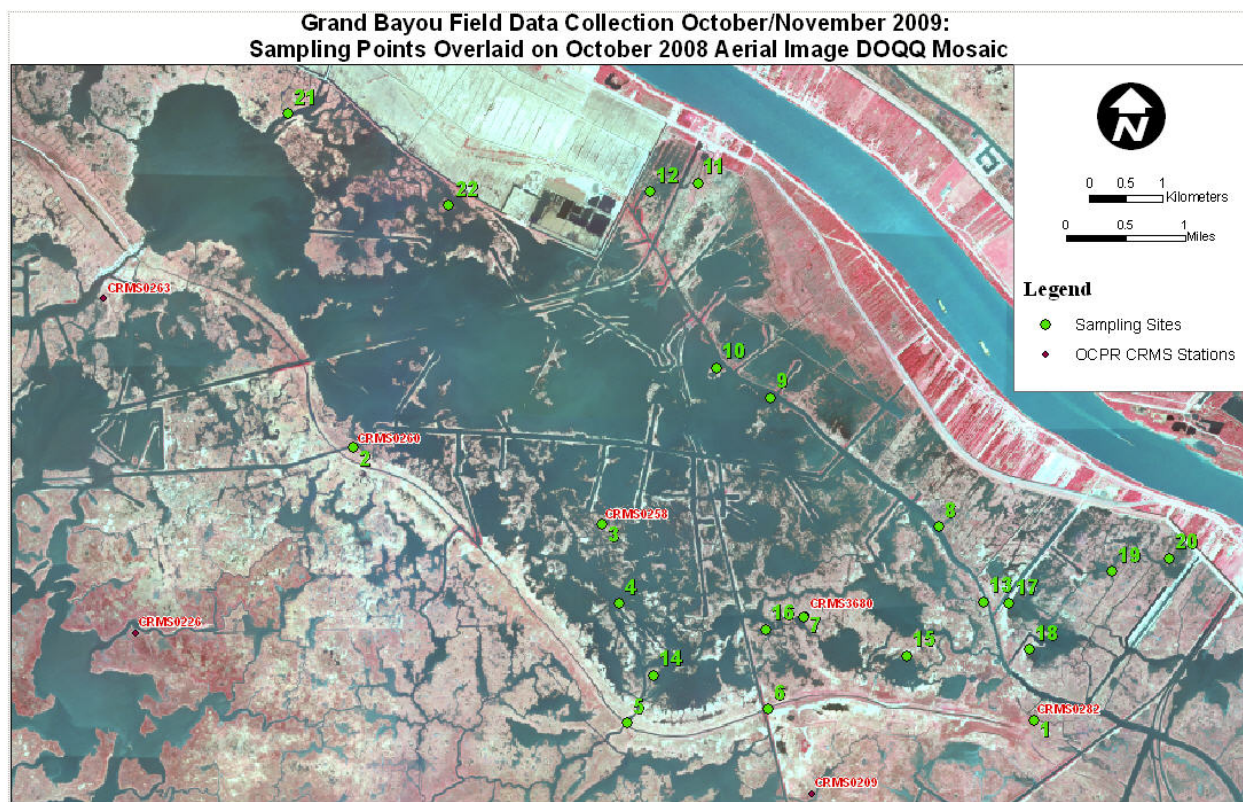


Figure 1. Sampling Points to Date Overlaid on November 2008 Aerial Image DOQQ Mosaic.

Final sampling site selection (Figure 1) was based on accessibility, extent of land loss observed, importance to the community, and availability of historical data (both TEK and scientific data). Sites were also evaluated with regard to their representation of various marsh conditions observed within the study area. Areas of broken and degraded marsh were chosen to contrast with other selected areas of relatively contiguous, ‘firm’ marsh.

Several trial field data collection campaigns were conducted to test and refine field data collection methods and to determine logistics relative to site accessibility, data and hardware needs, time required at each site, and personnel requirements for subsequent field sampling.

Instruments used in field data sampling included: Ocean Optics USB4000 Field Spectroradiometer; LI-COR LAI-2000 Plant Canopy Analyzer; and the FieldScout CM1000 Chlorophyll Meter.

The Ocean Optics USB4000 spectroradiometer system consists of two spectrometers connected together. One measures incoming sunlight and the other measures upwelling light from a target (~350-1045nm, at ~0.2nm resolution). A white reference panel (made to reflect 99% of incoming radiation) was also used to calibrate reflectance measurements. This configuration was originally developed at the University of Nebraska at Lincoln's Center for Advanced Land Management Information Technologies (UNL-CALMIT). The spectrometers were operated using a ruggedized laptop running the CALMIT Data Acquisition Program (CDAP). The simultaneous collection of upwelling and incoming radiation compensates for changes in lighting conditions between calibration and data collection.

Top of Canopy (TOC) reflectance measurements with the Ocean Optics USB4000 system were made by mounting the fiber optic of the spectroradiometer on a pole to allow for the collection of spectral reflectance data at an offset from the operator. This minimizes any shadows or interference in data collection by the user and allows for the collection of data from the top of the vegetation canopy. This configuration results in an approximate 27 inch instantaneous field of view (IFOV). The spectral reflectance field sampling configuration is shown in Figure 2.





Figure 2. Field data collection with the Ocean Optics USB4000 system.

Three reflectance measurements were made within a target data collection area (DCA) of 10 square meters and then averaged for each sampling site. One calibration measurement with the white reference panel was also made at each sampling location.

The LAI-2000 Plant Canopy Analyzer measures the probability of seeing the sky looking up through a vegetative canopy in different directions. Using these measurements, the LAI-2000 calculates foliage amount (LAI) and foliage orientation (mean foliage tilt angle) by measuring how quickly radiation is attenuated as it passes through the canopy. The LAI calculations require measurements above canopy periodically to calculate total transmittance at the time that below canopy measurements are made. In this manner, the LAI readings are calibrated for atmospheric conditions. If sky conditions are stable, one above canopy measurement will suffice for several subsequent below canopy measurements (LAI-2000, 1992). For this study, 1 above canopy measurement was made for every 4 below canopy measurements. At each sampling site three separate above/below canopy sampling sequences were made and averaged within a 10x10 meter area.

The FieldScout CM1000 Chlorophyll Meter was provided by the NASA-SSC, and senses light at wavelengths of 700nm and 840nm to estimate chlorophyll content in leaves (FieldScout, 2008). Chlorophyll *a* absorbs 700nm light and, as a result, the reflection of that wavelength from a leaf is reduced compared to the reflected 840nm light. Light having a wavelength of 840nm is unaffected by leaf chlorophyll content and serves as an indication of how much light is reflected due to leaf physical characteristics. As each measurement is taken, the result is displayed as an index with a range of 0 to 999. This index is based on the ratio of 700nm light to 840nm light reflected from the target, then multiplied by a constant. Research shows that the CM1000 produces results that are comparable with the SPAD502 chlorophyll meter that has been on the market and tested for a number of years as giving reliable estimates of chlorophyll content (Murdock et al., 2004). A standard method was used to obtain measurements with the CM1000 that included taking readings with the sun always at the user's back and at an angle of approximately 45 degrees between the user and the target. Five CM1000 measurements were taken within a 10x10 meter area and averaged at each sampling location (Figure 3).



Figure 3. Field data collection using the CM1000 Chlorophyll Meter.

## Image Calibration

The field data collected with the Ocean Optics USB4000 at the pre-defined sampling sites throughout the study area was the basis for atmospheric correction of the 10/30/2009 image dataset acquired for this project. The DCA of the field data collected at each sampling site approximates an area that includes 4 contiguous pixel values extracted and averaged from the image dataset. Image calibration was performed using an empirical line equation (ELC) between the reflectance values for the field spectroradiometer at each sampling site and the values for the same sites retrieved from the imagery.

The ELC method of calibration matches the spectral reflectance of remotely sensed images to in situ spectral reflectance measurements obtained at approximately the same time as the remote sensing overflight (Jensen, 2004). ELC is based on the following equation:

$$REFLECTANCE_k = A_k * BV_k + B_k,$$

where  $BV_k$  is the digital brightness value for a pixel of band  $k$ ,  $REFLECTANCE_k$  equals the *in situ* surface reflectance of the materials within the remote sensor IFOV at a specific wavelength,  $A_k$  is a multiplicative term (gain) affecting the  $BV_k$ , and  $B_k$  is an additive term (offset). The *in situ* and remote sensing–derived spectra are regressed and gain and offset values computed. The gain and offset values are then applied to the remote sensor data on a band by band basis, removing atmospheric attenuation (Jensen, 2004).

The spectral reflectance field data compared with the 10/30/2009 raw digital number (DN) values was acquired on 11/2/2009 (within three days of image acquisition). Reflectance values at each sampling location were averaged from the field dataset that corresponded to the spectral range of each band in the 10/30/2009 image used to calibrate the image (i.e., 450-520nm for band 1; 520-600nm for band 2; 630-690nm for band 3; and 760-900nm for band 4). These reflectance values were then averaged to obtain a single reflectance value for each band. 10 square meter areas of interest were created at each field sampling location on the 10/30/2009 image, and the pixel DN values were extracted for each area of interest. To perform the ELC process these values were averaged for each location and the resulting average DN value was matched with the corresponding derived field data reflectance value for several sampling sites.

To aid the ELC process, the 10/30/2009 image dataset of the study area was visually examined to identify a highly reflective (bright) area to represent the upper end of the regression line, and a low reflectivity (dark) area to represent the lower end of the regression line (Figure 4). Identification of these sites was aided through visual inspection of the raster attributes to identify maximum and minimum digital number (DN) values that determine the DN range of the dataset. The DN values are distributed between 0 and 255 in the data histogram. Selection of minimum

and maximum values from this histogram can be considered the extremes of the data distribution for each band. Collecting spectra from these bright and dark targets in the image of the study will provide a better ‘fit’ with the regression (Jensen, 2004). It is suggested by Smith and Milton (1999) that the empirical line method allows the calibration of remotely sensed data to reflectance with errors of only a few percent. Regression analysis was performed between the averaged Ocean Optics spectroradiometer reflectance values and the averaged raw DN values at each 10x10 meter sampling site for each Quickbird band. The results are as follows (values are R-square and Standard Error respectively): Band 1 – 0.99/0.74; Band 2 – 0.99/0.91; Band 3 – 0.99/1.5; and Band 4 – 0.98/5.29.

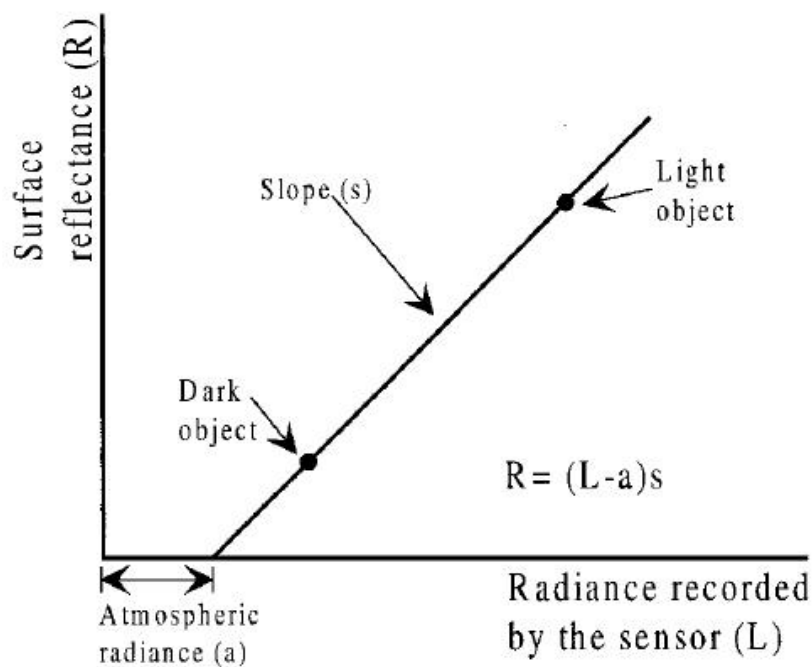


Figure 4. The development of a prediction equation from field calibration targets by the Empirical Line Method (Smith and Milton, 1999).

To validate the results of the atmospheric correction, the calibrated image was compared with the original image dataset. Using the Spectral profile tool in ERDAS Imagine, the two images were compared in terms of their spectral characteristics at the locations of each sampling site in an effort to determine if the spectra in the calibrated image matched expected field reflectance data. Examination of the spectra of other dark and light areas throughout the image was performed to determine if those areas exhibited expected reflectance characteristics (i.e., low NIR reflectance in areas of relatively deeper or clearer water, and high NIR reflectance with low red reflectance in areas of healthy marsh vegetation).

### **Estimated Chlorophyll Meter and LAI Map Production**

Because clouds and cloud shadows greatly influence reflectance values at their locations, it was necessary to mask those features as much as possible in the 10/30/2009 calibrated image (Figure 5). The purpose of this analysis was to estimate the marsh biophysical parameters sampled, all non-vegetation areas were masked out of the resulting calibrated image (i.e. water, and man-made features).

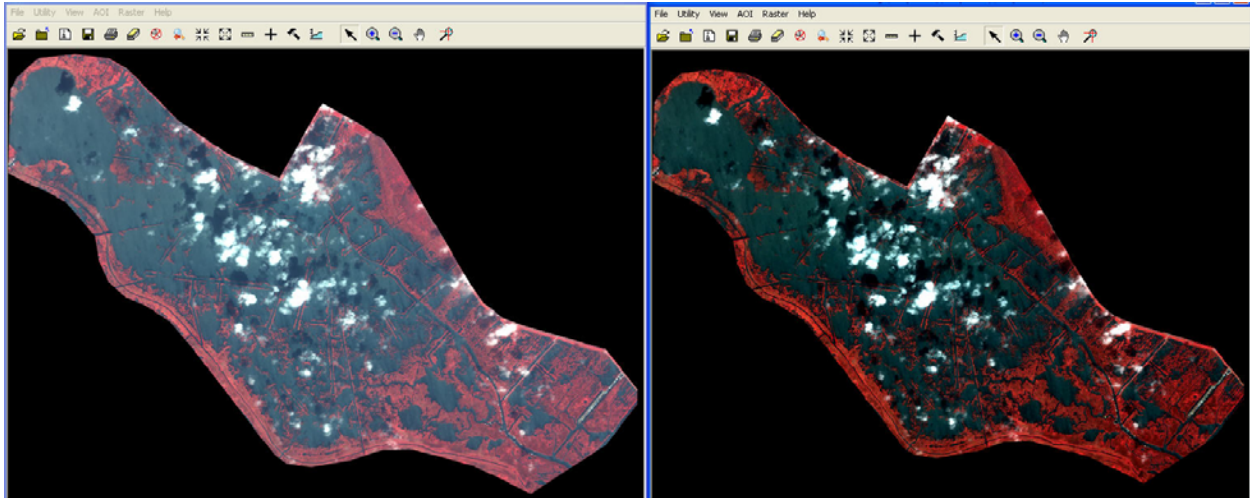


Figure 5. Uncalibrated (left, shown for comparison purposes) and Calibrated (right) 10/30/2009 image prior to masking of clouds, etc.

### **Producing the Calibrated Vegetation-Only Image**

Clouds were masked in the 10/30/2009 image by creating a thematic layer that contained pixel values that were unique to the clouds. These pixels were grouped into a ‘cloud’ class, and this class was recoded as zeros in the image attributes which indicated excluded areas. This ‘cloud mask’ file was intersected with the original extent of the calibrated 10/30/2009 image to mask out the areas obscured by clouds for later analyses. Subsequently, a supervised classification and threshold process was performed on the cloud-masked image using the methods described previously (*Chapter 3, Supervised Classification*). The resulting classes were recoded as either vegetation or non-vegetation. The non-vegetation areas were then masked out using the same procedure as was used to mask out clouds. The final calibrated, masked 10/30/2009 image dataset used in developing the estimated LAI and Chlorophyll maps is shown in Figure 6.

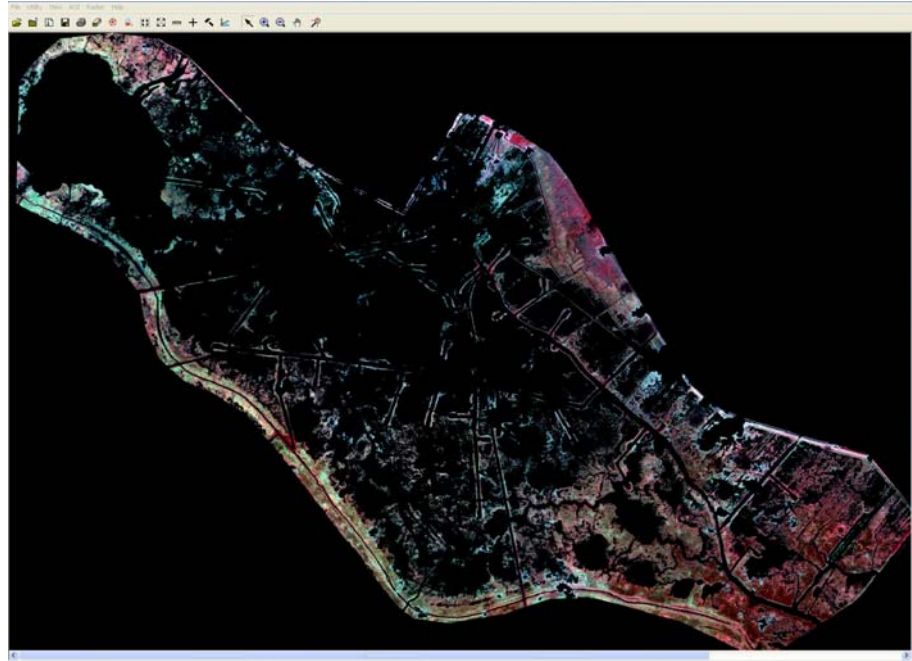


Figure 6. Calibrated, vegetation only 10/30/2009 image dataset.

### **Vegetation Indices Tested for Correlation with Chlorophyll and LAI Field Measurements**

Several vegetation indices were derived using the averaged reflectance values extracted from the 11/2/2009 reflectance field data that matched the calibrated image dataset for each band at each sampling site. The vegetation indices tested were found to be promising in mapping vegetative vigor as it relates to chlorophyll content and LAI in the literature review for this study. These vegetation indices were statistically assessed for correlation with the ground information acquired and are described below.

#### ***The Normalized Difference Vegetation Index (NDVI)***

The NDVI is one of the most widely used indices for measuring vegetation vigor and/or density (Zhang et al., 1997). The basis for the NDVI is that healthy vegetation is highly reflective in the near infrared band and plant chlorophyll is highly absorbent in the red band



(Tucker, 1979). The NDVI was calculated from the reflectance values of the red and near-infrared bands of the imagery as follows:  $NDVI = (near\ infrared - red) / (near\ infrared + red)$ .

The strength of the NDVI is that it reduces many forms of noise (illumination differences, cloud shadows, atmospheric attenuation, etc.) that may be present in the imagery. However, some disadvantages to the NDVI are that it can exhibit saturation with high biomass conditions, and is very sensitive to canopy background variations (such as soil differences and spectral influence). There are other vegetation indices which may be compared with the NDVI that have been developed to minimize the contribution of soil variation and atmospheric scattering, and could provide better results for wetland conditions (Baret and Guyot 1991, and Huete et al., 1994). Examples of these indices include the Soil Adjusted Vegetation Index (SAVI), the Atmospherically Resistant Vegetation Index (ARVI), and the Soil Adjusted and Atmospherically Resistant Vegetation Index (SARVI). A study by Zhang et al. (1997) used these indices applied to remotely sensed data to successfully estimate spatial patterns of biomass across a salt marsh in San Pablo Bay, California.

### ***The Ratio Vegetation Index (RVI)***

The RVI was first described by Jordan (1969), and is the most widely calculated vegetation index. A common application of the RVI is to eliminate various albedo effects in an image, but it has also been used to enhance vegetation variability in an image and relate to LAI. Wang et al. (2004) notes that there is a direct but nonlinear relationship between the RVI and NDVI, and thus the two indices contain similar information. The RVI was calculated as follows:  $RVI = (near\ infrared) / (red)$ . This index was included since it is very similar to the band ratio that the CM1000 chlorophyll meter uses to calculate its index measurements.

### ***The Green Normalized Difference Vegetation Index (GVI)***

The GVI has been used to assess plant growth performance, and has been proposed as a superior index to the NDVI (Gitelson et al., 1996). It has also been used to assess variation of biomass in green crops (Vigier et al., 2004). This index is similar to the NDVI, however it uses the green band instead of the red, and was calculated as follows:  $(\text{near infrared} - \text{green}) / (\text{near infrared} + \text{green})$ .

### ***The Atmospheric Resistant Vegetation Index (ARVI)***

The ARVI was introduced by Kaufman and Tanre (1992) and, in comparison to the NDVI, is resistant to atmospheric effects. Its resistance is accomplished through a self correcting process which uses the difference in the radiance between the blue and the red bands (Kaufman and Tanre, 1992). Qi et al. (1994) showed that the ARVI is slightly more sensitive to changes in vegetation than other indices tested and is less sensitive to the atmosphere and soil for moderate to high vegetation cover. The ARVI was-calculated as follows:  $\text{ARVI} = (\text{near infrared} - (2.0 * \text{red} - \text{blue})) / (\text{near infrared} + (2.0 * \text{red} - \text{blue}))$ .

### ***The Second Modified Soil Adjusted Vegetation Index (MSAVI2)***

MSAVI2 was developed by Qi et al. (1994) as an improvement on the Modified Soil Adjusted Index (MSAVI). The soil adjusted indices attempt to minimize soil background noise in an image. Soil adjusted indices reduce soil noise at the cost of decreasing the dynamic range of the index. As a result, these indices are slightly less sensitive to changes in vegetation cover, and are more sensitive to atmospheric variations than the NDVI (Qi et al., 1994). The MSAVI2 index was tested to determine if soil background noise was a factor in this analysis. It was calculated using the following formula:  $\text{MSAVI2} = (1/2) * (2 (\text{near infrared} + 1) - \sqrt{(2 * \text{near infrared} + 1)^2 - 8 (\text{near infrared} - \text{red})})$ .

### ***The Modified Triangular Vegetation Index (MTV12)***

The MTV12 has been used to estimate green leaf area index (Haboudane et al., 2004). MTV12 is included in a group of vegetation indices known as Chlorophyll-corrected vegetation indices. This index group has been shown to be more responsive to green LAI variations by suppressing the ratio of NIR to red to lower the sensitivity to chlorophyll effects (He et al., 2006; Haboudane et al., 2004). Because field data collection was conducted at the end of the growing season, plant chlorophyll concentrations may have been decreasing in the study area. This index was included because of its potential for estimating LAI despite chlorophyll variability. Variety differences in the marsh vegetation that were at varying phenological stages could have contributed to high variability in chlorophyll content at the time. The MTV12 was calculated as follows:  $1.5 * (1.2 * (\text{near infrared} - \text{green}) - 2.5 * (\text{red} - \text{green})) / \sqrt{(2 * \text{near infrared} + 1)^2 - 6 * \text{near infrared} + 5 * (\text{red})\sqrt{\text{red}}} - 0.5$ .

### ***The Wide Dynamic Range Vegetation Index (WDRVI)***

The WDRVI, a modification of the NDVI, enhances the dynamic range of the NDVI, which is known to exhibit reduced sensitivity to moderate to high vegetation density (Gitelson, 2004). Because this study area is generally characterized by high density marsh vegetation, the WDRVI was employed in this analysis. It was calculated using the following equation:  $\text{WDRVI} = (a * \text{near infrared} - \text{red}) / (a * \text{near infrared} + \text{red})$ , where  $a$  is a weighting parameter that can be fine tuned for a particular study area. Gitelson (2004) suggests that a value of 0.20 for  $a$  is recommended as generally effective in revealing more variation in settings with moderate to high LAI. Therefore, 0.20 was used for  $a$  in this study.

Each vegetation index described above was produced from the averaged field reflectance data that corresponded to each band in the 10/30/2009 image. Also, each vegetation index was computed for the calibrated, masked 10/30/2009 image dataset. This was done for the reflectance values at each sampling location. Two sampling sites (site ID #4 for Chlorophyll Meter and site #22 for LAI) were determined to be statistical outliers when examining the data distribution and semiovariogram/covariance cloud for the field data collected (Chlorophyll Meter value at ID #4 = 60, and LAI value at ID #22 = 1.14). These samples were declared erroneous and excluded from the dataset for further analysis. The remaining field data was normally distributed and included observations at 18 sites for Chlorophyll content and LAI.

Each field dataset (Chlorophyll Meter and LAI) was divided into a test and validation dataset so that the resulting estimated maps produced with the test datasets could be assessed for accuracy. Ten sampling sites were randomly chosen as the test dataset and the remaining 8 sites served as the validation dataset for each parameter estimated. The resulting test datasets are shown in Tables 1 and 2.

Table 1. Chlorophyll Meter test dataset for Stepwise Multiple Regression Analysis.

A	B	C	D	E	F	G	H	I	J	K	L	M
ID	ChlMeter	RefBand1	RefBand2	RefBand3	RefBand4	NDVI	WDRVI	ARVI	MSAVI2	MTVI2	Carter	GVI
1	148	1.15762	2.412855	2.041259	18.32636	0.799558	-0.05385	0.724732	0.885858	0.828377	8.977969	0.083428
2	164	2.445928	4.216032	3.944131	24.6053	0.723698	-0.23164	0.637753	0.836931	0.772647	6.238459	0.033321
5	93	3.898479	6.733978	7.24356	29.31252	0.603701	-0.42382	0.469256	0.749684	0.664938	4.0467	-0.03646
6	141	2.83957	5.071363	4.52556	23.3118	0.674857	-0.32003	0.579211	0.802468	0.754212	5.151141	0.056873
11	186	2.362729	5.035076	2.759116	35.68921	0.856477	0.127971	0.837532	0.921679	0.898091	12.93502	0.292007
16	106	1.810988	3.106064	3.789892	13.15788	0.552756	-0.48458	0.390406	0.70405	0.596874	3.471834	-0.09916
22	196	2.527135	4.462937	3.817864	22.17327	0.706218	-0.2652	0.625495	0.824555	0.780098	5.807767	0.0779
24	139	0.873749	1.841927	1.392057	13.63952	0.814782	-0.0102	0.754292	0.894479	0.852082	9.798102	0.139107
12	117	2.839639	5.032705	4.375023	29.49653	0.74167	-0.1946	0.666144	0.84951	0.793693	6.742027	0.069909
14	124	1.732042	3.115015	3.113748	19.01836	0.718622	-0.24163	0.617633	0.832613	0.760176	6.107868	0.000203

Table 2. LAI test dataset for Stepwise Multiple Regression Analysis.

A	B	C	D	E	F	G	H	I	J	K	L	M
ID	LAI	RefBand1	RefBand2	RefBand3	RefBand4	NDVI	WDRVI	ARVI	MSAVI2	MTVI2	Carter	GVI
1	2.94	1.15762	2.412855	2.041259	18.32636	0.799558	-0.05385	0.724732	0.885858	0.828377	8.977969	0.083428
2	3.24	2.445928	4.216032	3.944131	24.6053	0.723698	-0.23164	0.637753	0.836931	0.772647	6.238459	0.033321
4	2.06	2.847164	5.071322	4.78088	30.23304	0.726915	-0.22521	0.636535	0.839639	0.772193	4.0467	-0.03646
5	2.15	3.898479	6.733978	7.24356	29.31252	0.603701	-0.42382	0.469256	0.749684	0.664938	5.151141	0.056873
6	3.03	2.83957	5.071363	4.52556	23.3118	0.674857	-0.32003	0.579211	0.802468	0.754212	4.937863	-0.03193
11	4.05	2.362729	5.035076	2.759116	35.68921	0.856477	0.127971	0.837532	0.921679	0.898091	5.485915	0.053365
16	1.95	1.810988	3.106064	3.789892	13.15788	0.552756	-0.48458	0.390406	0.70405	0.596874	6.469027	0.009401
24	3.06	0.873749	1.841927	1.392057	13.63952	0.814782	-0.0102	0.754292	0.894479	0.852082	9.798102	0.139107
12	3.81	2.839639	5.032705	4.375023	29.49653	0.74167	-0.1946	0.666144	0.84951	0.793693	6.742027	0.069909
14	2.96	1.732042	3.115015	3.113748	19.01836	0.718622	-0.24163	0.617633	0.832613	0.760176	6.107868	0.000203

Stepwise multiple regression and multiple correlation analysis were performed on each test dataset using SAS software (SAS Institute, 2002) to determine the best band combination/vegetation index to use for each dependant variable tested (ChlMeter and LAI values), and to test for the presence of multicollinearity among the variables in the regression model (Cody and Smith, 1991). The statistical regression analysis was performed to ensure a relationship existed with the imagery, and given that relationship, the image processing technique determined to have the strongest relationship with the field data collected was used to create the estimated Chlorophyll Meter and LAI maps. The parameter estimates for the regression chosen as the best estimate for each dependant variable was applied to the corresponding 10/30/2009 index image.

The resulting vegetation index ranges for the estimated chlorophyll content and LAI images were used to recode the image into relative categories of vegetative health and produce a classed 'relative' marsh health map. The class threshold values were determined based on statistical analyses of the vegetation index values across the study area and consultation with OCPR project collaborators. As a result, a 3 class Natural Breaks (Jenks) classification of the

continuous data values for each estimated map was used for display and recoded as high, medium, and low relative marsh health classes.

It should be noted that the Chlorophyll Meter and LAI measurements were collected late in the growing season (late October to early November) at a time when natural senescence was occurring in the marsh vegetation. This timeframe was not ideal for data collection related to marsh health given that vegetative stress measured could be due to natural plant phenology in this area.

### **Fragmentation Map Production**

The final land-water image for each historical image date was used to produce fragmentation maps. This was accomplished with the Landscape Fragmentation tool in ArcGIS, which testing has shown to be equivalent to procedures used by Vogt et al. (2007). For the purposes of this study, landscape fragmentation classes were used based upon research by Vogt et al. (2007) for mapping spatial patterns and further refined by consultation with the collaborating OCPR scientists with the aim of a mapping product that could be easily integrated into their existing decision-support system. As a result the land class in each image was further classified into 6 categories: Perforated; Edge; Patch; Small Core (< 250 acres); Medium Core (between 250 and 500 acres); and Large Core (> 500 acres). Each land-water input image was then recoded as: 1 = the land covers causing the fragmentation (i.e. water); and 2 = the land covers for which fragmentation was analyzed (i.e. land). An edge width parameter was specified as 15 meters. The edge width parameter is the distance over which the fragmented land cover type of interest can be degraded by the fragmenting land cover types. The literature indicates that the edge width varies by the issue of interest (Riitters et al., 2000; Vogt et al., 2009). The edge effect distance was chosen after testing several different values for this parameter, and

based on visual examinations of the resulting fragmentation maps and input datasets, it was decided that 15 meters represented the optimum distance for edge effect influence for this dataset.

The fragmentation maps were then combined in ArcGIS with the corresponding historical land change image. This procedure combines multiple raster input datasets so that a unique output value is assigned to each unique combination of input values (ESRI, 2010). The resulting combined images showed areas where the land loss class from the land change images intersected with the fragmentation map classes. These areas were represented as separate classes in the combined images that were labeled as: Land Loss to Patch; Land Loss to Edge; Land Loss to Perforated; Land Loss to Core 1; Land Loss to Core 2; and Land Loss to Core 3. Area was calculated for each of these classes in the combined image, and then the proportion of the total area that went to land loss was calculated for each fragmentation class for each historical image date.

The proportions of each fragmentation class that went to land loss for each date were statistically analyzed in SAS with a General Linear Model (GLM) to determine any significant difference existing among the land loss proportions of the fragmentation classes (Cody and Smith, 1991). GLM was used instead of an Analysis of Variance (ANOVA) procedure because it is similar to an ANOVA, but is used to analyze unbalanced designs (Cody and Smith, 1991). Since the Core class was merged, there were more observations for this class than the others, thus making it an unbalanced design. A Duncan's multiple comparison test was performed to further investigate any differences existing between the fragmentation classes (Cody and Smith, 1991).

The result of this statistical analysis was used to rank the fragmentation classes for risk of loss. The fragmentation map procedure was then applied to the 2009 final land-water image to create the 2009 fragmentation map. The 2009 fragmentation map was recoded according to the risk of loss determined from the statistical analysis of the historical loss proportions of fragmentation classes. The 2009 fragmentation map displaying areas ranked for risk of loss based on historical spatial trends was then combined with the maps estimating biophysical marsh vegetation parameters (i.e. plant health) to produce a map depicting relative risk of loss for the remaining marsh land of the study area.

To combine the derived datasets to map relative risk of loss, the values of the derived datasets representing estimated chlorophyll content, estimated LAI, and fragmentation class were all reclassified to a common measurement scale (High, Medium, and Low risk of loss). Values representing water were restricted from this analysis so that only marsh areas would be included. A Weighted Overlay was performed in ArcGIS where the input datasets were assigned percentages of influence in the resulting map. The higher the percentage, the more influence a particular dataset has in the resulting map. The estimated chlorophyll content and LAI input datasets were each weighted at 25%, and the fragmentation map was weighted at the remaining 50%. The input datasets were weighted in this way so that the total weighting would be divided equally between the biophysical (chlorophyll content and LAI) and spatial relationship (fragmentation class) measurements.



## RESULTS

### Estimated Chlorophyll Meter and LAI Map Production Results

The results of the statistical analysis indicate that the best model for estimating Chlorophyll Meter values is a GVI (green vegetation index) with these parameter estimates: intercept = 127.94741, and slope = 217.98764. The R-Square for this model = 0.47 and is significant with a P-value of 0.0278. A noise reduction filter was applied to the resulting estimated Chlorophyll Meter map and the result is shown in Figure 7.

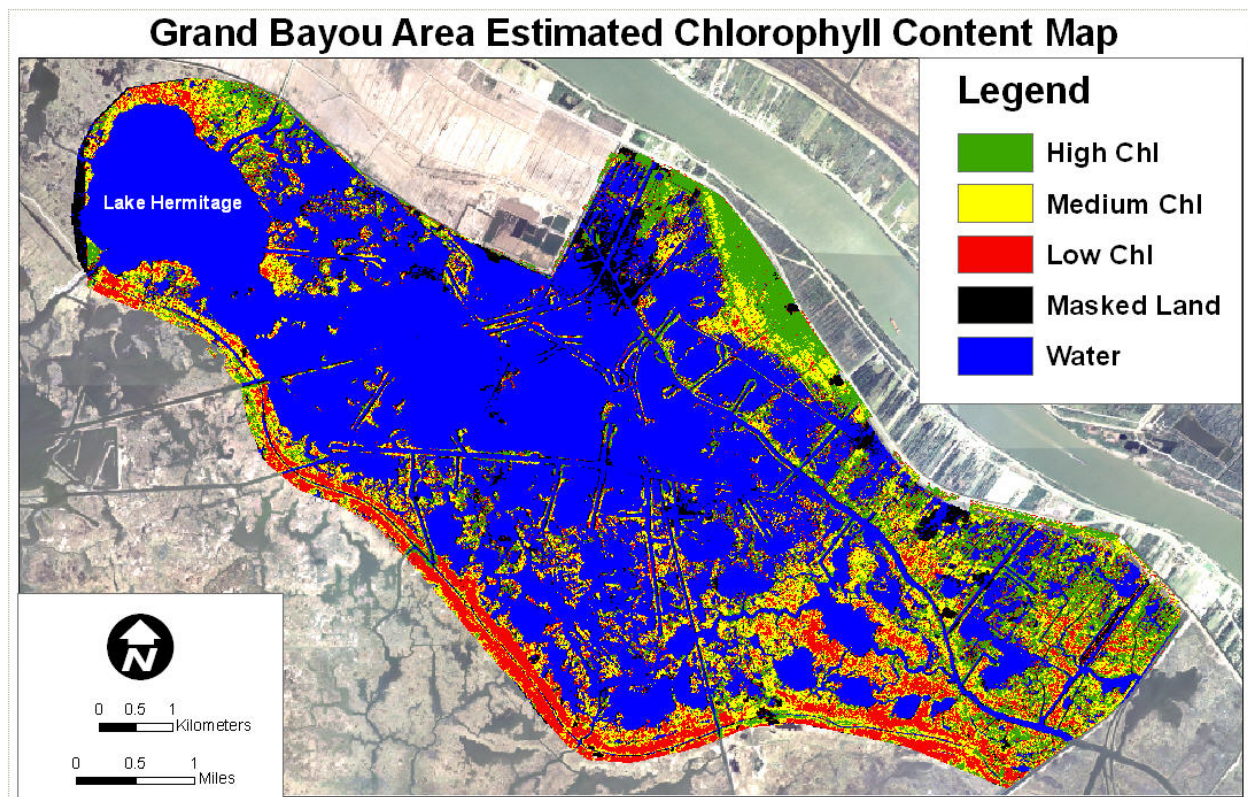


Figure 7. Estimated chlorophyll content map.

The results of the accuracy analysis of the estimated Chlorophyll Meter map produced using the validation dataset are shown in Figures 8 and 9. The standard error resulting from the regression of predicted values versus actual was 31.64.

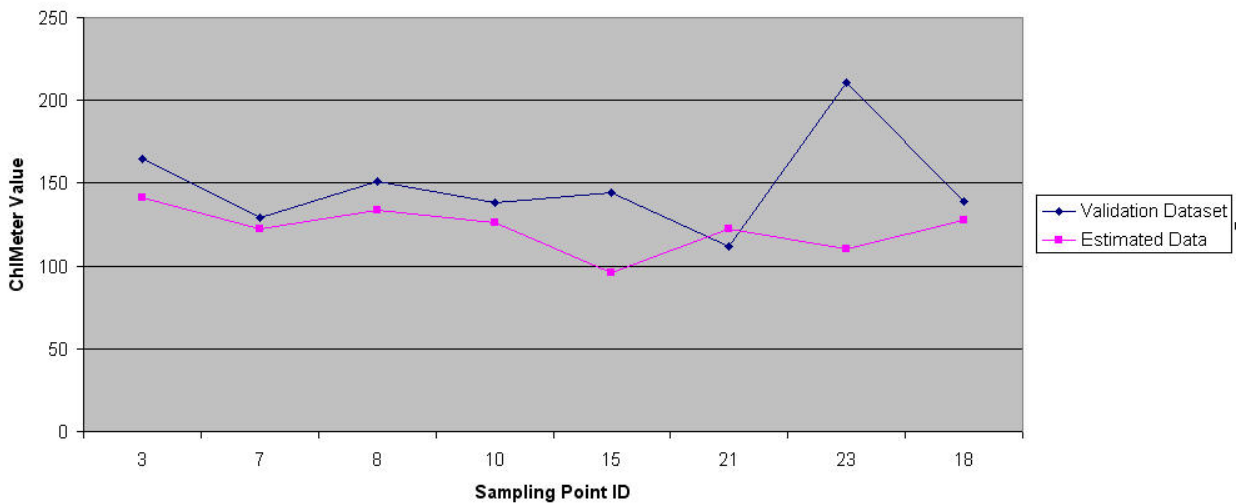


Figure 8. Estimated chlorophyll meter map validation dataset plot.

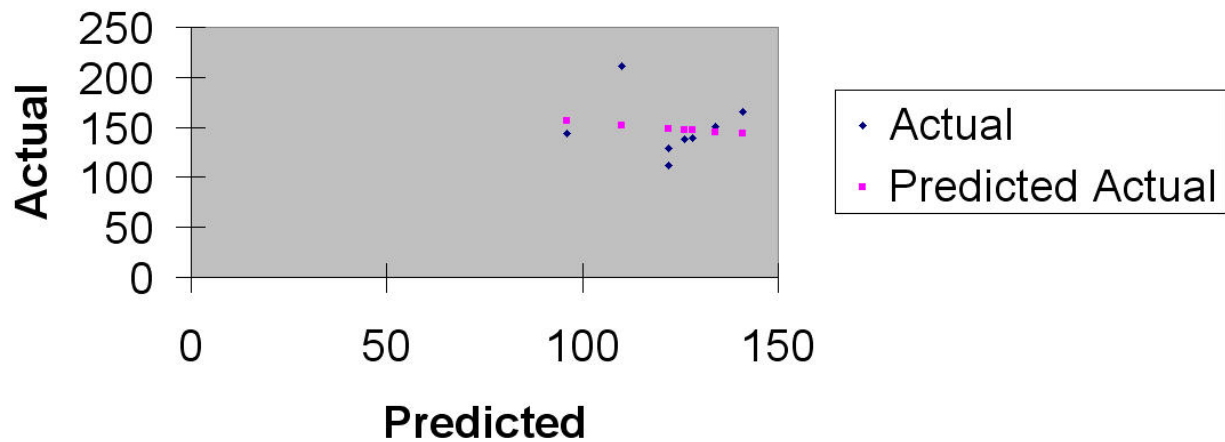


Figure 9. Chlorophyll meter validation plot of predicted versus actual values.

The best model for producing the estimated LAI map is an MTV12 (modified triangular vegetation index) with these parameter estimates: intercept = -1.84060, and slope = 6.19449. The R-Square for this model = 0.59 and is significant with a P-value of 0.0098. A noise reduction filter was also applied to the resulting estimated LAI map and the result is shown in Figure 10.

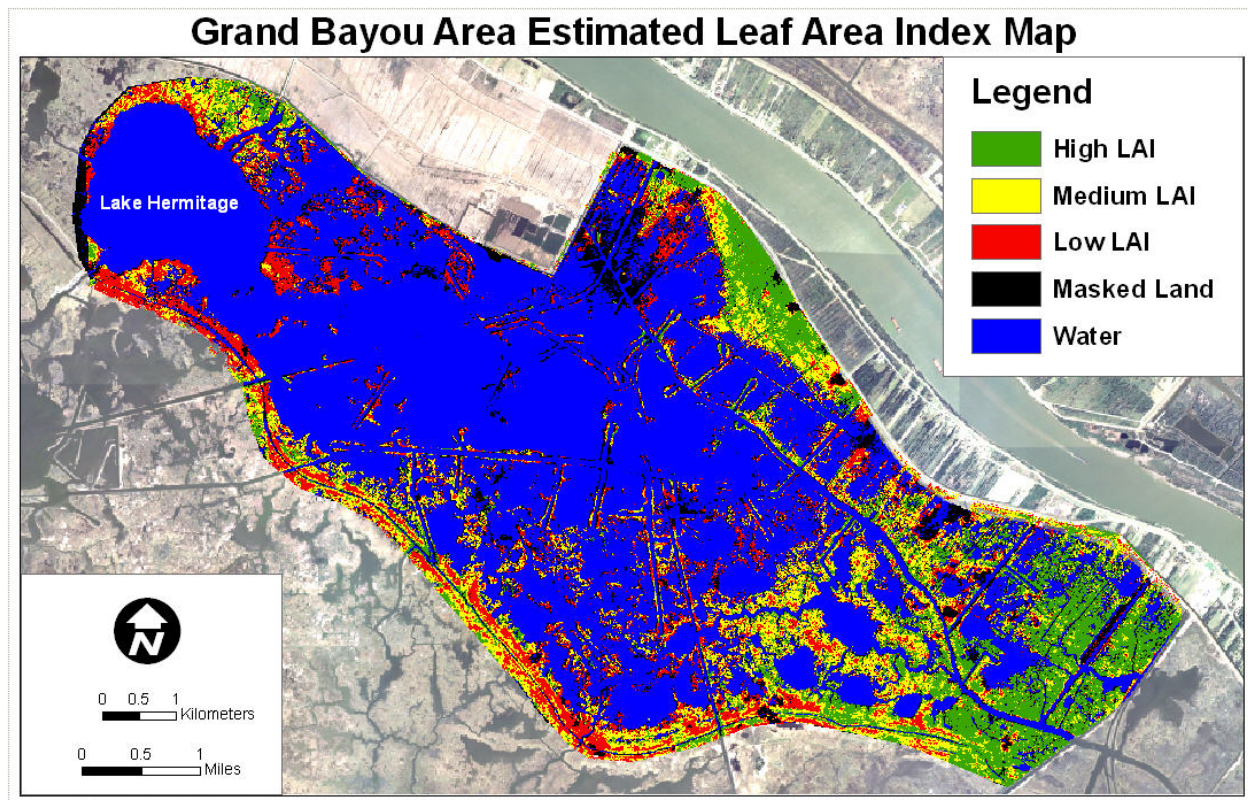


Figure 10. Estimated Leaf Area Index map.

The results of the accuracy analysis of the estimated LAI map produced using the validation dataset are shown in Figures 11 and 12. The standard error resulting from the regression of predicted values versus actual was 0.68.



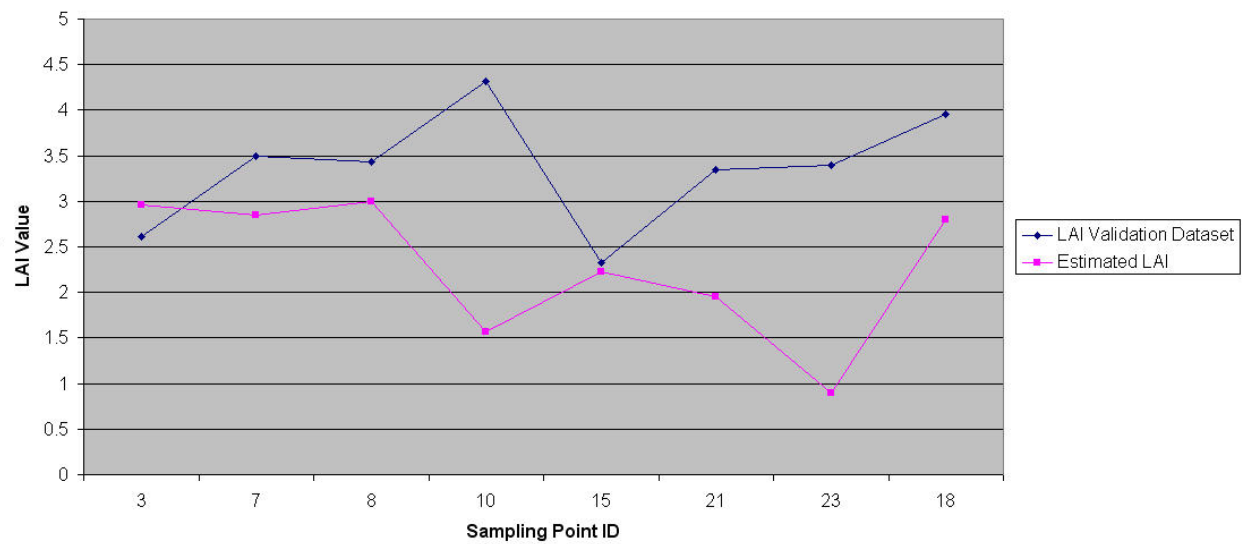


Figure 11. Estimated LAI map validation dataset plot.

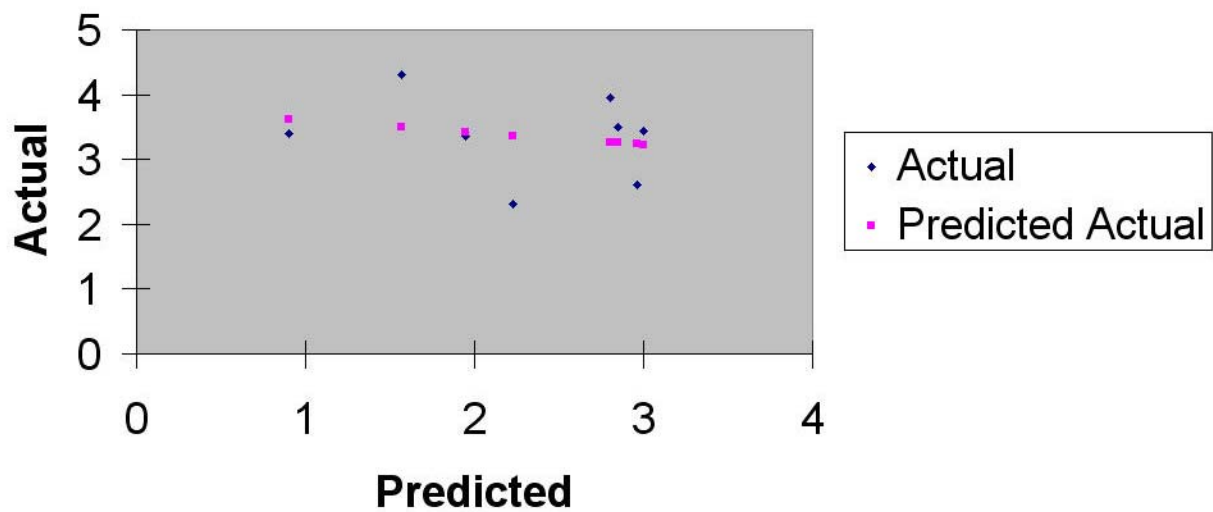


Figure 12. LAI validation plot of predicted versus actual values.

### Fragmentation Map Results

The fragmentation maps produced from each historical land-water image are shown in Figures 13 through 19.

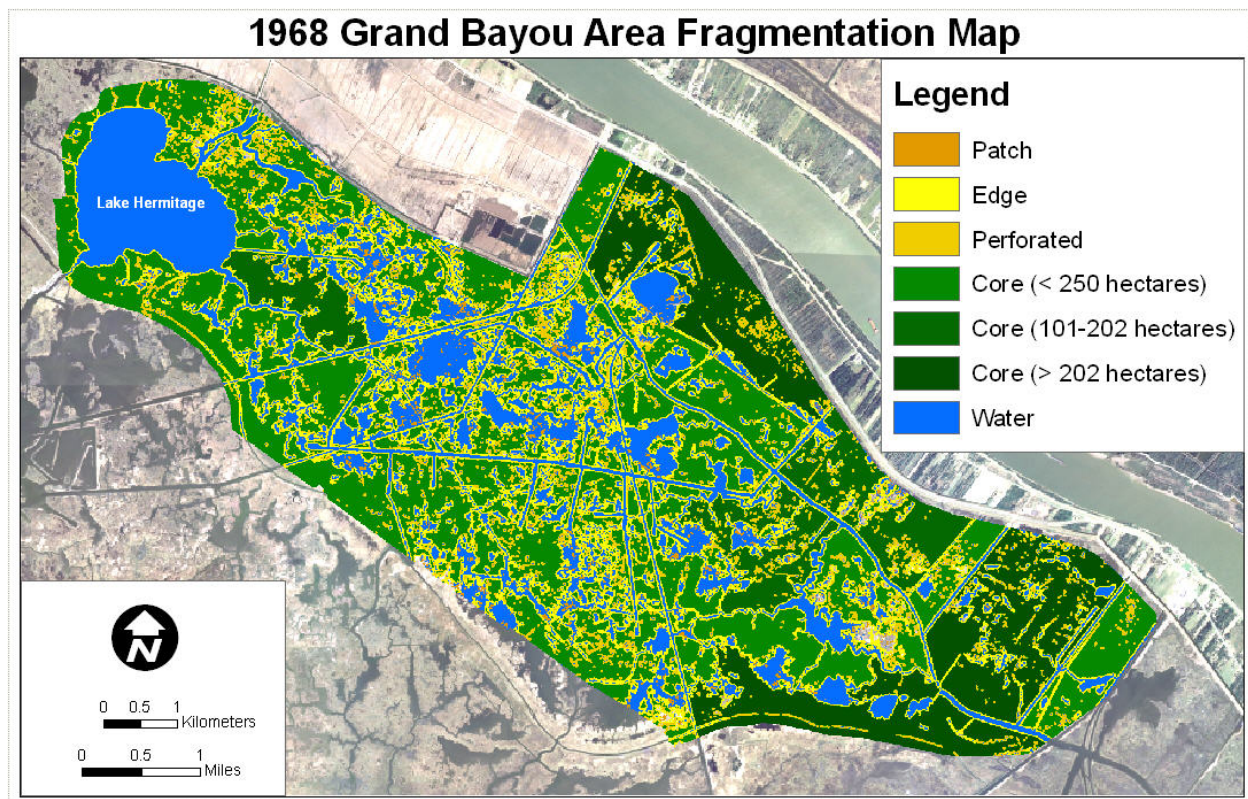


Figure 13. 1968 Grand Bayou area fragmentation map.

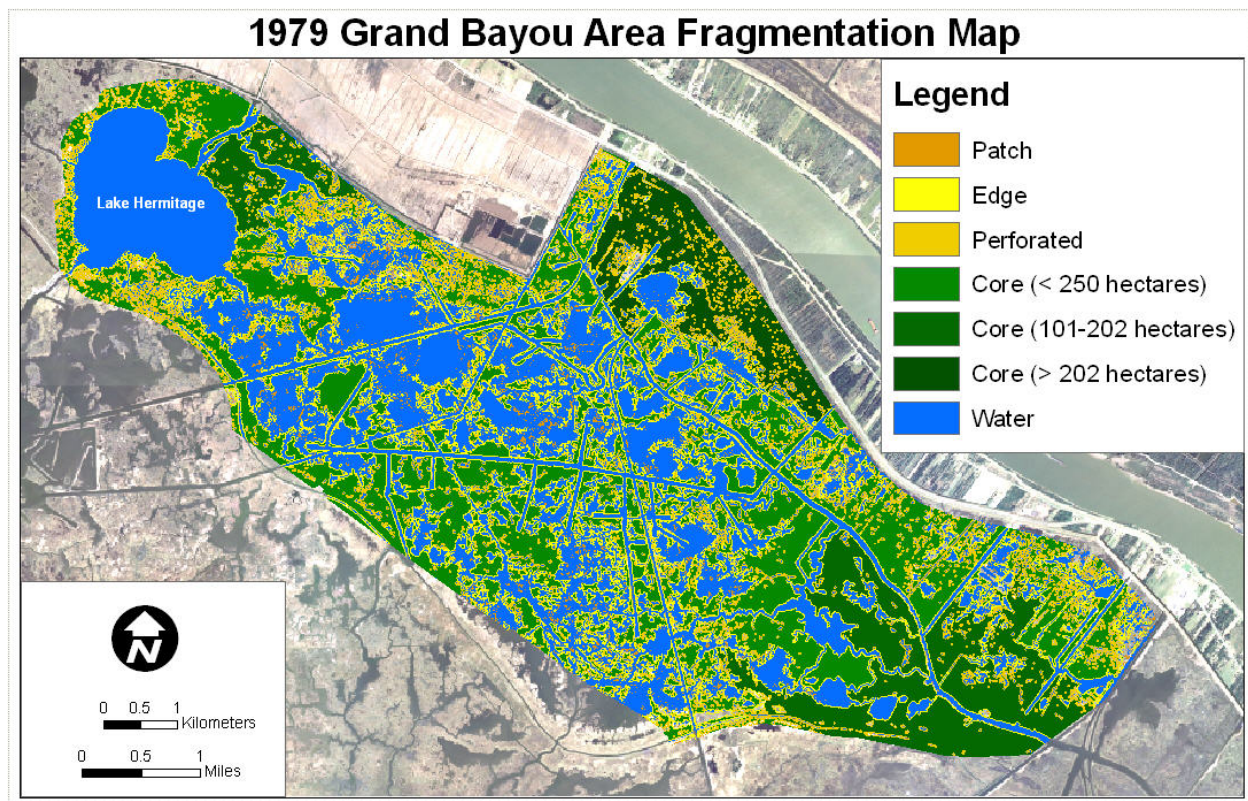


Figure 14. 1979 Grand Bayou area fragmentation map.



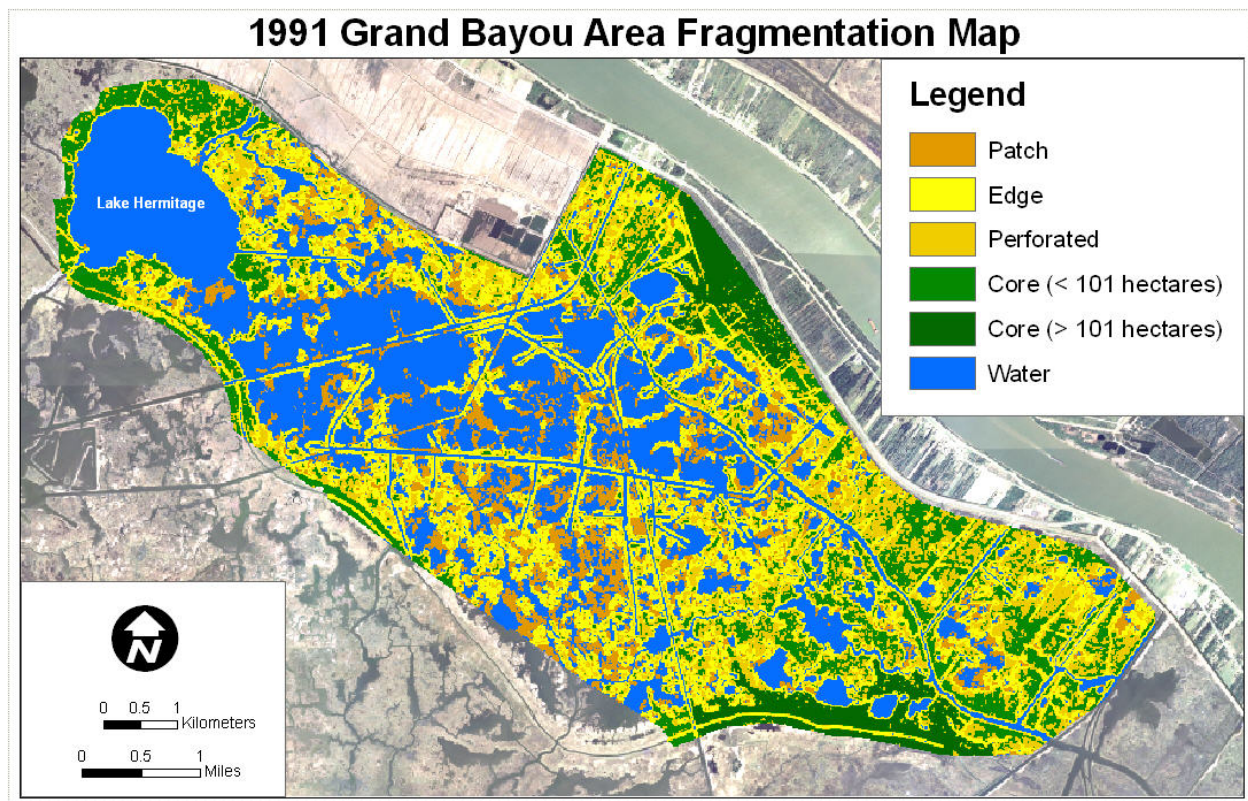


Figure 15. 1991 Grand Bayou area fragmentation map.

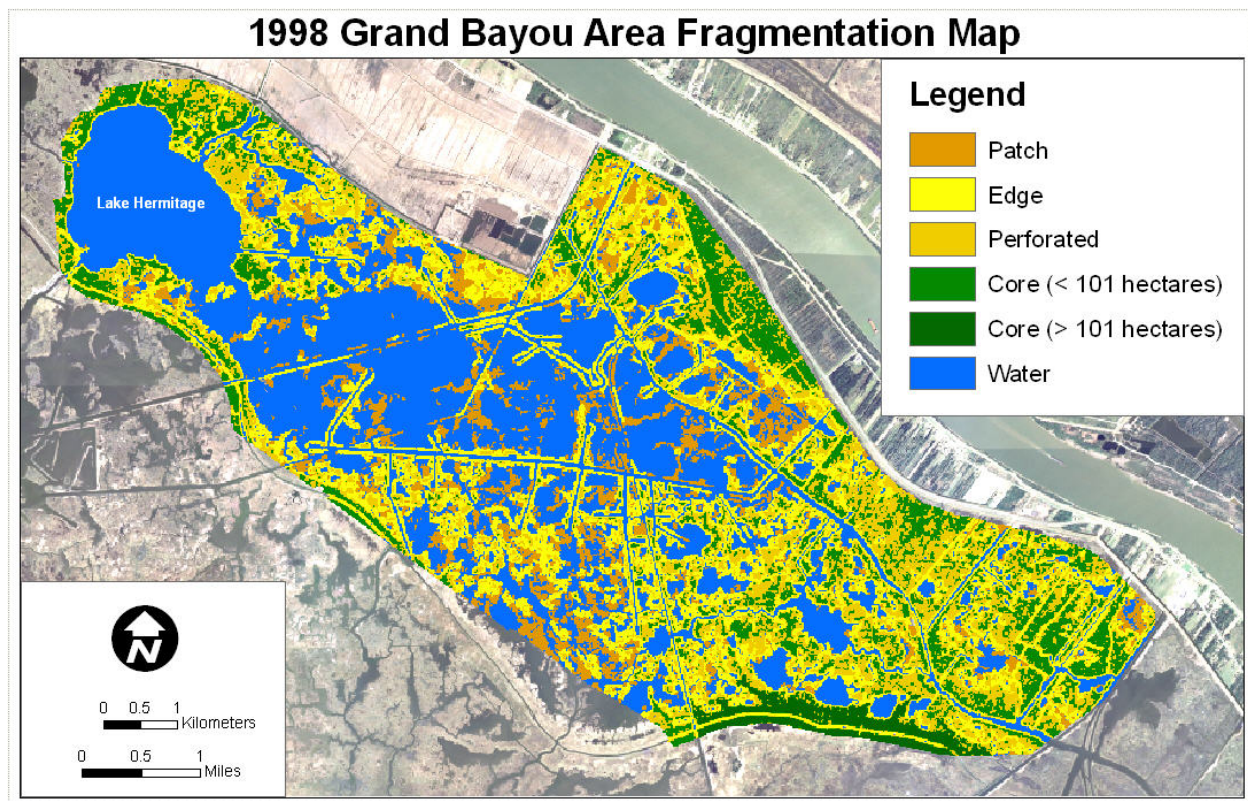


Figure 16. 1998 Grand Bayou area fragmentation map.



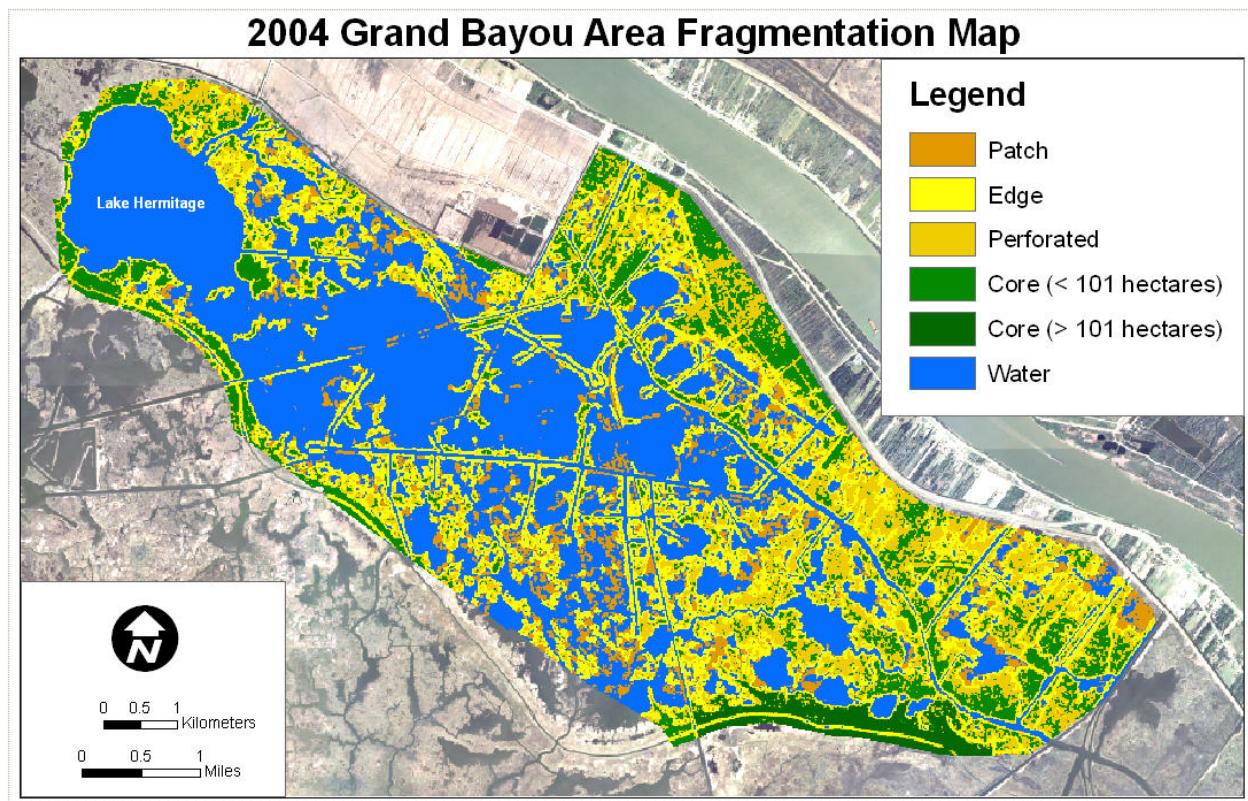


Figure 17. 2004 Grand Bayou area fragmentation map.

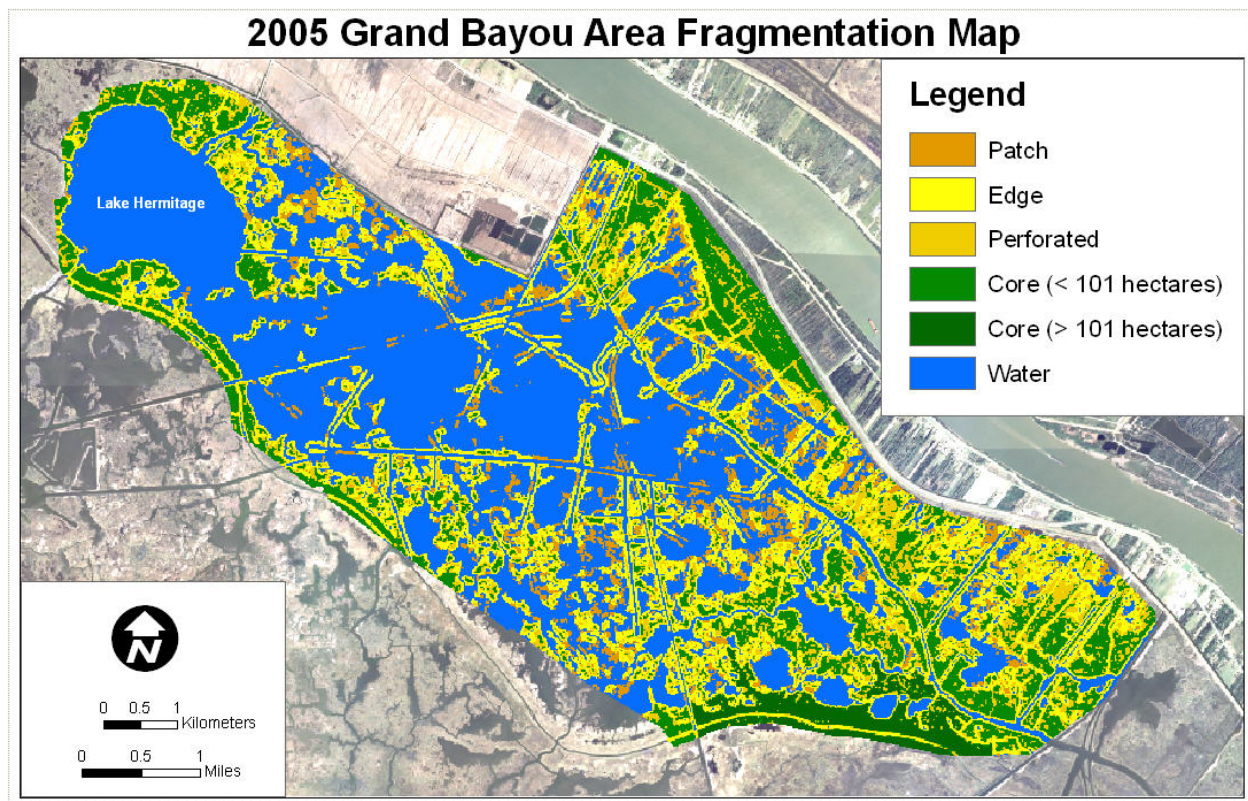


Figure 18. 2005 Grand Bayou area fragmentation map.



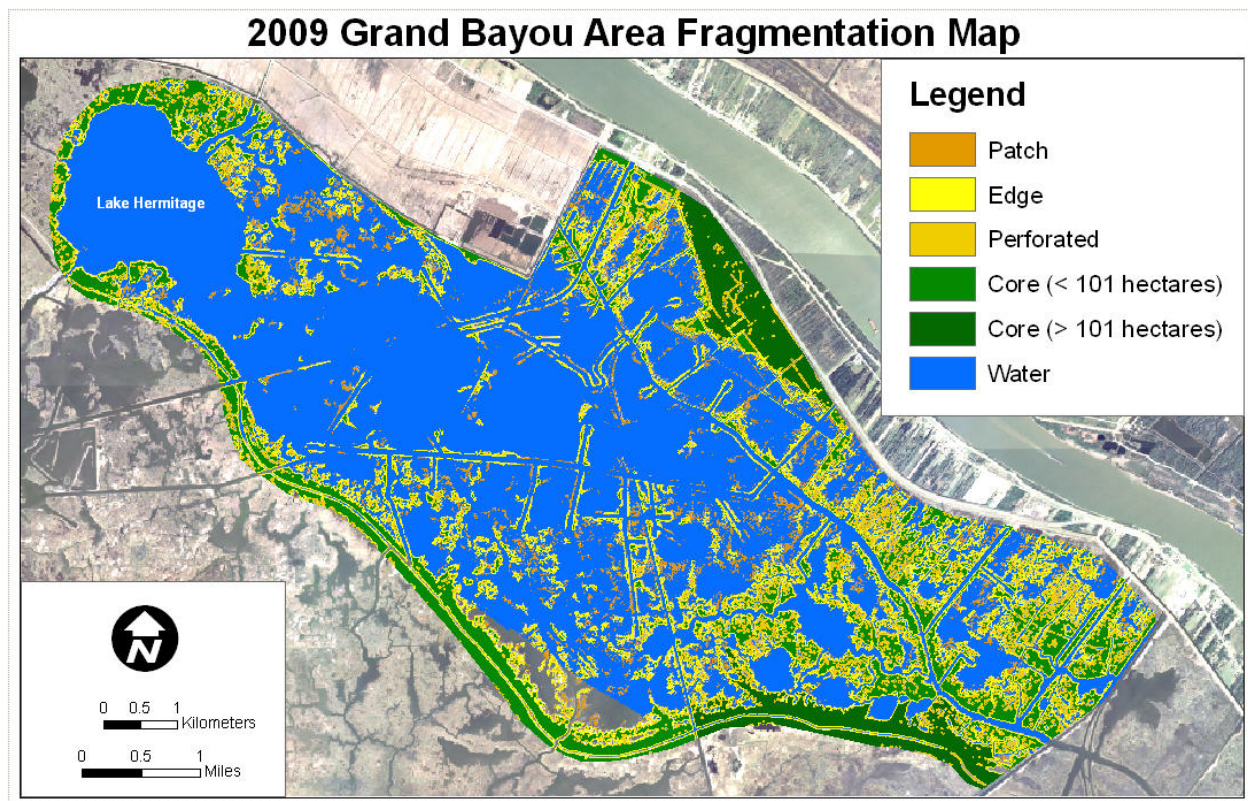


Figure 19. 2009 Grand Bayou area fragmentation map.

The fragmentation class land loss proportions calculated for each combined image is reported in Table 3.

Table 3. Fragmentation class land loss proportions calculated for each combined image.

	A	B	C	D	E	F	G
1	Combine Image	Patch to Land Loss	Edge to Land Loss	Perforated to Land Loss	Core1 to Land Loss	Core2 to Land Loss	Core3 to Land Loss
2	1968 Combine	0.7364	0.6005	0.4577	0.4121	0.3647	0.1416
3	1979 Combine	0.7159	0.533	0.364	0.2691	0.2167	0.0827
4	1995 Combine	0.4533	0.2444	0.1339	0.0781		
5	1998 Combine	0.5385	0.2893	0.1885	0.0739	0.0025	
6	2004 Combine	0.4342	0.2545	0.1557	0.0706	0.005	
7	2005 Combine	0.4858	0.2681	0.1414	0.0433	0.0136	

The results of the GLM statistical analysis showed that the model was significant with an F-value of 13.38 (df = 3), and a  $Pr > F = < 0.0001$ . The Duncan's multiple range test (alpha = 0.05) showed that the Patch class was significantly more likely to be lost than any other class.

While the Edge class is significantly more likely to be lost than the Core class, it is not significantly different from the Perforated class. The Core class is significantly less likely to be lost than is either Patch or Edge areas, but is not significantly different from Perforated areas. The Duncan grouping and respective means are shown in Table 4.

Table 4. Results of Duncan's multiple range test of fragmentation class loss risk assessment.

**Means with the same letter are not significantly different.**

<b>Duncan Grouping</b>	<b>Mean</b>	<b>N</b>	<b>Class</b>
<b>A</b>	<b>0.56068</b>	<b>6</b>	<b>Patch</b>
<b>B</b>	<b>0.36497</b>	<b>6</b>	<b>Edge</b>
<b>B</b>			
<b>C</b>	<b>0.24020</b>	<b>6</b>	<b>Perforat</b>
<b>C</b>			
<b>C</b>	<b>0.13645</b>	<b>13</b>	<b>Core</b>

As a result of this analysis, the 2009 fragmentation map was recoded as follows: Patch class = High risk of loss; Edge class = Medium risk of loss; and Perforated and Core areas were combined to = Low risk areas of loss. This recoded 3-class fragmentation map was then combined with the estimated chlorophyll content and estimated LAI maps with the same classification scheme to produce the final marsh vulnerability map shown in Figure 20.

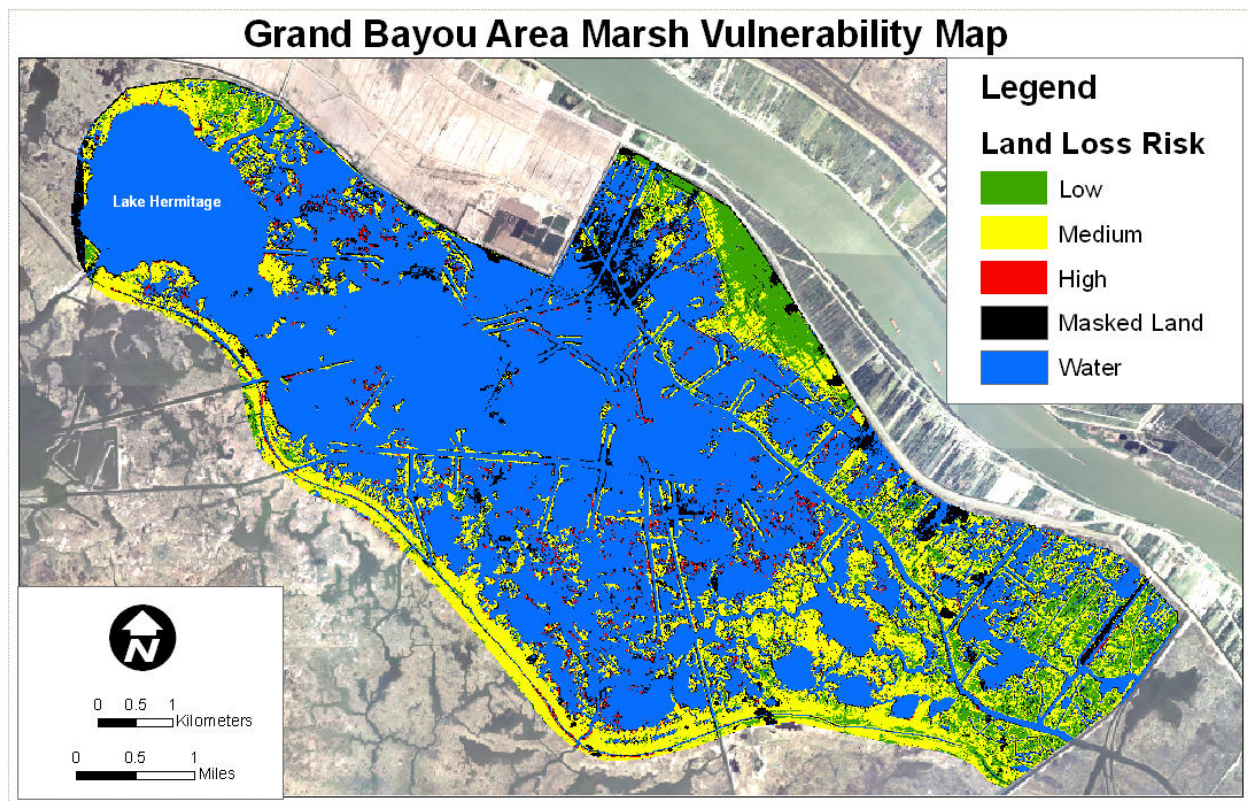


Figure 20. Marsh vulnerability map produced using a weighted overlay in ArcGIS.

## DISCUSSION

The information produced in this analysis has provided valuable insight as to the condition of the marsh vegetation and landscape fragmentation in the Grand Bayou study area. The historical fragmentation maps clearly show the degradation and decline of large areas of once contiguous land to open water. The land fragmentation patterns exhibit similar trends over time as those observed in the historical land loss analysis, especially in the noticeable change of landscape patterns from 1979 to 1991. In this respect, the historical landscape fragmentation analysis confirms the land loss patterns described in Chapter 3. Additionally, this analysis has produced a usable procedure for creating biophysical and landscape fragmentation information



that can be applied to other coastal marsh areas. In combination, the time series landscape fragmentation maps provide information on the type of change that is occurring in the landscape at a detailed scale. Generation of fragmentation statistics further describes the changes that occurred and more importantly provides the basis for the creation of the 2009 fragmentation map recoded for areas most at risk for loss based on spatial attributes. This information was augmented by the integration of the estimated and tested marsh biophysical parameters relating to vegetative health. Taken together, the input datasets provide a powerful tool for insight on areas vulnerable to loss.

The estimated chlorophyll content map shows high variability in chlorophyll content across the study area, particularly from northeast to southwest. The ‘Ravine’ natural ridge forming the northwest to southeast border of the study area is estimated to have relatively low chlorophyll content, while the area around the siphon and northeast of Grand Bayou canal are generally estimated to have relatively high chlorophyll content. In addition, broken or ‘patchy’ areas in the central part of the study area exhibit relatively low to medium chlorophyll content estimates.

The validation analysis of the estimated chlorophyll map shows a fairly good fit with the field data. However, the estimates resulting from the regression consistently (with the exception of site #21) underestimate actual CM1000 readings. The average difference of CM1000 values was 26 on a possible scale of 0 to 999, with one site (#23) representing a 101 value underestimate (a significantly greater difference than any other site). Given that the standard error was 31.64 and the final estimated chlorophyll content map was recoded into three general classes (High, Medium, and Low), these results show that the estimated chlorophyll content map

is a fairly good representation of CM1000 values across the study area when grouped into three broad classes.

The relatively low chlorophyll content estimated along the ‘Ravine’ natural ridge may have been due in part to the fact that field sampling and image acquisition didn’t occur until late October to early November, 2009. Nearing natural fall senescence, the marsh vegetation in this area was a different dominant variety than was observed in other parts of the study area. An example of this was at sampling site #5 that is shown in Figure 21. The browning of the marsh vegetation just prior to fall senescence is visible in this area, whereas other areas with different dominant marsh vegetation varieties were ‘greener’ (Figure 22).



Figure 21. Photo showing marsh condition at sampling site #5 along the Ravine ridge.





Figure 22. Photo showing sampling site #11 near siphon.

Arrangements with the U. S. Army Corps of Engineers JALBTCX group at Stennis Space Center, Mississippi had been made to acquire a hyperspectral dataset of the study area during the summer of 2009, when the marsh vegetation was at peak growth. However, this acquisition was delayed for reasons beyond the control of the research team. In late August, when it became apparent that the JALBTCX mission would not happen before the fall of 2009, it was decided to purchase the DigitalGlobe 2009 multispectral dataset used in this study. However, adverse weather conditions producing cloudy skies over the study area at times when the Quickbird satellite was in position to acquire an image delayed image acquisition and coincident field sampling for almost 2 months. This type of inclement weather is typical for Southeastern Louisiana for that time of year, and thus makes scheduling satellite remote sensing missions difficult. Adverse weather conditions are the main reason that land change studies of coastal Louisiana typically utilize remotely sensed images acquired in the late fall or winter

when the weather pattern is generally more stable with more chances of experiencing cloud free skies (Barras et al., 2003).

The estimated LAI map shows high variability in LAI across the study area as well. The ‘Ravine’ natural ridge shows variable estimated LAI along its course. Most areas Southeast of Grand Bayou Village and in the vicinity of Happy Jack have relatively high estimated LAI values, while the areas around Lake Hermitage and patchy marsh areas in the central region have predominantly low estimated LAI values. In addition, the core marsh areas remaining in the Northeast part of the study area near the siphon exhibit relatively high estimated LAI values.

The validation analysis of the estimated LAI map shows that the LAI values were consistently underestimated with respect to the actual LAI readings (with the exception of site #3). This was a similar result to the estimated CM1000 values which were underestimated for the most part. The average difference of LAI values was 1 on a possible scale of 0 to 5. Sampling site #23 showed a significant difference (2.5 LAI value) between the validation and estimated datasets, which was interesting since this same site showed a significant difference with the CM1000 datasets as well. The two similar results may indicate that measurements made at sampling site #23 were in error. These results show that the estimated LAI map was generally within about 1 LAI value of the field data (with a standard error of 0.68). Since the final estimated LAI was recoded to three classes (High, Medium, and Low estimated LAI), this difference of 1 on a scale of 0 to 5 was considered acceptable for producing the final mapping product for estimated LAI.

The highly variable LAI estimates across the study area reflect the actual conditions noted on the ground. Marsh vegetation type and condition varied greatly across the study area as is evidenced in Figure 23 that shows several sampling sites and the different marsh conditions

experienced at each. Because LAI measures the amount of foliage in a vegetative canopy (biomass) with lesser influence from the spectral properties of the vegetation resulting from pigment content differences, the browning of the marsh vegetation just prior to fall senescence would not have had as much influence on LAI measurements that it may have had on the chlorophyll data (LAI-2000, 1992).

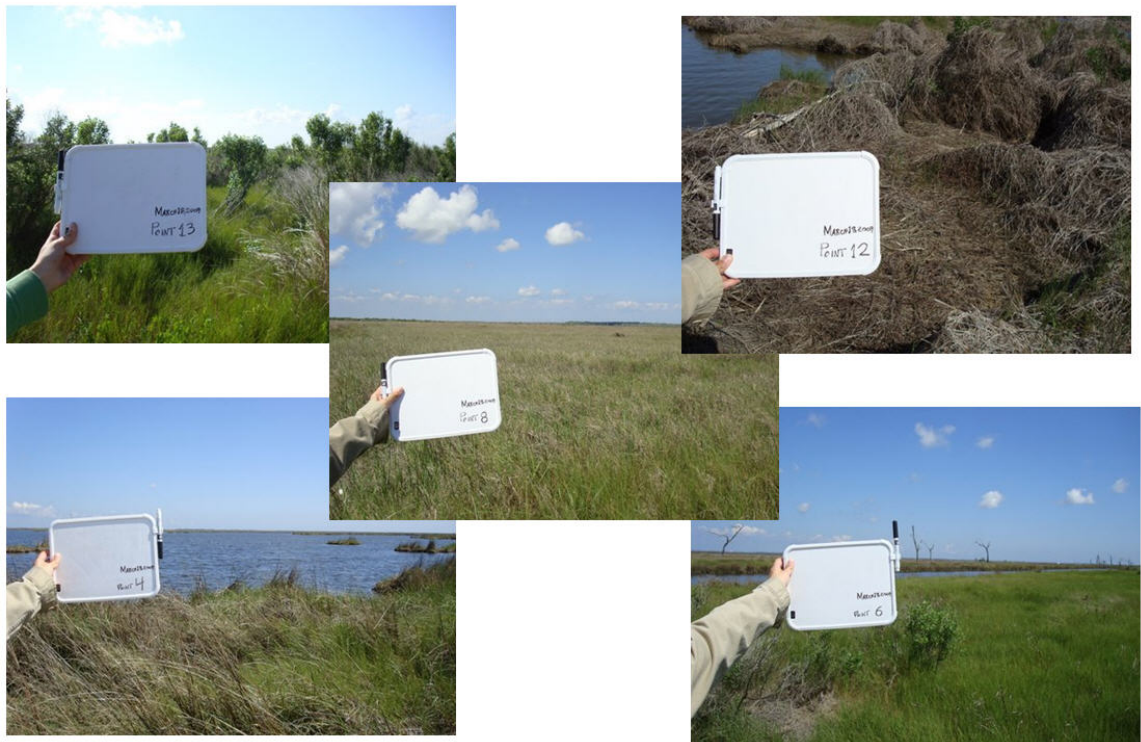


Figure 23. Pictures showing the various marsh conditions observed within the study site.

Looking at the fragmentation maps it is easy to see the advancement of man-made canals into interior core areas, as well as the enlargement of large ponds and lakes from 1968 to 1979. The amount of interior core marsh decreased and the edge and perforated marsh increased dramatically from 1979 to 1991. Edge and Perforated marsh, along with emerging Patch areas, remain dominant classes until the present. Also, there are clear trajectories of land change that

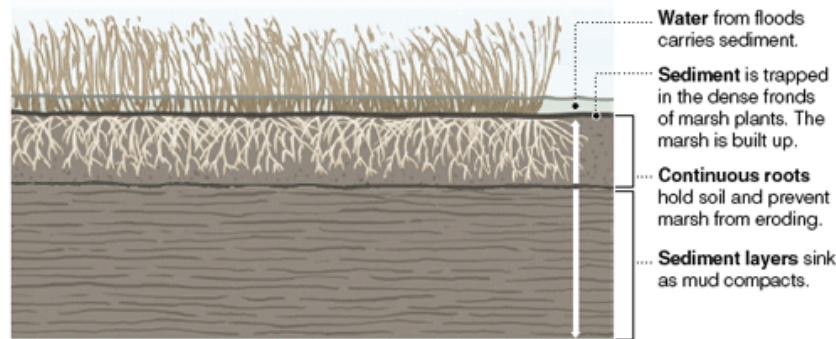
display a spatial pattern suggesting a concentration of historical land loss and land loss potential around areas of previous land loss and man-made canals. These changes indicate a spatial inertia of land loss that tends to take place around locations of recent loss. Openings in contiguous 'Core' areas of marsh increase accessibility of the fragmenting feature, water, into these areas. There is therefore a strong spatial spread effect of fragmentation class change from Core, to Perforated Core, to Edge, to Patch, to open water. Marsh fragmentation trends observed in this analysis are consistent with the process of marsh fragmentation and loss described by Dr. Shea Penland (Dean, 2005) and illustrated in Figure 24

## When Marshes Disintegrate

Wetlands in Louisiana were already ailing before Hurricane Katrina came ashore in August. Scientists are trying to determine if the damage can be reversed.

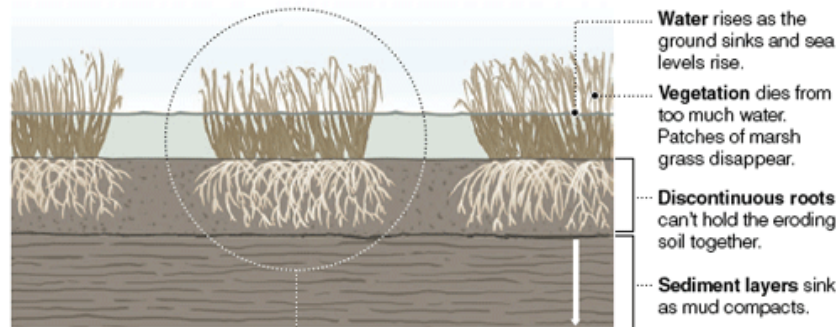
### HEALTHY MARSH

The marshes were built with sediment carried by floodwaters. Over time that sediment compacted and sank, but new sediment flooded in to replace it.



### UNHEALTHY MARSH

Once levees were built along waterways, sediment no longer flowed into the marshes. Deprived of new sediment, the marshes are disappearing.



When storms come through, remaining sections of plant life break off as clumps called marsh balls.

Source: Shea Penland, University of New Orleans

Figure 24. Illustration of the marsh fragmentation and disintegration process by Shea Penland.

The areas of high land loss risk identified in the marsh vulnerability map (Figure xx) are predominantly the patchy areas located in the central and northeastern sections of the study area where significant degradation and loss has occurred in the last decade. Low risk areas include the intact core area near the siphon and areas southeast of Grand Bayou Village and near Happy Jack. The intact core area along the natural ridge of the Ravine is classified as medium risk.

The main weaknesses of this approach to modeling marsh vulnerability include: the difficulty of separating the correlation between marsh vulnerability and the parameters tested from causality of loss; the difficulty of determining the direction of causality; and the limitations inherent in integrating only chlorophyll content, LAI, and landscape fragmentation characteristics into a model for marsh vulnerability, while ignoring other variables possibly playing key roles in the land loss process. This analysis therefore only provides a prediction of vulnerability from three specific input datasets related to marsh vegetative health and spatial orientation and proximity to water, which is due to be complimented by other relevant datasets before a comprehensive understanding of marsh vulnerability to loss for this area can be achieved. However, the model developed in this analysis allows for additional variables found to be key influences in land change to be included for future marsh vulnerability analysis.

## **CONCLUSIONS**

1. The results of the regression analysis performed using reflectance data with the chlorophyll content and LAI field data indicated that a relationship exists (coefficient of determination = 0.47 and 0.59 respectively) for the GVI and the MTV12 vegetation indices. These correlations were not particularly strong, however validation analysis of the results show acceptable estimates across the study area to produce 3 class maps of these parameters. These input datasets significantly influenced the final Marsh Vulnerability Map primarily by causing otherwise low risk core areas to be classified as medium risk in the final map. An example of this can be seen at the natural ridge of the Ravine which was a core area generally exhibiting relatively low estimated chlorophyll content and LAI. As a result, this area was primarily classified as medium risk of loss in the final map. This classification may be partly

due to the late season condition of marsh vegetation at that location. Higher correlations and thus more accurate estimated maps may be produced from field and image data acquired at peak times during the growing season, instead of near fall senescence as was the case in this study.

It is important to remember that these results represent a single trial of one growing season. To be able to make definite conclusions as to the effectiveness of using a GVI and MTV12 in estimating chlorophyll content and LAI of marsh vegetation, similar data from several growing seasons needs to be analyzed. Also, with time, correlation with any future land loss and these biophysical parameter estimates, as well as the final marsh vulnerability map can be made. This will allow for any necessary adjustments to the classification of these maps that will more appropriately represent values associated with risk of future land loss.

2. The information resulting from this model could be used to evaluate restoration potential. A strategy to reduce vulnerability might be focused on places that are at or near critical thresholds. For example, a strategy to reduce marsh vulnerability to loss might be to focus on filling in perforated regions of core areas, since the historical pattern shows that perforated core areas will grow and coalesce, then lead to broken patchy areas that are likely to be lost. In this way, fewer resources would be needed to stop marsh degradation in these areas than would be needed to reverse the trend of the badly degraded patchy areas to open water.
3. The greatest impact of this analysis may be the methods and model, not the particular results, although the results provide unique information about the study area that did not previously



exist for restoration management. This model enables restoration managers to change not what they think, but the way in which they think. If it is important that restoration managers consider spatial pattern and biophysical parameters of marsh vegetation in relation to restoration planning or monitoring activities as a means of acquiring suitable tools to address the issues. This model is a way to introduce landscape pattern and marsh biophysical parameters associated with plant health into a discussion that is now typically dominated by statistics on the amount of land lost for a given area. Furthermore, this methodology is presented as a flexible tool within an image processing/GIS environment that allows for biophysical and landscape fragmentation variables to be adapted or replaced according to a particular user's needs and available datasets related to these two variables.

## REFERENCES

- Baret, F. and G. Guyot. 1991. Potentials and limits of vegetation indices for LAI and APAR assessment. *Remote Sensing of the Environment*, 35: pp. 161-173.
- Barras, J. A., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota, and J. Suhayda. 2003. Historical and projected coastal Louisiana land changes: 1978-2050. *U.S. Geological Survey Open-File Report 03-334*, 39 p.
- Carter, G. A., and B. A. Spiering. 2002. Optical Properties of Intact Leaves for Estimating Chlorophyll Concentration. *Journal of Environmental Quality*, 31: pp. 1424-1432.
- Chen, J. M., and T. A. Black. 1992. Defining leaf area index for non-flat leaves. *Agricultural and Forest Meteorology*, 57: pp. 1-12.
- Cody, R. P., and J. K. Smith. 1991. Applied Statistics and the SAS Programming Language. 4<sup>th</sup> edition, Prentice Hall, Upper Sadle River, New Jersey, pp. 445.
- Dean, C. 2005. Louisiana's Marshes Fight for Their Lives. *The New York Times*, published November 15, URL: <http://www.nytimes.com/2005/11/15/science/earth/15marsh.html?pagewanted=all>
- ESRI. 2010. ArcGIS Geoprocessing Resource Centers, Landscape Fragmentation Tool help documentation. URL: <http://resources.esri.com/geoprocessing/index.cfm?fa=codeGalleryDetails&scriptId=16793>
- Fieldscout CM1000 Chlorophyll Meter. 2008. Spectrum Technologies, Inc. URL: [http://www.specmeters.com/Chlorophyll\\_Meters/CM\\_1000\\_Chlorophyll\\_Meter.html](http://www.specmeters.com/Chlorophyll_Meters/CM_1000_Chlorophyll_Meter.html)
- Gergel, S. E., and M. G. Turner. 2003. *Learning Landscape Ecology: A practical guide to concepts and techniques*, Springer-Verlag New York, Inc. 316 pp.
- Gitelson, A. A., Y. J. Kaufman, and M. N. Merzlyak. 1996. Use of a green channel in remote sensing of global vegetation from EOS-MODIS. *Remote Sensing of the Environment*, Vol. 58, pp. 289-298.
- Gitelson, A. A. 2004. Wide dynamic range vegetation index for remote quantification of biophysical characteristics of vegetation. *Journal of Plant Physiology*, 161: pp. 165-173.
- Gustafson, E. J. 1998. Quantifying landscape spatial pattern: what is the state of the art? *Ecosystems*, 1: pp. 143-156.

- Haboudane, D., J. R. Miller, E. Pattey, P. J. Zarco-Tejada, and I. Strachan. 2004. Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: Modeling and validation in the context of precision agriculture. *Remote Sensing of the Environment*, Vol. 90(3): pp. 337-352.
- He, Y., X. Guo, and J. Wilmshurst. 2006. Studying mixed grassland ecosystems I: suitable hyperpectral vegetation indices. *Canadian Journal of Remote Sensing*, Vol. 32, No. 2: pp. 98-107.
- Huete, A., C. Justice, and H. Liu. 1994. Development of vegetation and soil indices for MODIS-EOS. *Remote Sensing of the Environment*. 49: pp. 224-234.
- Jensen, J. R. 2004. *Introductory Digital Image Processing*, 3<sup>rd</sup> Ed., Upper Saddle River, New Jersey: Prentice Hall, 526 pp.
- Jordan, C. F. 1969. Derivation of leaf area index from quality of light on the forest floor. *Ecology*, Vol. 50, pp. 663-666.
- Kaufman, Y. J., and D. Tanre. 1992. Atmospherically Resistant Vegetation Index (ARVI) for EOS-MODIS. *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 30, pp. 261-270.
- LAI-2000 Plant Canopy Analyzer. 1992. Instruction Manual. Lincoln, Nebraska: LI-COR, Inc.
- Murdock, L., D. Call, and J. James. 2004. Comparison and Use of Chlorophyll Meters on Wheat (Reflectance vs. Transmittance/Absorbance). University of Kentucky Cooperative Extension Service, Publication AGR-181.
- Nilsson, H. E. 1995. Remote Sensing and image analysis in plant pathology. *Annu. Rev. Phytopathol.*, Vol. 15, pp. 589-527.
- O'Neill, R. V., C. T. Hunsaker, K. B. Jones, K. H. Ritters, J. D. Wickham, P. M. Schwartz, I. A. Goodman, B. L. Jackson, and W. S. Baillargeon. 1997. monitoring environmental quality at the landscape scale. *BioScience*, 47: pp. 513-519.
- Qi, J., A. Chehbouni, A. R. Huete, and Y. H. Kerr. 1994. Modified Soil Adjusted Vegetation Index (MSAVI). *Remote Sensing of the Environment*, Vol. 48, pp. 119-126.
- Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. Global-scale patterns of forest fragmentation. *Conservation Ecology*, Vol. 4(2): 3. URL: <http://www.consecol.org/vol4/iss2/art3/>
- SAS Institute, Inc. 2002. SAS/STAT Users Guide, ver. 9.2. Cary, NC: SAS Institute Inc.

- Smith, G. M., and E. J. Milton. 1999. The use of the empirical line method to calibrate remotely sensed data to reflectance. *International Journal of remote Sensing*. Vol. 20, No. 13, pp. 2653-2662.
- Tucker, Compton J., 1979. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. *Remote Sensing of Environment*, 8:127-150.
- Turner, M. G., R. H. Gardner, and R. V. O'Neill. 2003. *Landscape Ecology in Theory and Practice: Pattern and Process*. Springer-Verlag New York, Inc. 401 pp.
- Turner, M. G., and R. H. Gardner. 1991. *Quantitative methods in landscape ecology*. Springer-Verlag, New York, New York, USA.
- Vigier, B. J., E. Pattey, and I. B. Strachan. 2004. Narrowband Vegetation Indexes and Detection of Disease Damage in Soybeans. *IEEE Geoscience and Remote Sensing Letters*, Vol. 1, No. 4, pp. 255-259.
- Vogt, P., K. Riitters, C. Estrenguil, J. Kozak, T. Wade, and J. Wickham. 2007. Mapping spatial patterns with morphological image processing. *Landscape Ecology*, Vol. 22: pp. 171-177.
- Vogt, P., J. R. Ferrari, T. R. Lookingbill, R. H. Gardner, K. H. Riitters, and K. Ostapowicz. 2009. Mapping functional connectivity. *Ecological Indicators*, Vol. 9: pp. 64-71.
- Wang, Y., C. E. Woodstock, W. Buermann, P. Stenberg, P. Voipio, H. Smolander, T. Hame, Y. Tian, J. Hu, Y. Knyazikhin, and R. B. Myneni. Evaluation of the MODIS LAI algorithm at a coniferous forest site in Finland. 2004. *Remote Sensing of the Environment*, Vol. 91: pp. 114-127.
- Zhang, M., S. L. Ustin, E. Rejmankova, and E. W. Sanderson. 1997. Monitoring Pacific Salt Marshes using Remote Sensing. *Journal of Ecological Applications*. 7(3): pp. 1039-1053.

## **CHAPTER 6**

### **MERGING THE SCIENTIFIC AND TEK DATASETS TO SUPPORT COASTAL RESTORATION DECISION-MAKING WITH NEW INFORMATION TOOLS**

#### **INTRODUCTION**

Coastal restoration studies have tended to focus on representing the biophysical characteristics of the area of interest. As an example, the Wetland Value Assessment Methodology (WVA) is an attempt to quantify habitat-based assessment for use in determining wetland benefits of restoration project proposals submitted for funding under CWPPRA. The WVA is a component of the current coastal restoration decision-making process, and provides an estimate of the number of acres benefited or enhanced by a proposed project and the net acres of habitat protected or restored (CWPPRA, 2006). The WVA model has been developed and used for “determining the suitability of Louisiana coastal wetlands in providing resting, foraging, breeding, and nursery habitat to a diverse assemblage of fish and wildlife species” (CWPPRA, 2006). Variables are entered into the WVA model that are considered to be important in characterizing fish and wildlife habitat, and a Habitat Suitability Index (HSI) is produced. The HSI ranges from 0.1 to 1.0, and is a numerical representation of the overall habitat quality of the particular wetland being evaluated.

Whereas the WVA has been proven useful in assessing potential impact to the habitats of fish and wildlife during the coastal restoration planning process, little such effort has been made

to understand the social and cultural dimensions within which the biophysical resources are embedded. One reason for this lack of attention may be that the qualitative TEK data is not readily compatible for input into mathematical models such as the habitat variables of the WVA. This is because scientific models, such as are used for restoration planning and assessment, are typically built to utilize only technical knowledge. Technical knowledge is derived from systematic observations and experiments that target limited environmental facets (Balram et al., 2004). However, using only technical knowledge to inform restoration management and planning prevents the ability to effectively deal with value differences in local information, or to collectively consider the social, cultural, and political impacts of restoration” (Balram et al., 2004).

Studies such as Petch et al. (1995) have shown that there are many benefits to integrating TEK and technical knowledge in a GIS spatial framework. However, there are very few examples of spatial knowledge integration research from technical and local knowledge sources to inform coastal restoration decision-making. Because aspects of the multiple dimensions of resource use are inherent in all local knowledge, coastal Louisiana, with its rich and unique cultural diversity and long history of inhabitants who are tied intricately to the environment, offers a wealth of local knowledge that can serve to compliment technical knowledge. In order to demonstrate how this knowledge fusion may be used to enhance the current restoration decision-making process, this study presents a collaborative GIS method for integrating TEK and technical knowledge with spatial environmental data in an interactive participatory process for establishing restoration priorities. This integration process is based in the GIS operations of union, intersection, clip, weighted overlay, etc. of features and dataset layers created and mapped from technical and local knowledge. The integrated dataset allows the local and technical

knowledge experts to share, explore, manage, analyze, and interpret the multi-dimensional data in a standard spatial context to develop more informed restoration decisions. This knowledge integration process is represented in Figure 1 by Balram et al. (2004) and serves as a basis for the methods developed to integrate the datasets produced for this study.

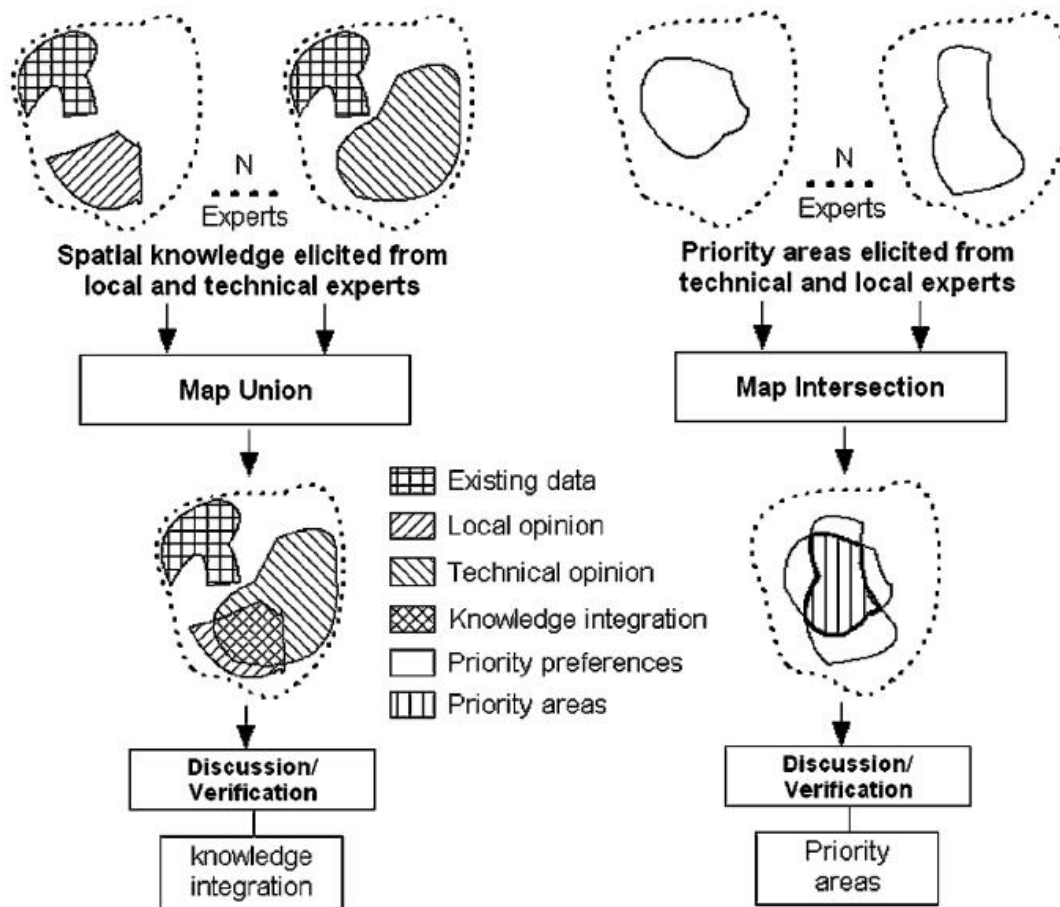


Figure 1. Map processes in knowledge integration and priority areas setting (Balram et al., 2004)



## **METHODS**

### **Spatial Cluster Analysis of High Risk Areas**

Pattern analysis was performed on the vulnerability map produced from the weighted overlay of the estimated chlorophyll and LAI maps with the 2009 fragmentation map (see Chapter 5) to determine significantly clustered areas of high land loss risk. This analysis was performed to determine the probability that spatial clustering was not due to random chance. Once this is determined, the causes of the clustering can be examined. This cluster and outlier analysis was determined to be necessary to provide spatial information to restoration managers regarding high risk areas mapped that are not the result of random environmental conditions or error, but are the result of driving environmental variables. This data can be overlaid on other datasets to determine if a relationship exists between the identified ‘hot spots’ of high risk and areas of land loss. As such, this information can be used to aid restoration decision-making and to further investigate causes of marsh degradation experienced in this study area.

The cluster and outlier analysis involved identifying clusters of features with similar values (in this case the three class values – Low, Medium, and High risk), as well as spatial outliers, using ArcGIS 9.3 to calculate a Local Moran’s I value, a Z score, a p-value, and a code representing the cluster type for each feature. The Z score and p-value represent the statistical significance of the computed Local Moran’s I index value (Allen, 2009). Local Moran’s I is a statistical indicator of spatial association that evaluates the existence of clusters in the spatial arrangement of a given variable. The calculation of the Local Moran’s I statistic is shown in Figure 2.

The Local Moran's  $I$  statistic of spatial association is given as:

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^n w_{i,j} (x_i - \bar{X}) \quad (1)$$

where  $x_i$  is an attribute for feature  $i$ ,  $\bar{X}$  is the mean of the corresponding attribute,  $w_{i,j}$  is the spatial weight between feature  $i$  and  $j$ , and:

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^n w_{ij}}{n - 1} - \bar{X}^2 \quad (2)$$

with  $n$  equating to the total number of features.

The  $z_{I_i}$ -score for the statistics are computed as:

$$z_{I_i} = \frac{I_i - E[I_i]}{\sqrt{V[I_i]}} \quad (3)$$

where:

$$E[I_i] = -\frac{\sum_{j=1, j \neq i}^n w_{ij}}{n - 1} \quad (4)$$

$$V[I_i] = E[I_i^2] - E[I_i]^2 \quad (5)$$

Figure 2. The calculation of the Local Moran's  $I$  statistic (Anselin, 1995).

The Local Moran's index indicates whether a feature occurs near other features of similar value (i.e. High risk areas). A positive index value indicates that the feature is surrounded by features with similar values (i.e. High risk values) and thus is part of a cluster. A negative index value indicates that the feature is surrounded by features with dissimilar values, and thus is an outlier. The Local Moran's index can only be interpreted for significance within the context of the computed Z score and p-value. The code for cluster type (COtype) that is output in the cluster and outlier analysis distinguishes between statistically significant (0.05 level) cluster of

high values (HH), cluster of low values (LL), outlier high value surrounded primarily by low values (HL), and outlier low value surrounded primarily by high values (LH) (Allen, 2009).

The output dataset was queried for all areas corresponding to the High risk of loss class, and subsequently only high risk areas that were significantly clustered were selected. An example of this dataset with significantly clustered high risk areas is shown in Table 1 and Figure 3. The resulting selections were output as a separate feature layer and overlaid on the Marsh Vulnerability Map (Figure 4).

Table 1. Table showing results of cluster and outlier analysis and selection of significantly clustered high risk areas.

FID	Shape *	ID	GRIDCODE	LMiIndex	LMiZScore	LMiPValue	COType
6225	Polygon	622	3	1.70875	7.0618	0	HH
6226	Polygon	622	3	1.95014	7.91535	0	HH
6227	Polygon	622	3	1.90432	7.71458	0	HH
6228	Polygon	622	2	0.134657	0.466397	0.640931	
6229	Polygon	623	2	-0.010415	-0.054052	0.956894	
6230	Polygon	623	2	-0.077577	-0.494408	0.621018	
6231	Polygon	623	2	-0.103988	-0.32931	0.741921	
6232	Polygon	623	3	1.26792	5.81812	0	HH
6233	Polygon	623	3	1.29341	3.82711	0.00013	HH
6234	Polygon	623	3	1.54751	4.95035	0.000001	HH
6235	Polygon	623	2	-0.102553	-0.724236	0.468921	
6236	Polygon	623	2	-0.140595	-0.509666	0.610285	
6237	Polygon	623	1	1.21563	4.54498	0.000005	LL
6238	Polygon	623	2	-0.072667	-0.395282	0.692635	
6239	Polygon	624	2	-0.112612	-0.356382	0.721554	
6240	Polygon	624	3	1.65749	7.39963	0	HH
6241	Polygon	624	2	-0.12256	-0.644472	0.519269	
6242	Polygon	624	3	1.47829	2.98079	0.002875	HH
6243	Polygon	624	2	-0.114038	-0.508446	0.61114	
6244	Polygon	624	3	-0.011722	-0.060184	0.952009	
6245	Polygon	624	2	0.043345	0.221714	0.824536	
6246	Polygon	624	2	0.005752	0.032736	0.973885	
6247	Polygon	624	2	-0.101899	-0.84619	0.397447	
6248	Polygon	624	2	-0.015949	-0.084609	0.932573	
6249	Polygon	625	1	1.78808	7.23421	0	LL
6250	Polygon	625	1	1.28225	9.76709	0	LL
6251	Polygon	625	2	-0.217813	-0.447185	0.654742	
6252	Polygon	625	3	2.90309	9.28408	0	HH
6253	Polygon	625	3	2.6552	9.27122	0	HH
6254	Polygon	625	2	-0.136931	-0.561725	0.574303	
6255	Polygon	625	2	-0.15578	-0.576347	0.56438	
6256	Polygon	625	2	0.025797	0.148602	0.881867	
6257	Polygon	625	2	0.053578	0.235191	0.814061	
6258	Polygon	625	3	1.43092	8.18461	0	HH
6259	Polygon	626	2	-0.080578	-0.468143	0.639682	
6260	Polygon	626	2	-0.063547	-0.405696	0.684966	
6261	Polygon	626	3	1.34521	6.22736	0	HH
6262	Polygon	626	1	0.525916	3.18336	0.001456	LL
6263	Polygon	626	3	2.16896	12.181	0	HH
6264	Polygon	626	3	2.82774	10.5742	0	HH
6265	Polygon	626	3	1.76267	8.35972	0	HH

Record: 1 Show: All Selected Records (12899 out of 56716 Selected) Options

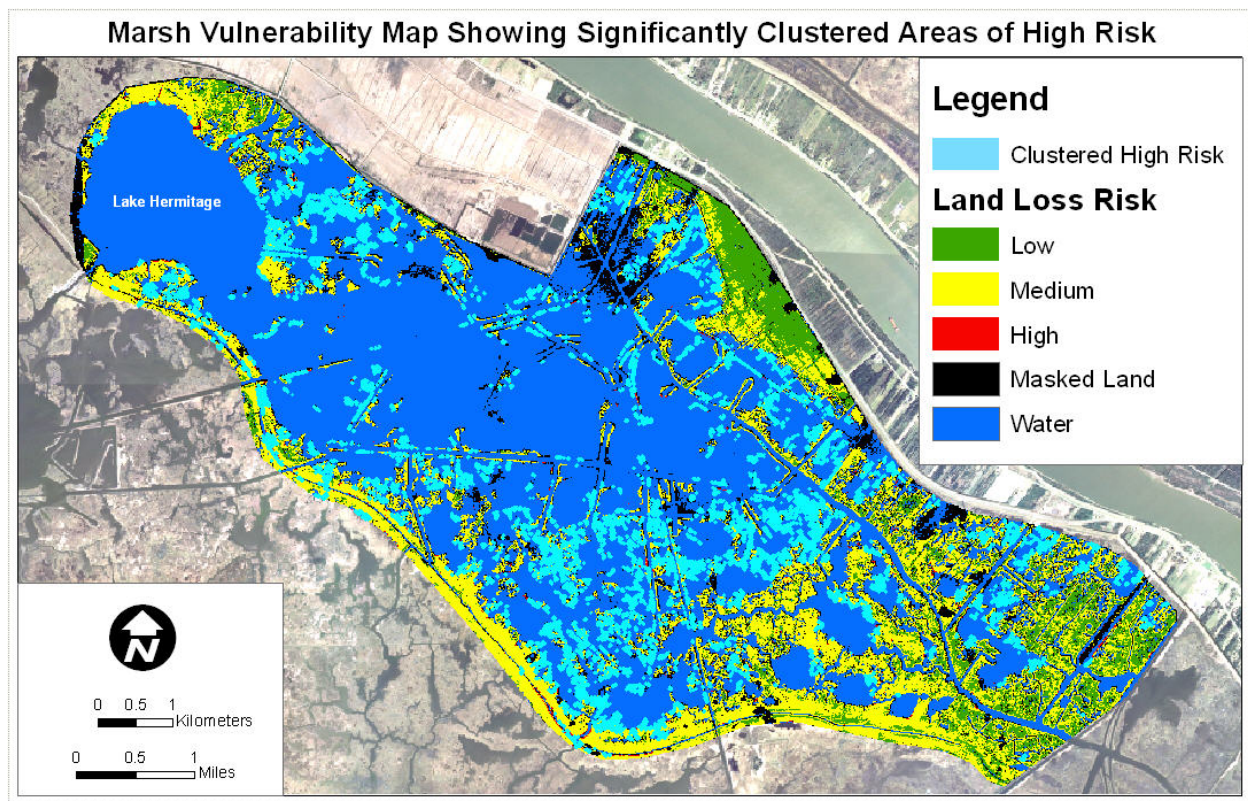


Figure 3. Significantly clustered areas of high risk of loss overlaid on the Marsh Vulnerability Map.



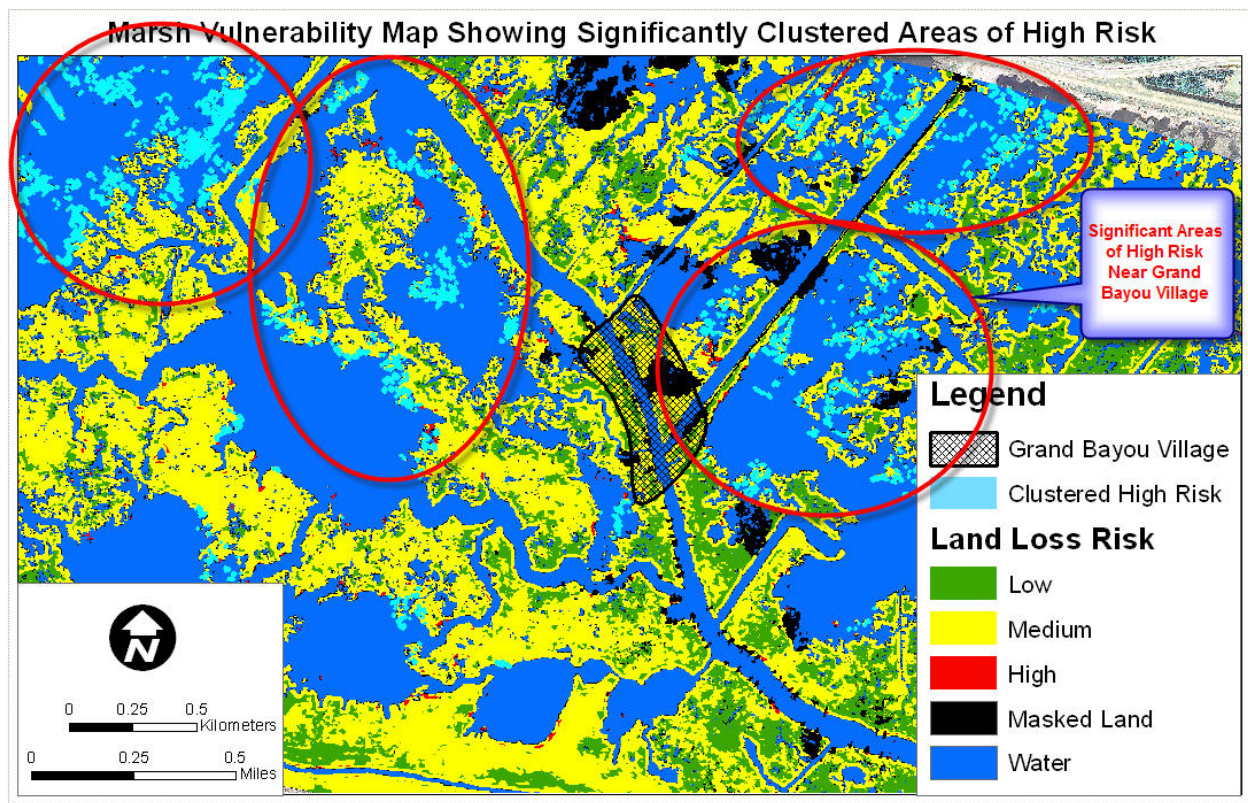


Figure 4. Significantly clustered areas of high risk in the vicinity of Grand Bayou Village.

### Overlay of Marsh Vulnerability Map with TEK-derived Maps

Using the derived spatial datasets created with this research (Clustered High Risk Areas for Loss, the TEK-Based Areas of Observed Change, and the TEK-Based Areas of Restoration Priority data layers), GIS overlay, selection by attribute and location, and intersection operations were used to generate detailed maps highlighting areas of high risk which also represent high restoration priorities for the community. This analysis was driven by three criteria: knowledge about risk of land loss derived from scientific data and analyses; knowledge of community-based priorities for continued sustainability; and knowledge of observed change at these priority areas as it relates to the effect on natural resources and ecosystem health on which the community relies. This GIS analysis allowed the researchers to identify areas of concern, explore different

criteria for selection of the most suitable areas for restoration, and rank areas at risk for each concern within a geographical context. The final output were a set of digital maps showing optimal areas for strategic coastal restoration activities based on the criteria selected. The complete image and GIS processing steps are detailed in the Grand Bayou Project Mapping Process Flow Chart in Appendix A. The specific criteria for the final map shown in Figure 5 were: 1) Areas that corresponded to the Most Important Restoration Priority (RP) class; 2) areas that corresponded to both the Extreme Negative and Negative Observed Change (OC) classes; and 3) areas that were identified as significantly clustered High Risk for loss. Table 2 shows the table associated with the TEK-based map data layer and the specific features selected that meet the criteria specified for this query. When the criteria of the OC input was changed to include only areas of Extreme Negative Observed Change, the final map that resulted was modified to show only the clustered high risk of loss areas that met the new criteria (Figure 6). This modification of the input criteria narrowed the output selection areas to the immediate vicinity of Grand Bayou Village. The selected areas were exported to a new data layer so that this information can be used with other maps and datasets. These selected areas identify where there is an urgent need for restoration or other conservation action, and where the greatest restoration benefits for the community can be achieved for a fixed level of financing.



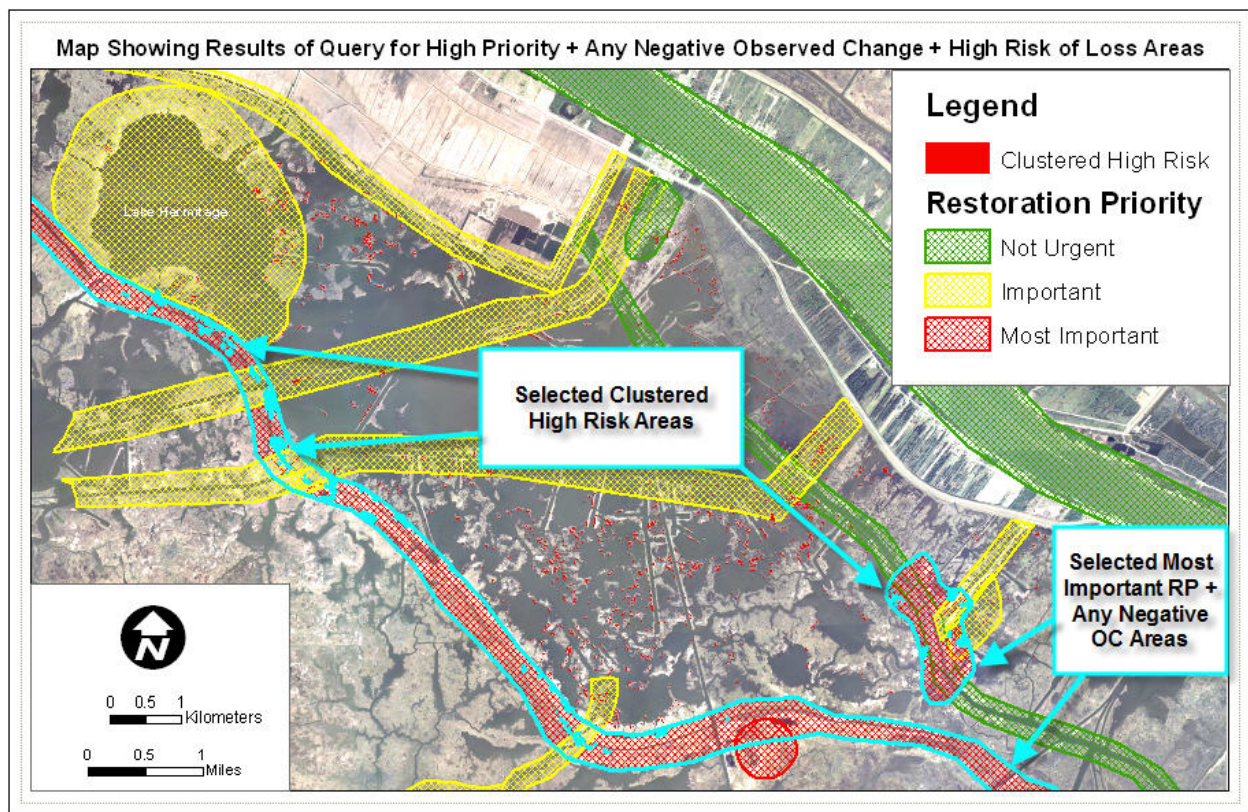


Figure 5. Final map showing clustered High Risk for loss areas that are within areas of any Negative OC and the Most Important RP.

Table2. Feature dataset table for TEK-based data layer showing results of query.

FID	Shape	Id	Name	Weight	VI_Info	RP_Info	VI	RP
0	Polygon	1	Bay Roquette	0	high levels of land loss observed	good trapping in this area	-0.3182	0.2308
1	Polygon	3	Bay Batiste	0	large island here has disappeared	good area for oysters and shrimp	-0.0455	0.1538
2	Polygon	9	Ravine	0	highest place, only area with trees but dying	acts as barrier from storm surge, very important	-0.1482	0.4615
3	Polygon	11	Freeport Canal	0		shrimping location	0.0909	0
4	Polygon	10	Mississippi River	0	fast current	contains enough sediment to rebuild marsh	0.0455	0
5	Polygon	12	Wilkinson Bay	0	land has washed away rapidly since canal dug	shrimping/fishing in past, restoration needed here	-0.3182	0.1538
6	Polygon	13	Crane Island	0	used to be an island, now water	many birds used to flock here	-0.1364	0.0769
7	Polygon	14	Grand Bayou Pass	0	natural bayou, large amounts of land loss		-0.0455	0
8	Polygon	19	Back Levee	0			0.037	0.0769
9	Polygon	20	Bay Sansbois	0	keeps getting bigger over time	shrimping in this bay, not as good fishing now	-0.2593	0
10	Polygon	21	Bayou Traverre	0	a natural bayou that cuts the Ravine	large shrimp in this area	-0.1111	0.2308
11	Polygon	22	Bayou Stephan	0		location of old community trappers camp	-0.1852	0.2308
12	Polygon	17	Old Evacuation Spot	0	not enough protection from storms to use it today	where community would ride out storms together	-0.2963	0.3846
13	Polygon	23	Pond Behind the School	0		located behind the old community school	-0.2963	0.3846
14	Polygon	24	Grand Bayou Village	0	ground relatively high; property has washed away	residents live, meet, and dock boats here	-0.3333	0.8462
15	Polygon	25	Texas Company Canal	0	really widened; land loss accelerated	need to close off for effective restoration	-0.2273	0.0769
16	Polygon	26	Jefferson Lake Canal	0	land around canal has been eaten up	blocking off this canal would help restoration	-0.2963	0.3077
17	Polygon	27	Siphon	0	relatively firm land	not helpful or efficient with restoration	0	-0.3846
18	Polygon	2	Lake Hermitage	0	used to act like a bulkhead with trees	need to close channels in this area	-0.1852	0.0769
19	Polygon	16	Indian Mounds	0	hard marsh same as other areas used to be	important to protect	0.1364	0.6154
20	Polygon	7	Foster's Canal	0	used to have trees, now stumps	access to community; rice grown nearby in past	-0.0909	0.2308



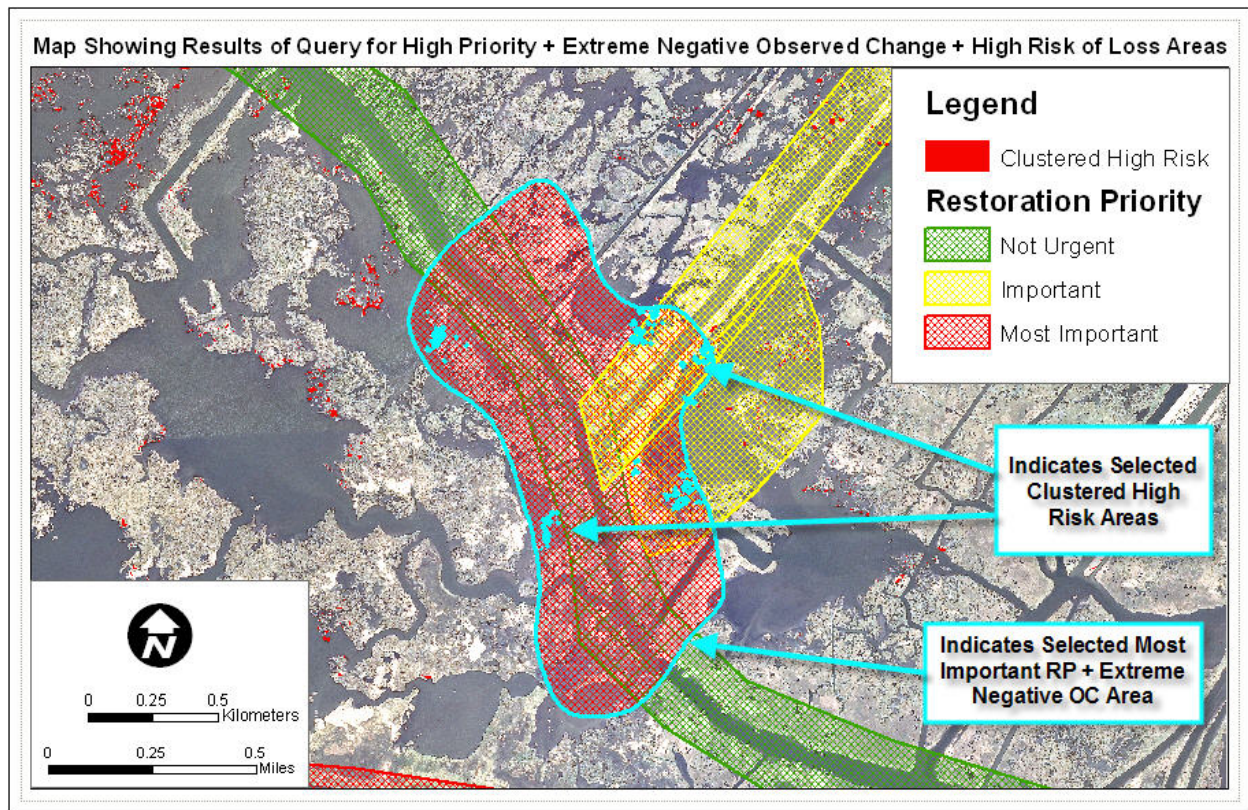


Figure 6. Final map resulting from modified criteria that selected only areas around Grand Bayou Village.

## DISCUSSION

The results of the spatial cluster analysis showed that there are significantly clustered areas of high risk to loss throughout the study area. However, these areas were separated from more randomly distributed, isolated areas of high risk to loss that probably constituted the majority of error inherent in the mapping process. In addition, the randomly distributed, isolated areas of high risk to loss may represent areas where so much land has been lost that they are inherently isolated. Excluding these isolated areas from the high risk data layer increases confidence in the mapping results and decisions made from these results.

The final maps produced for this study detailing optimal areas for restoration were based on the specific set of input criteria selected based on the assumptions of the researchers for this study. These input criteria can be modified as demonstrated to fit the particular needs of decision-makers. For example, if expert knowledge determined that the most cost effective use of restoration resources is to focus on areas which are less likely to be lost in the near future, then the selected input criteria for the Land Loss data layer can be modified to include only significantly clustered areas of Medium and/or Low risk of loss classes. This modification would produce much different results than what are shown in Figures 5 and 6. This example demonstrates the flexibility and utility for restoration decision-making offered with the methods and tools presented in this study. Furthermore, these methods provide restoration managers with a practical, effective, and beneficial means of integrating TEK-based information into their decision-making process.

### **Applicability of Results to Recommendations of the Louisiana Coastal Area (LCA) Science and Technology Program**

The LCA Science and Technology Program is a partnership between the State of Louisiana, the U.S. Army Corps of Engineers (USACE), the U.S. Geological Survey (USGS), and other Federal agencies for the purpose of informing the use of coastal restoration strategies in Louisiana aimed towards achieving and sustaining a coastal ecosystem that can support and protect the environment, economy, and culture of southern Louisiana (Louisiana Coastal Area, 2010). Goals of the LCA Science and Technology Program include providing “the necessary science and technology to effectively address coastal ecosystem restoration needs”, as well as to “provide analytical tools and recommendations to the [LCA] Program Management Team for appropriate studies to reduce uncertainties” (Louisiana Coastal Area, 2010).

In the Summary Report of the January 13-15, 2010 meeting of the LCA Science and Technology (S&T) Program Science Board, board member Dr. Connor Bailey offered the following recommendations for the LCA Science and Technology Program:

“the research supported by the LCA S&T office has studiously ignored the social, economic, and political implications of coastal restoration. Hesitancy to engage in these domains is a reflection of institutional limitations within the USACE, the Louisiana DNR [Department of Natural Resources], and USGS to articulate appropriate research questions that would complement the more technical and scientific dimensions of wetland restoration” (LCA, 2010).

This study demonstrates how scientists can engage local residents to address some of the issues Dr. Bailey raises in coastal restoration research, and perhaps provide a basis from which new ideas and applications of these methods and tools can evolve. Dr. Bailey also directs the LCA S&T Program to support research that integrates scientific and local knowledge, and recognizes the benefit in doing so:

Another approach would be to devote research attention to the question of local knowledge. Coastal communities in Louisiana have demonstrated significant resiliency in the face of hurricanes and a shifting coastline. Those of us with Ph.D. degrees have one kind of knowledge, and however important is such knowledge, there are other ways of knowing. I hope that the LCA S&T office will support research that focuses on local ecological knowledge and that such knowledge can inform scientific discourse and lead to improved project planning (e.g., location of diversions that would not adversely affect oyster beds and spawning grounds, or lead to destruction of culturally important features such as cemeteries).

He concludes: “As a Science Board, we should insist that these human dimensions of coastal wetlands be included as part of the S&T Office research program. Failing to consider social questions – and the role of power – does not mean that the questions cease to exist” (LCA, 2010).

This research has directly addressed this recommendation by Dr. Bailey. As such comments are noted, it becomes clear that the current restoration decision-making process does not include the TEK-based information presented in this study. However, the recognition of the importance of including TEK in this process is apparent as well. This research provides decision-makers with one method of doing so.

### **The CPRA Current Restoration Prioritization Model**

Currently CPRA uses The Project Prioritization Model to support decision-making regarding the location of proposed restoration projects, and ranks the projects for expected benefits and costs. This model uses mathematical calculations to prioritize proposed projects based on the following four Master Plan objectives: 1) Reduce economic losses from storm based flooding; 2) Promote a sustainable coastal ecosystem; 3) provide habitats for commercial and recreational activities; and 4) Sustain the unique heritage of Coastal Louisiana. This model is designed to support restoration decision-making, not supplant it, and was designed to be an adaptable tool that allows for the inclusion of new information to support better decisions (CPRA, 2009). In fact, CPRA's Office of Coastal Protection and Restoration (OCPR) encourages ideas from the public as to how this model and other restoration tools can be improved. As the data driving the model improves, the model's rankings will help OCPR decide how to fund future restoration projects (CPRA, 2009).

There is currently no way to include TEK-based information into the Project Prioritization Model. The OCPR prioritization approach consists of assembling a group of experts (referred to as the Project Scoring Team) to develop qualitative scores for the net benefit of each project for ten different performance metrics drawn from the Master Plan. For the 2010 Annual Plan, "the best professional judgment was relied upon heavily" to score proposed and

ongoing restoration projects (CPRA, 2009). OCPR is currently working to refine this data and information to support more quantitative assessment for the 2011 and future plans. As an example, the project benefit scoring criteria for Master Plan objective #4 (Sustain Coastal Heritage) is shown in Table 3.

Table 3. Project benefit scoring criteria for Objective 4 (CPRA, 2009).

<b>Objective 4: Sustain Coastal Heritage</b>			
<b>Score</b>	<b>Coastal Heritage</b> Whether the project supports community resiliency and ability to survive	<b>Natural Resources</b> How the project affects two types of natural resources – wildlife/fisheries and agriculture	<b>Sustainable Balance</b> How the project affects community access to natural resources
<b>++</b>	Improve protection including structural protection.	Increased substantially	Increased substantially
<b>+</b>	Improve protection	Increased	Increased
<b>=</b>	No change from current protection conditions	Neutral	Neutral
<b>–</b>	Reduce protection	Decreased	Decreased
<b>– –</b>	Communities not viable	Decreased substantially	Decreased substantially

The restoration project prioritization calculations are performed in the following 5 steps as reported in CPRA’s 2010 Annual Plan (2009):

- 1) Convert the qualitative benefit scores to numeric scores
- 2) Combine the numeric benefit scores across metrics to generate benefit scores for each Master Plan objective
- 3) Modify the Master Plan objectives #2 and #3 benefit scores by scaling factors
- 4) Derive project prioritization scores for each Master Plan objective
- 5) Derive a single project prioritization score for each restoration project



An example of how the qualitative benefit and scaling scores are converted to numeric scores is shown in Table 4, and then combined with relative weights calculated across the Master Plan objectives as shown in Table 5 to derive a final prioritization score for each restoration project considered in the model.

Table 4. Qualitative benefit score conversion matrix (CPRA, 2009).

Master Plan Objective	Master Plan Metric	Qualitative Score				
		--	-	=	+	++
Objective 1	Concentrated Asset Areas	0	n/a	33	67	100
	Distributed Asset Areas	0	n/a	33	67	100
	Strategic Resources	0	n/a	33	67	100
Objective 2	Ecosystem Productivity	-50	-25	0	25	50
	Process Exchanges	-50	-25	0	25	50
Objective 3	Habitat Suitability	-50	-25	0	25	50
	Wetland Area	-25	0	25	50	75
Objective 4	Coastal Heritage	-50	-25	0	25	50
	Natural Resources	-50	-25	0	25	50
	Sustainable Balance	-50	-25	0	25	50

Table 5. Master Plan metric relative weights (CPRA, 2009).

Master Plan Objective	Master Plan Metric	Relative Weight
Objective 1	Concentrated Asset Areas	50%
	Distributed Asset Areas	15%
	Strategic Resources	35%
Objective 2	Ecosystem Productivity	50%
	Process Exchanges	50%
Objective 3	Habitat Suitability	40%
	Wetland Area	60%
Objective 4	Coastal Heritage	50%
	Natural Resources	25%
	Sustainable Balance	25%

The methods and mapping products produced in this study have the potential of improving this current restoration prioritization model with new quantitative and qualitative



information that is currently not being utilized in the decision-support process. This new information was produced in the form of spatial data and GIS products with collaborative input from CPRA scientists so that it can be integrated into this existing model. Specifically, land loss maps such as shown in Figure 7 are used to identify locations at risk and subsequently justify areas for restoration project proposals that are entered into CPRA's Project Prioritization Model. As detailed in Chapter 3, these maps are typically produced by the USGS from 30-meter resolution Landsat datasets, and while they may be good for regional assessment of land loss trends and future predictions, they may not be adequate for a detailed assessment of localized trends and predictions relevant to local community needs and sustainability.

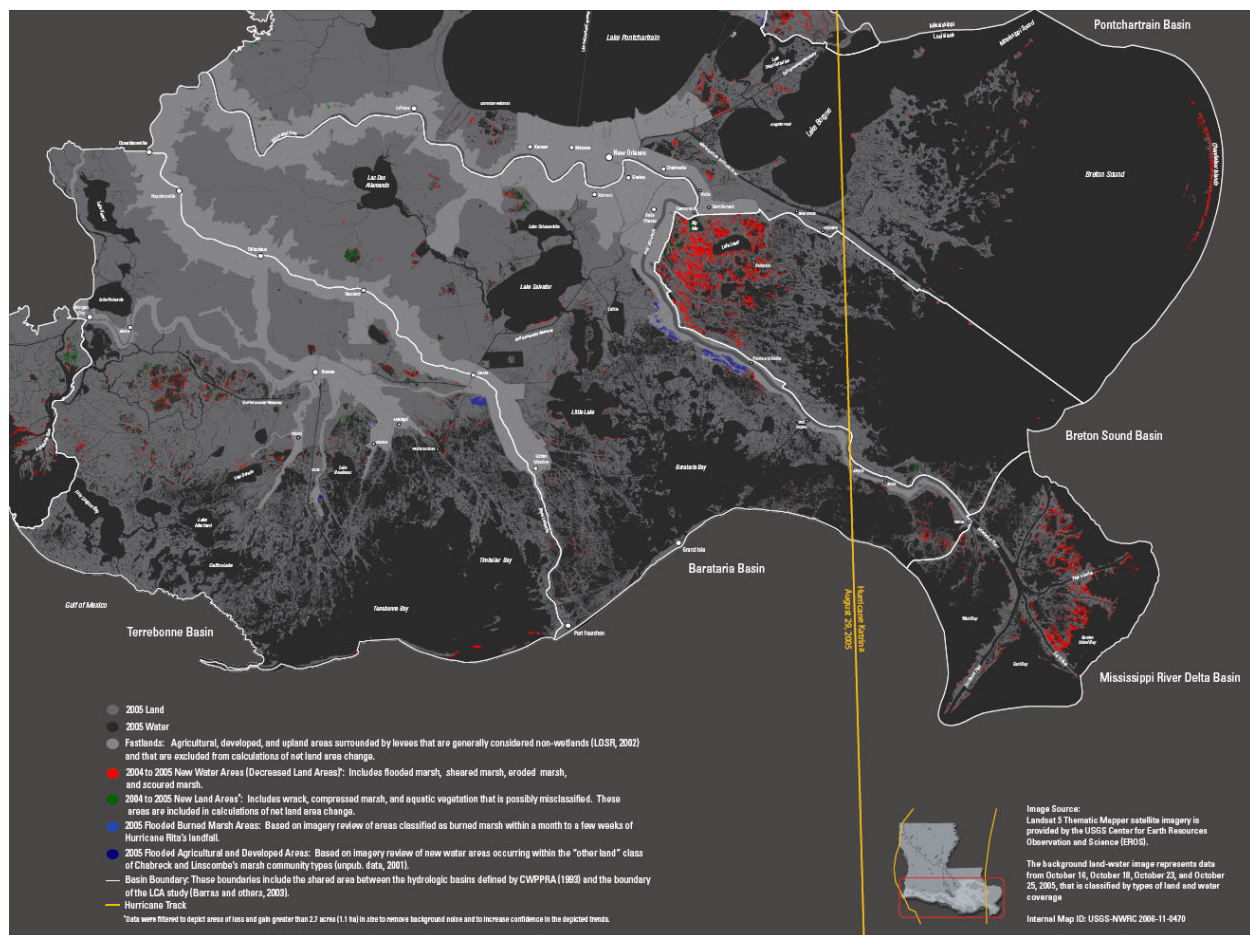


Figure 7. Southeast Louisiana land loss represented in a USGS map typically used in the restoration project decision-making process (Barras, 2007).

Figure 8 shows the Grand Bayou study area from the map in Figure 7, and for comparison purposes, Figure 9 shows the land change map produced for this study for a similar time period. A detailed quantitative comparison of these land loss maps is not appropriate since the map produced by Barras (2007) covers the time period from “fall 2004 to the fall of 2005”, while the map produced for this study details change from 1/21/2004 to 10/27/2005. However, a qualitative comparison assessment can be made with this difference considered. General land loss trends are similar in both maps, however the map from Barras (2007) includes additional areas of land loss that are not present in the map produced for this study even though the Barras (2007) map represents land loss over a time period that is approximately 9 months shorter. There are also areas of loss shown in the map produced for this study that do not appear in the Barras (2007) map which may be due to the additional time considered in the change map for this study. In addition, the loss of patch areas noted in the map for this study is noticeably absent in the Barras (2007) map due to the coarser spatial resolution of the input datasets which cannot resolve these features.

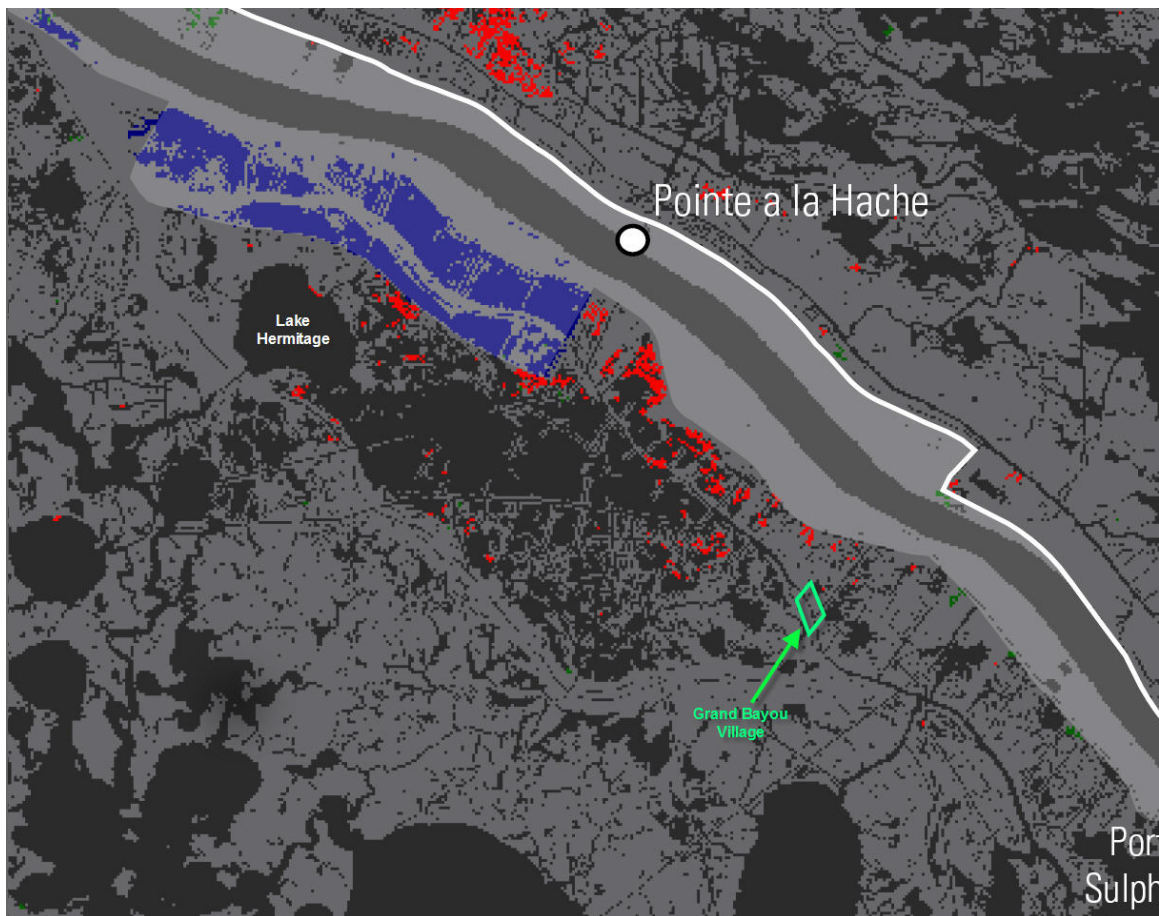


Figure 8. Grand Bayou area from map in Figure 7 zoomed in to show differences and similarities with similar datasets produced for this study.



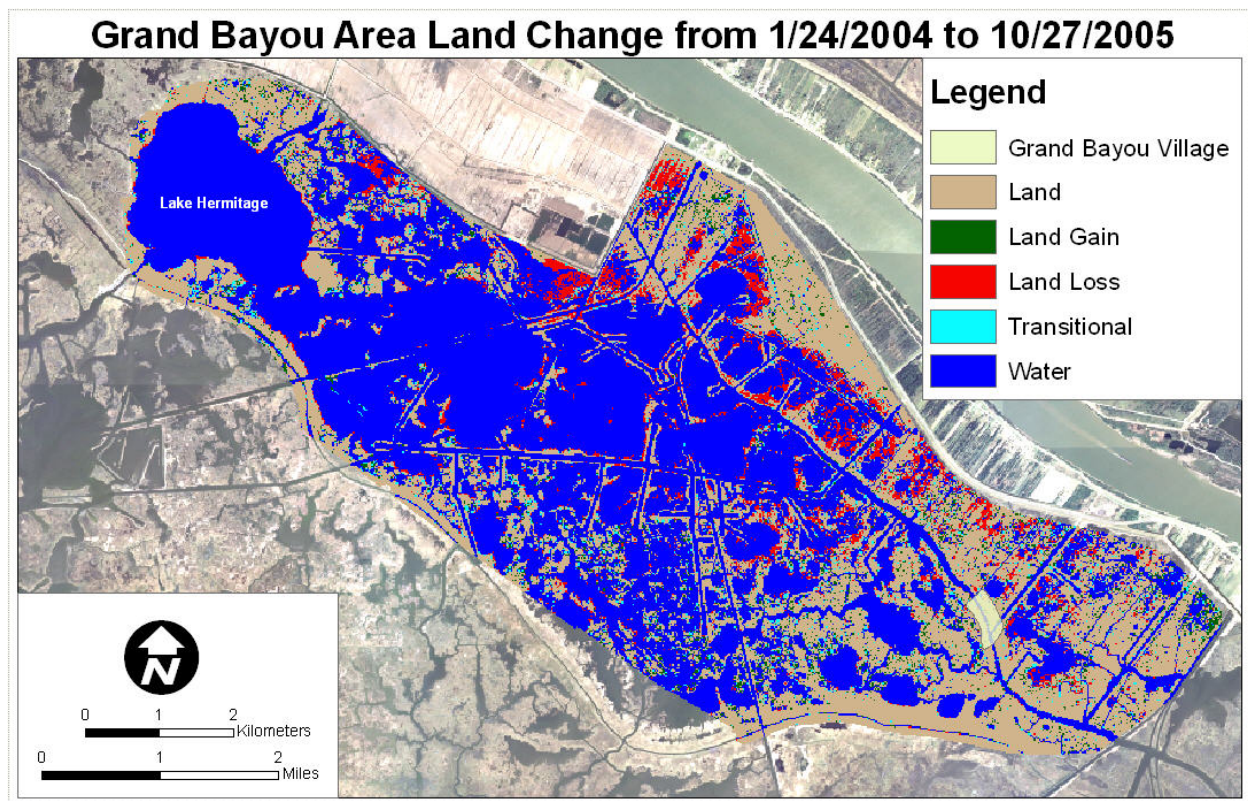


Figure 9. Grand Bayou land change map (1/21/2004 to 10/27/2005) produced for this study.

The level of detail produced for the Grand Bayou area land change maps in this study is propagated throughout the subsequent derived products (i.e. the Marsh Vulnerability Map and significantly clustered areas of high risk). This level of detail is not currently utilized in predicting land loss based on trends from maps such as that by Barras (2007). An example of a projected land loss map produced from such datasets is shown in Figure 10, with the Grand Bayou study area shown enlarged in Figure 11. According to this map, practically the entire study area is projected to be lost to open water by 2050. This information may be useful in noting that out of the Southeast Louisiana region in general the Grand Bayou area is a hotspot for projected land loss, and may possibly be a candidate area for inclusion into the list of proposed restoration projects to consider for input into the CPRA Project Prioritization Model. However, the new information that is included with the more detailed datasets produced from this study

integrated with the local community-based TEK datasets provide much more comprehensive information specific to this area. This allows more informed local environmental processes and community needs to be adequately considered in the model.

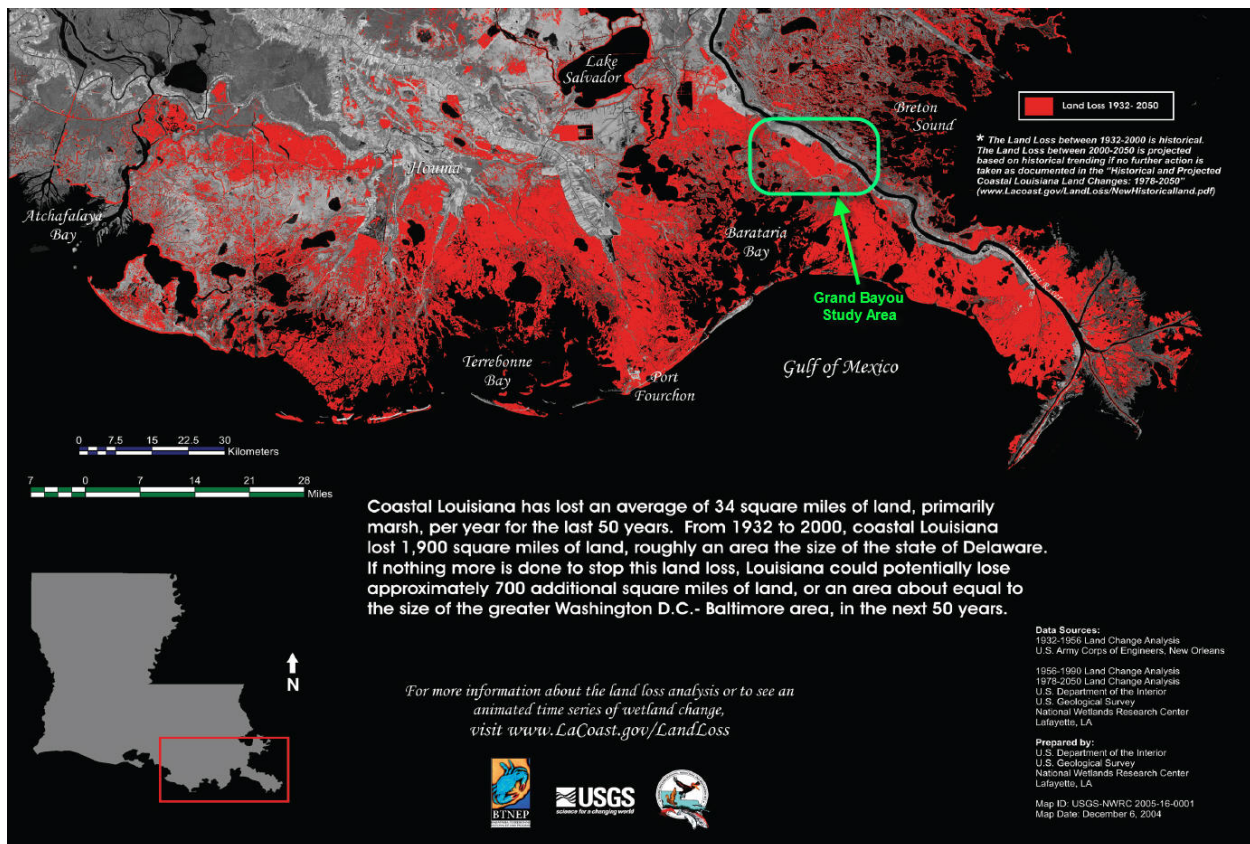


Figure 10. Southeastern Louisiana projected land loss map produced by USGS (USGS, 2005).



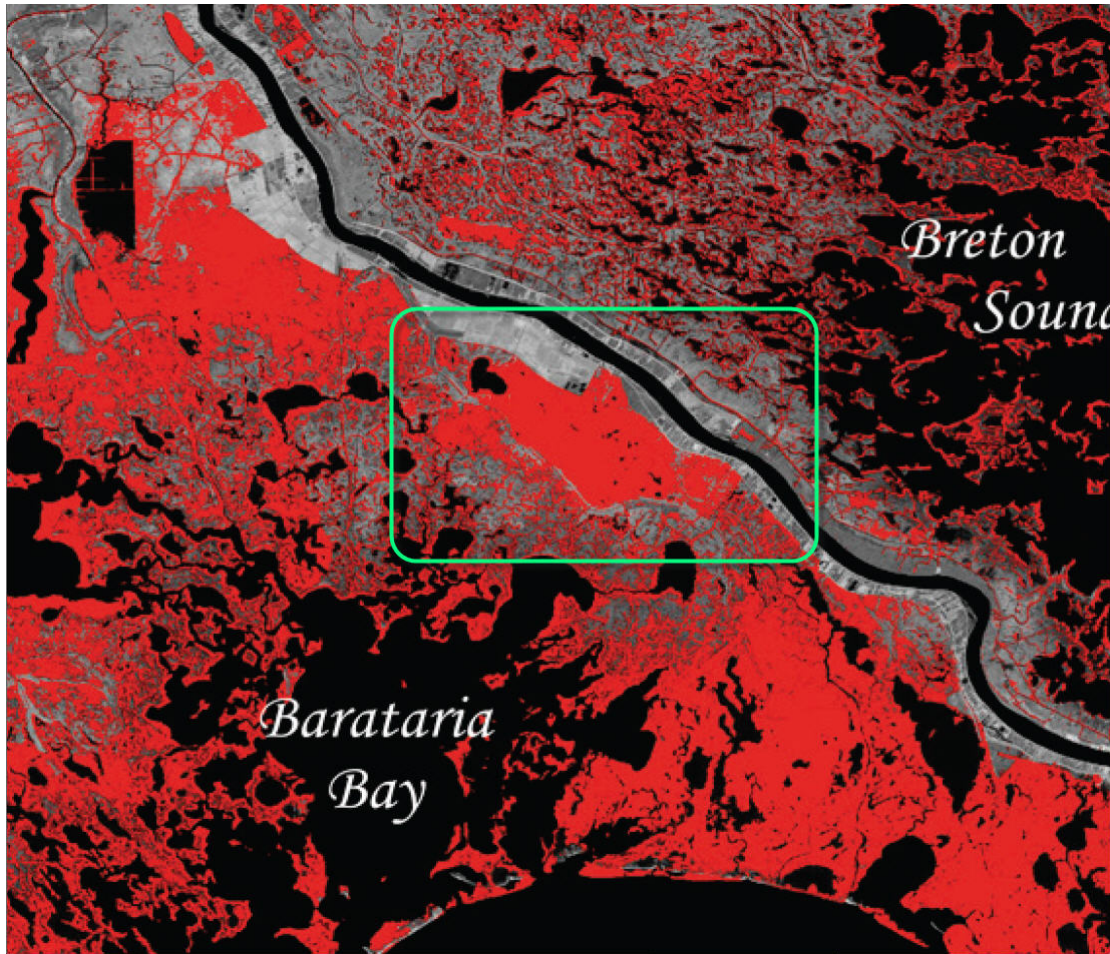


Figure 11. Grand Bayou study area enlarged to show detail from Southeastern Louisiana projected land loss map (USGS, 2005).

### **Comparison of Study Results with Proposed Local Restoration Projects Based on Current Decision-Making Process**

A comparison can be made between the results of this study and the results of the current coastal restoration decision-making process given that there are two specific restoration projects that were selected and authorized through this process. These projects are currently in the engineering and design phase, and were approved in 2006 (BA-42) and 2007 (BA-47). These two projects are described as follows on the LaCoast.gov website: The goals of the Lake Hermitage Marsh Creation “are to create approximately 593 acres of wetlands, reduce tidal

exchange in marshes surrounding Lake Hermitage, and reduce fetch and turbidity to promote submerged aquatic vegetation”. The project area encompasses 1,600 acres and the total estimated cost and approved funds for this project are \$38,000,000 (LaCoast, 2010a). This planned restoration project is detailed in Figure 12.

The results of this study show that this restoration project area is within and near features identified as important to restore from the community perspective (Figure 13). In addition, this research shows that the project location includes significant clusters of high risk areas to loss. Therefore, the results of this study would most likely validate that the Lake Hermitage Marsh Creation project is a good location for restoration in this area. However, is it the best?

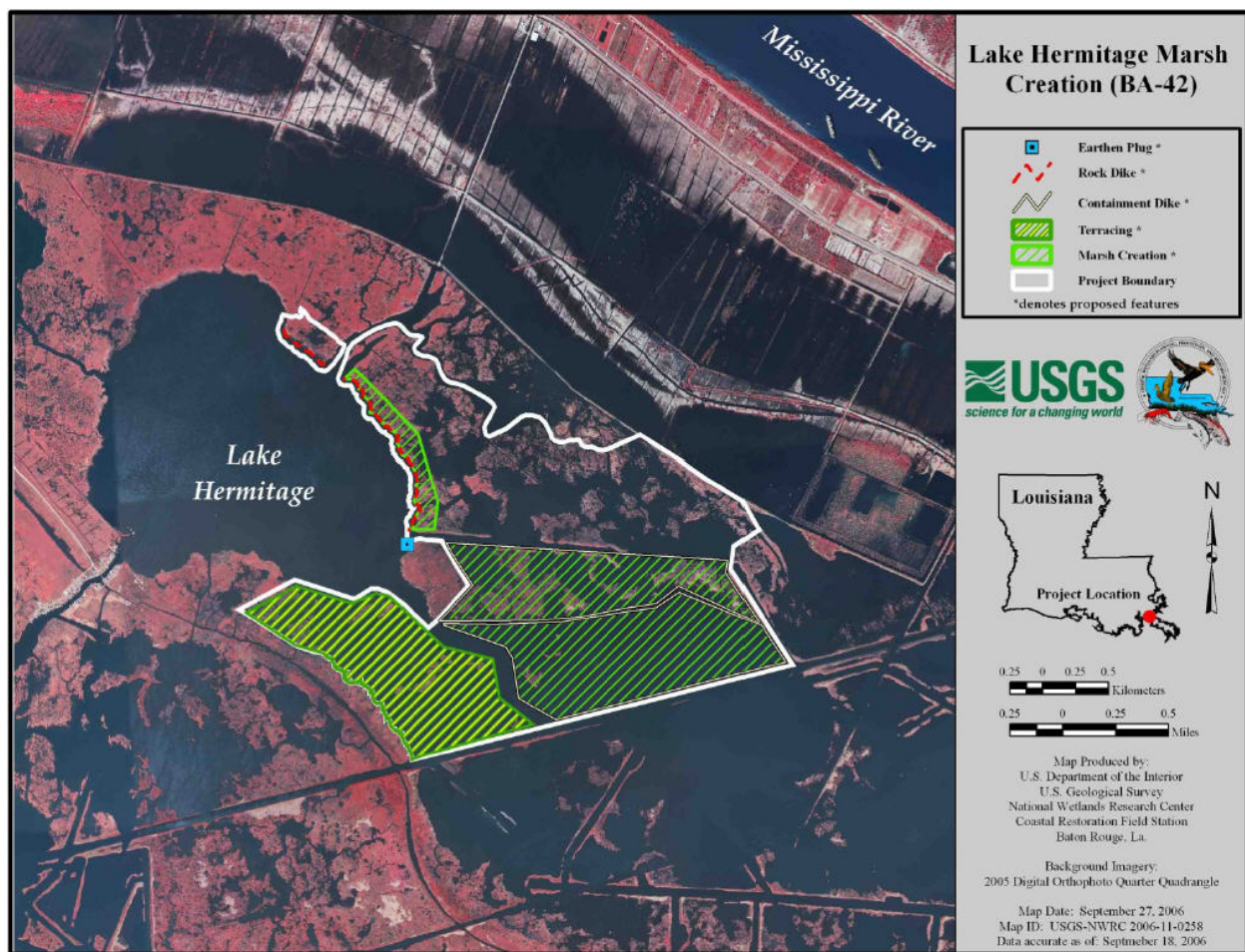


Figure 12. Lake Hermitage Marsh Creation restoration project (LaCoast, 2010a).



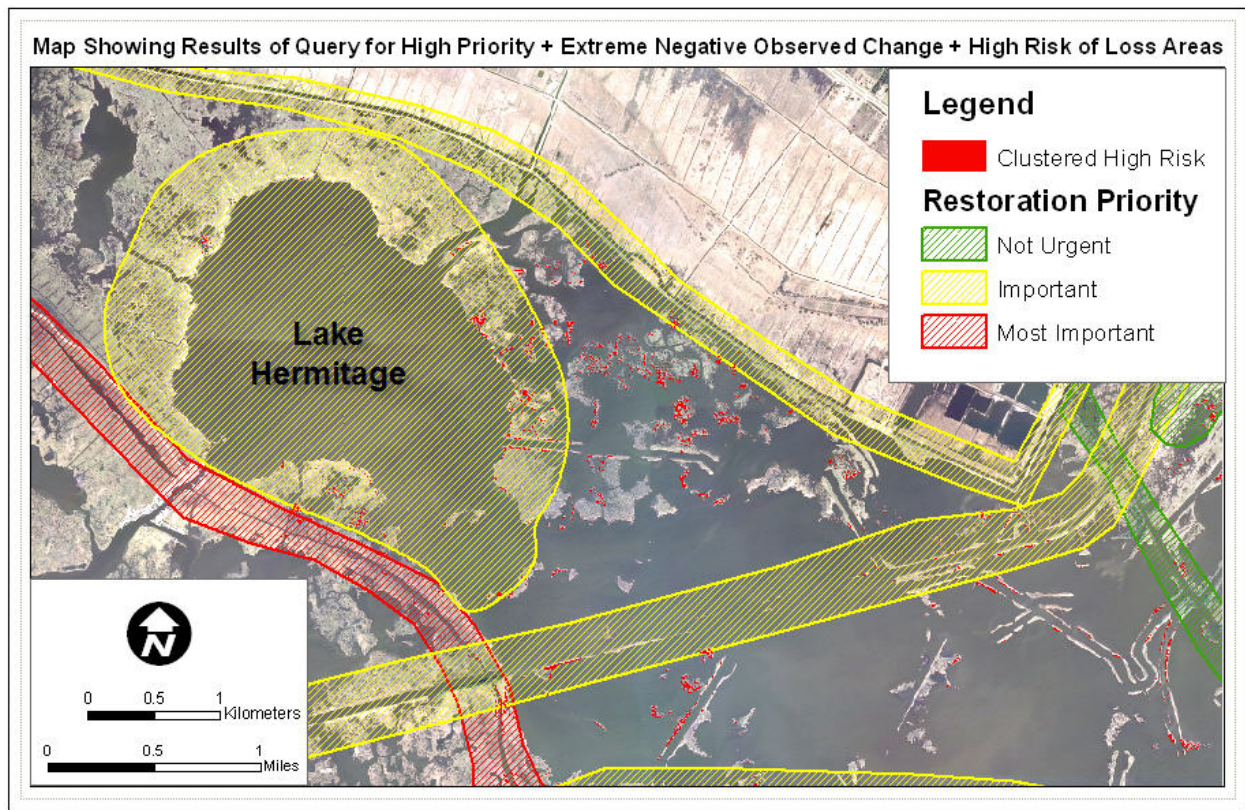


Figure 13. Map showing TEK-based restoration priorities and high risk of loss areas for the location of the Lake Hermitage Marsh Creation project.

The goal of the West Pointe a la Hache Marsh Creation project is to “recreate marsh habitat in the area just west of the Jefferson Lake Canal by harvesting sediment from the Mississippi River and pumping it via pipeline to the proposed site”, and thus “converting approximately 250 acres of open water habitat to intermediate marsh, nourishing approximately 102 acres of existing intermediate marsh with dredged material, and maintaining 203 acres of created/nourished marsh over the 20-year project life” (LaCoast, 2010b). The project area includes 352 acres, and total estimated cost is \$16,100,000, however approved funds are \$1,620,000 according to the LaCoast.gov website. This planned restoration project is shown in Figure 14.

This research shows that there are few remaining marsh areas that are high risk to loss within this project location since almost all marsh has already been lost to open water, though this information may be irrelevant in this case as the goal is to convert open water to marsh. Similar to the Lake Hermitage Marsh Creation project, results of this study show that the West Pointe a la Hache Marsh Creation project area is within and near features identified as important to restore from the community perspective (Figure 15). Therefore again, the results of this study would most likely validate that the West Pointe a la Hache Marsh Creation project is a good location for this particular type of restoration in this area. However, the question must be asked: are they the best restoration projects for this local area given the results of this study? The answer is no. According to the results of this study, the best location for restoration given limited resources available for restoration in this area are near Grand Bayou Village where there are significant areas of high risk to loss. This result assumes location selection based on: 1) Extreme Negative Observed Change; 2) Most Important community-based Restoration Priority; and 3) significantly clustered areas of High Risk to loss. It must be noted that there are many other factors in the decision-making process that are not accounted for in this analysis such as project cost and land rights issues which certainly influence the final project selections. However, the inclusion of the integrated datasets produced in this study would have influenced the final selections with the new information, and thus may have resulted in other areas being selected.

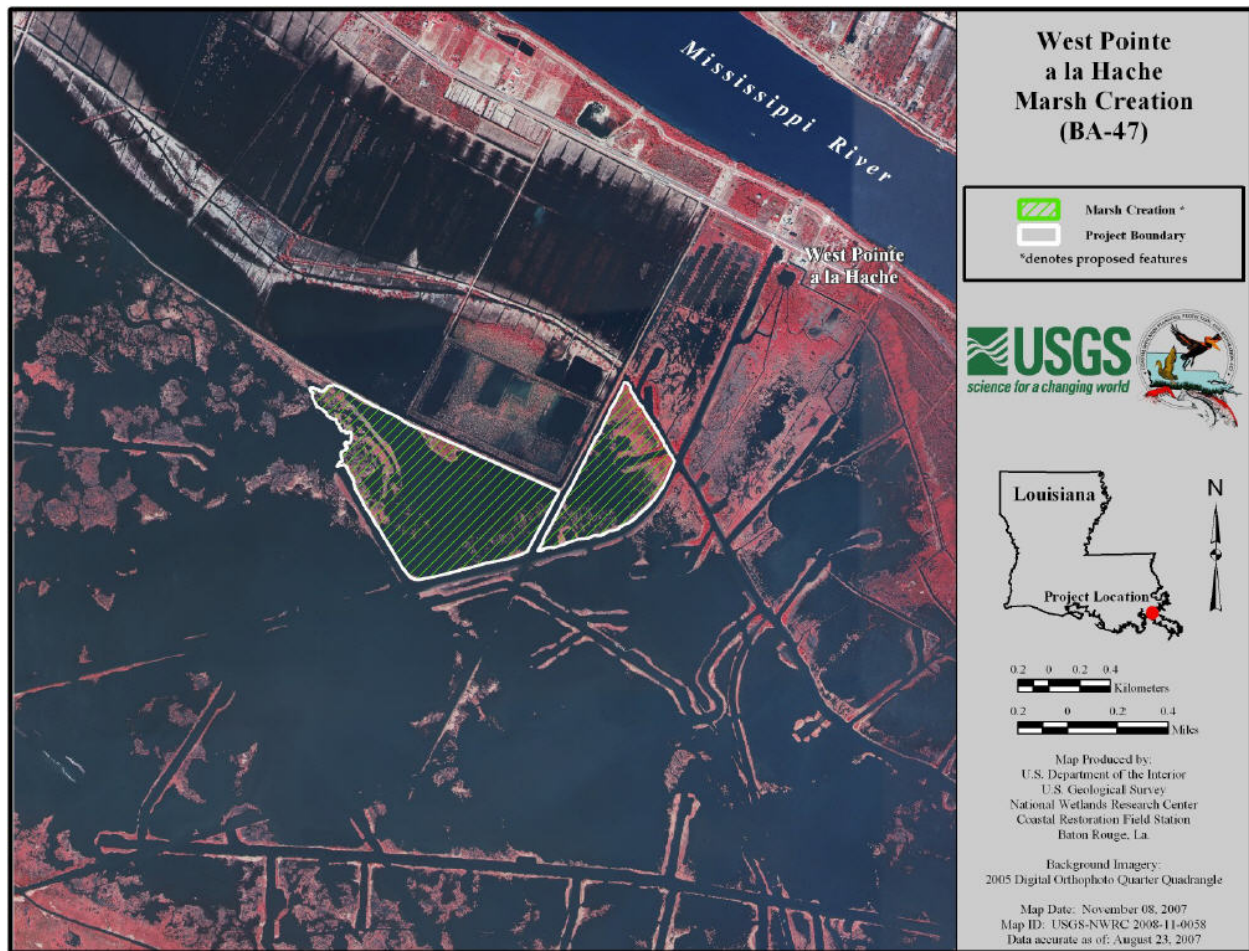


Figure 14. West Pointe a la Hache Marsh Creation restoration project (LaCoast, 2010b).



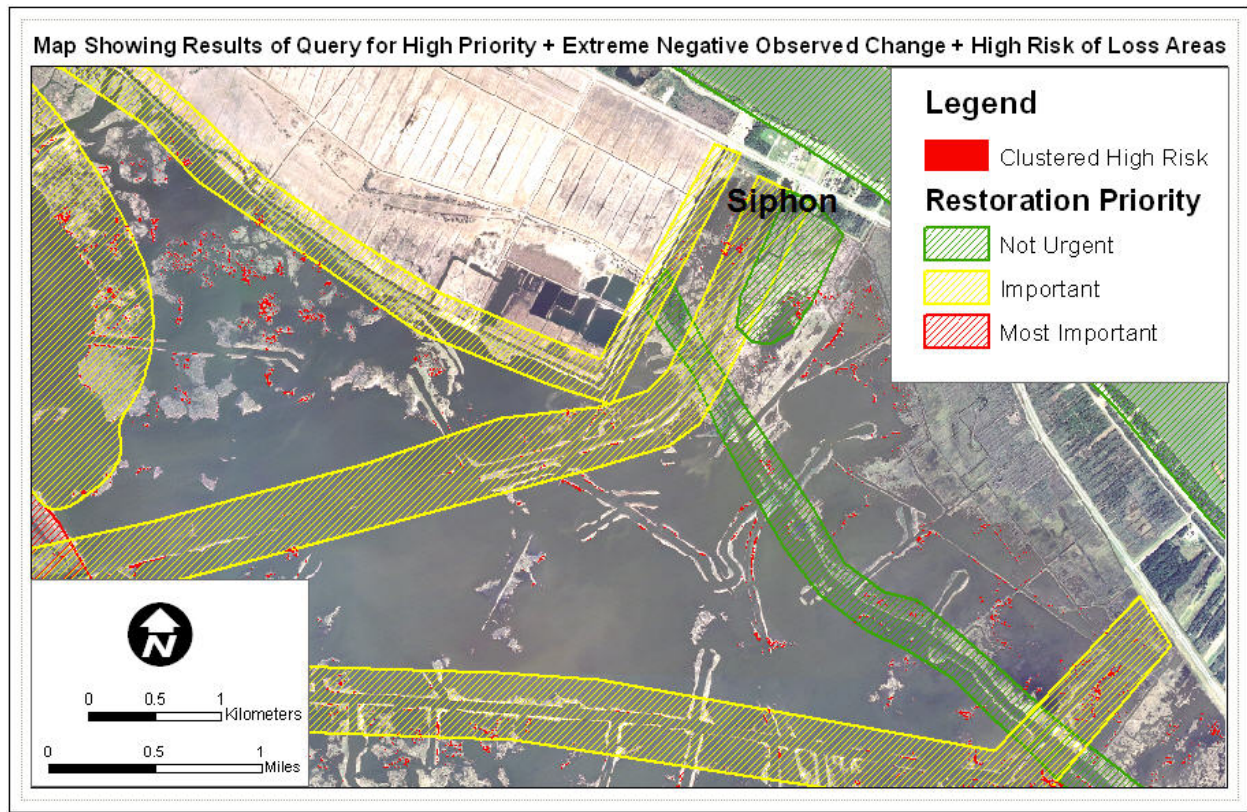


Figure 15. Map showing TEK-based restoration priorities and high risk of loss areas for the location of the West Pointe a la Hache Marsh Creation project.

## CONCLUSIONS

1. The blending of the traditional ecological knowledge (TEK) of people that utilize an ecosystem for livelihood and sustenance with knowledge obtained through the scientific process results in a more comprehensive set of tools with which to make decisions regarding restoration. As noted in several studies, there are many advantages to blending these datasets (Goodwin, 1998; Huntington, 2000; and Hrenchuck, 1993). Some common reasons stated for integrating scientific data and TEK are: to empower communities local to the studied resource through direct participation so that they have a ‘voice’ in stewardship activities; to aid in field data collection and interpretation; and to insure that the resulting information is

driven by ‘real-world’ community concerns rather than theory or basic research only. Other studies have concluded that the process of integrating TEK with conventional science studies improves local commitment, trust, and the adoption of new management practices (Calheiros et al. 2000, Ticktin and Johns 2002, and Castillo et al. 2005).

2. There are significant obstacles to blending TEK with scientific data, however, that have resulted in widespread reluctance to do so from both the scientific community and local residents that possess TEK. This resistance to integration of the two types of information stems from the differences in how the information is acquired, as well as a general lack of understanding by each group (i.e. scientists and traditional knowledge holders) of what the knowledge of the other offers them and how they may benefit from it. Some of these obstacles are reported in a study by Ballard et al. (2008) in which the use and integration of local knowledge and conventional science in ecological stewardship and monitoring by seven community-based forestry demonstration projects was examined. The authors report that particular challenges to this type of data integration are: differences in priorities among participating scientists and local traditional knowledge holders; communication difficulties; and the reluctance of scientists to use data collected in less formal ways. An additional obstacle identified was “the relationships of power already in place for the traditionally under-represented local people and Native American tribes who were asked to be involved”, with the result that “formal structures such as meetings in offices and symposia with presentations may have reinforced the power inequities and made participation more difficult” (Ballard et al., 2008).

In conducting the work with the residents of Grand Bayou, the researchers have experienced each of these challenges mentioned by Ballard et al. There are other obstacles, of course, but these became most evident at the beginning of the project during attempts to build a working relationship with the participating members of the community. For instance, the researchers quickly realized that formal settings and structured interviews to acquire TEK were unreasonable given the conflicting communication styles and priorities of the collaborating residents. The community does not have a history of question and answer communication methods, rather, their information and knowledge is exposed as they tell stories. They feel more comfortable relating the stories in familiar settings, such as at a resident's house, or out on a boat while surveying the marsh. The result has been a greater wealth of TEK divulged in these settings. This takes time and patience on the part of researchers; however, it results in a more comprehensive picture of the environmental changes taking place in the area.

This level of interaction with local residents requires additional time and resource commitments by scientists that are not normally factored into traditional scientific studies. Most scientists will not view favorably the cost/benefit ratio resulting from the additional requirements necessary to obtain and integrate TEK into their project plans. Simply put, with few precedents quantitatively showing a significant improvement in research results associated with utilizing TEK, a scientist will not go 'outside-the-box' and incur additional project costs and time requirements if he/she does not understand a benefit to doing so.

The reluctance of scientists to use data collected in less formal ways stems from how conventional scientists are trained and from the nature of the scientific method itself. Specifically, conventional scientists are trained in rigorous sampling design and standardized



data collection and verification/validation methods. Typically, TEK is what is learned from experiences and observations of an area collected over years of living there, though not recorded or organized in a formal manner. Scientific researchers propose hypotheses as explanations of phenomena, and design experimental studies to test these hypotheses. According to scientists, these steps must be repeatable in order to dependably predict any future results. Because the scientific method holds the conviction that the process be objective to reduce biased interpretations of the results, there is significant skepticism among scientists regarding TEK acquired from local peoples on the grounds that it is biased to reflect the views and experiences of the informants.

3. A review of the current restoration decision-support process shows that the methodologies and tools produced in this study are suitable for inclusion. In addition, these data products can inform the process and influence the results with meaningful, new information that is geared to meet localized needs rather than regionally based criteria. This study demonstrates that once hotspots of land loss are identified on a regional scale and further prioritization is needed for selection of restoration projects on a local level, the information made available through the methodologies and tools used in this study can be included with other criteria, such as cost estimates, to make more informed restoration decisions.

## REFERENCES

- Allen, D. W. 2009. GIS Tutorial II, Spatial Analysis Workbook. ESRI Press, Redlands, California: 407 pp.
- Anselin, Luc. 1995. Local Indicators of Spatial Association – LISA. *Geographical Analysis*, 27(2): pp. 93–115.
- Ballard, H. L., M. E. Fernandez-Gimenez, and V. E. Sturtevant. 2008. Integration of local ecological knowledge and conventional science: a study of seven community-based forestry organizations in the USA. *Ecology and Society* 13(2): 37.
- Balram, S., S. Dragicevic, and T. Meredith. 2004. A collaborative GIS method for integrating local and technical knowledge in establishing biodiversity conservation priorities. *Biodiversity and Conservation*, Vol. 13: pp. 1195-1208.
- Barras, J. A. 2007. Land area changes in coastal Louisiana after Hurricanes Katrina and Rita, in Farris, G. S., Smith, G. J., Crane, M. P., Demas, C. R., Robbins, L. L., and Lavoie, D. L., eds., Science and the storms: the USGS response to the hurricanes of 2005: U. S. Geological Survey Circular 1306, p. 98-113, <http://pubs.usgs.gov/circ/1306/pdf/c1306>
- Calheiros, D. F., A. F. Seidl, and C. J. A. Ferreira. 2000. Participatory research methods in environmental science: local and scientific knowledge of a limnological phenomenon in the Pantanal wetland of Brazil. *Journal of Applied Ecology* 37(4):684–696.
- Castillo, A., A. Torres, A. Velazquez, and G. Bocco. 2005. The use of ecological science by rural producers: a case study in Mexico. *Ecological Applications* 15(2):745–756.
- CPRA. 2009. Fiscal Year 2010 Annual Plan: Integrated Ecosystem Restoration and Hurricane Protection in Coastal Louisiana, April 27, 2009. Coastal Protection and Restoration Authority of Louisiana. Baton Rouge, LA.
- CWPPRA. 2006. Wetland Value Assessment Methodology Introduction. Prepared by: Environmental Work Group, U.S. Fish and Wildlife Service. URL: <http://www.lacoast.gov/reports/wva/WVA%20Introduction.pdf>
- Goodwin, P. 1998. ‘Hired Hands’ or ‘Local Voice’: Understandings and Experience of Local Participation in Conservation. *Transactions of the Institute of British Geographers*, New Series, Vol. 23, No. 4: pp.481-499.
- Hrenchuck, C. 1993. Native Land Use and Common Property: Whose Common?. Pages 69-86 in J. T. Inglis, editor. *Traditional Ecological Knowledge Concepts and Cases*. International Program on Traditional Ecological Knowledge and International Development Research Centre, Ottawa, Ontario, Canada.

- Huntington, Henry P. "Using Traditional Ecological Knowledge in Science: Methods and Applications" *Ecological Applications*, 10(5), 2000, pp. 1270-1274.
- LaCoast. 2010a. Lake Hermitage Marsh Creation (BA-42). *Louisiana Coastal Wetlands Conservation and Restoration Task Force*. URL: <http://www.lacoast.gov/projects/list.asp>
- LaCoast. 2010b. West Pointe a la Hache Marsh Creation (BA-47). *Louisiana Coastal Wetlands Conservation and Restoration Task Force*. URL: <http://www.lacoast.gov/projects/list.asp>
- LCA Science and Technology Program Science Board. 2010. *Summary Report of the January 13-15, 2010 Meeting*. 16 pp.
- Louisiana Coastal Area. 2010. Louisiana Coastal Area (LCA) Science and Technology Program. URL: <http://www.mvd.usace.army.mil/lcast/index.html>
- Petch, J. P., E. Pauknerova, and D. I. Heywood. 1995. A strategy for GIS in nature conservation: the Zdarske Vrchy project. *ITC Journal*, Vol. 2: pp. 133-142.
- Ticktin, T., and T. Johns. 2002. Chinanteco management of *Aechmea magdalenae*: implications for the use of TEK and TRM in management plans. *Economic Botany* 56(2):177–191.
- USGS. 2005. Depicting Coastal Louisiana Land Loss. USGS Fact Sheet 2005-3101, July 2005. USGS National Wetlands Research Center, Lafayette, LA.

## **CHAPTER 7**

### **CONCLUSIONS**

The rapid rate of land loss witnessed across coastal Louisiana, and in particular observed in the vicinity of Grand Bayou for this study, results in at risk coastal communities and an endangered ecosystem which supports these communities. The Louisiana coastal wetlands' tremendous biological diversity provides one of the richest concentrations of natural resources on the planet. The preservation of this unique and productive ecosystem is not only vital to the communities which depend upon it to sustain their very existence, but also to the Nation as a significant source of seafood and domestic petroleum production. The people who live and work along the coast of Louisiana have a deeply rooted connection to place, interwoven with and dependent on the rich natural resources found in this region (Gramling and Hagelman, 2005). The presence of this culture that is intertwined with the environment (an environment that is rapidly degrading and being lost) provides an opportunity to better understand, protect, and restore this dynamic place. Better restoration decision-making is critical to combat the complex forces (both natural and anthropogenic) that contribute to land loss and to enhance local community resilience in this region.

This study was centered on Grand Bayou, Louisiana and focused on the village's surrounding ecologically dependent livelihood base. This area has experienced some of the most rapid and extensive land loss in coastal Louisiana. The relatively rapid land loss rate that has occurred in this area since the 1960s provided a unique opportunity to study the morphological evolution to current conditions and how these changes have impacted the community residents

who rely upon the area's natural resources. This study resulted in the development of a methodology and mapping products for detailed assessment of historical land loss trends, prediction of 'hotspots' that are vulnerable to loss, and integration of TEK with these datasets in a spatial context that is suitable for informing the existing restoration decision support system.

In Chapter 3, a detailed land change analysis for the study area was constructed. The historical land change mapping methodology developed for this study was created on the basis of methods used by Barras et al. (2003), Barras (2007), Barras et al. (2008), and Bernier et al. (2006) to map historical land loss in coastal Louisiana. A variety of historical remotely sensed images and photographs of the study area from 1968 to 2009 were obtained and processed in order to identify and interpret the changes that took place between each time period at a level of spatial detail that did not previously exist for this location. Based on the resulting analysis, it was determined that the study area has undergone a complex morphological evolution that includes large core areas of once unbroken marsh being perforated with small ponds, leading to a significant increase in broken or patchy marsh areas that eventually were lost to open water. In addition, it was determined that episodic storm events have caused as much as a 400% increase in land loss rate, as was noted for the 2005 storm season. The dramatic effect of these storm events on the study area persists for years after such an event, as was noted by the relatively high rate of land loss that continued during the 2005 to 2009 time period. It was also noted that historical land loss increased significantly in the study area from 1979 to 1991 during a time in which previous studies reported that land loss rates significantly declined for the southeast Louisiana coastal region in general (Barras et al., 2008; Britsch and Dunbar, 1993).

Chapter 4 focused on the TEK data collection and TEK-map production methodology. Land loss in the vicinity of Grand Bayou, and throughout Coastal Louisiana for that matter,

results from a complicated set of environmental and anthropogenic causes which include: canal dredging; subsidence; erosion; storms; levees; and even climate change (Bernier et al., 2006; Michot et al., 2004; Walker et al., 1987; Turner, 1997; and Penland et al., 1996). Because of its complexity, isolating specific causes and trends of land loss in the study area is a daunting task given limited funding and resources available. However, an advantage of working closely with local residents and utilizing TEK in this scientific study is that the study focus can be effectively narrowed to identify the likely major causes of local land loss and shape the investigation accordingly. In analyzing the TEK obtained for this study, an emphasis was placed by the community informants on the effects of oil company constructed canals which dominate the study area today. Secondary ecological effects that resulted from the construction of these canals are noted in the TEK as allowing salt-water intrusion and natural hydrological flow alteration, which in turn accelerated the land loss observed. Furthermore, the TEK analyses identified a timeline for observed relative land loss change (i.e. acceleration) and construction of the canals so that the researchers could identify and acquire image datasets from relevant time periods allowing scientific assessment of this land loss.

The methodology developed to produce the TEK-based maps for this study demonstrates a means by which such qualitative information can be converted into mapping products that are more suitable for inclusion into the existing restoration decision-support system. Moreover, the methodology used to gain access to the TEK utilized in creating the TEK-based maps, serves as an example of how scientists can effectively engage indigenous local communities as partners in similar collaborative efforts.

Chapter 5 provided a biophysical and spatial analysis of marsh characteristics in the study area with an emphasis on marsh chlorophyll content, LAI, and fragmentation. The historical



land change maps developed in Chapter 3 were used to identify the locations of previous land loss and to aid in the determination of future vulnerability to loss based on overlay and statistical analyses with the historical fragmentation maps produced. A satellite image was acquired coincident with field data collection, and the in-field marsh biophysical data collected was successfully correlated with the processed image data resulting in estimated chlorophyll and LAI maps that detailed the relative physiological status of the marsh across the study area. This biophysical information was merged with a current fragmentation map in a GIS to produce a marsh vulnerability map of the study area.

The model used to create the marsh vulnerability map can be used to evaluate an area in detail for restoration potential. This methodology demonstrates how scientific field sampling data can effectively be merged with information on landscape pattern and trends within a GIS to make marsh vulnerability projections in a spatial context.

In Chapter 6, the mapping products produced in Chapters 4 and 5 were integrated using GIS techniques. This integration methodology resulted in mapping products that are suited for inclusion into the current CPRA Restoration Prioritization Model. These results were presented to the collaborating CPRA-OCPR scientists. One of the scientists who is responsible for monitoring the effects of the West Pointe a la Hache Siphons to the study area commented that this information “will be very useful” for restoration management and planning in the area. After assessing the new information provided with these mapping products, another CPRA-OCPR manager who collaborated on this research recognized the cultural and physical importance of the Ravine to the community as well as the local ecosystem. The information products resulting from this study also allowed him to quickly determine that this important feature has been degraded significantly over time and is vulnerable at key locations (specifically

where the natural ridge has been cut by several canals that altered the natural hydrology and now allows storm surges and saltwater to penetrate into the study area from the open waters of the Gulf. With this new information, he began to conceptualize a small, targeted restoration project that would close off these canals at the Ravine and help to restore the natural flow of this vital stream, while at the same time reducing the effects of these canals on the degradation of the marsh in the study area. With the scale and scope of such a restoration project in mind, he then began to brainstorm about ways to acquire the needed resources and funding to implement such a restoration project (which was minimal by typical restoration project standards). He concluded that the idea would be a good, inexpensive, and relatively fast restoration action that could possibly make a dramatic positive impact to the local area ecosystem. A restoration project such as this could also serve to validate the methods proposed in this study if found to be beneficial to the local area over time with proper monitoring and performance assessments.

Previously mentioned in Chapter 6 were some of the published benefits of blending TEK with scientific data, though there are additional benefits particularly relevant to the Grand Bayou project including those reported by Castillo et al. (2005) in a study of the role of ecological science and TEK in promoting sound environmental decisions in rural Mexico. Castillo et al. (2005) state that the “generators of scientific knowledge must work closely with its users to identify problems, construct ad hoc solutions, and participate in decision-making processes ranging from the local level to that of policy formulation”, so that the results of such research is “turning scientific findings into actions”. In other words, a good understanding and use of TEK which incorporates cultural characteristics, indigenous land-use patterns, information needs and requirements, and changing resource availability, is required for effective application of ecological scientific information for restoration.

Not only did the TEK obtained in this study aid in increasing the efficiency of the scientific data analyses for the research objectives, but as Ballard et al. (2008) report, local knowledge of the landscape proves invaluable in conducting field data collection in a cost-effective, efficient manner. The researchers have experienced this through the field sampling site selection process, as the community informants have knowledge of which locations are accessible and practical for sampling. Without this knowledge, field sampling site selection would undoubtedly have been far more time consuming, and in fact dangerous.

To ensure acceptance of these TEK/scientific data integration methods by scientists, the researchers attempted to address the typical scientific concerns with incorporating TEK as previously stated in Chapter 6. First, this research ensured that the TEK information obtained for this study involves repeated observations of field sites by several different individuals to reduce the impact of any information bias. As a result, the information obtained from any one informant did not dominate the ‘coded’ information that is mapped and integrated with the scientific data collected.

Second, TEK data verification and validation procedures are included in the data collection and integration methods developed for this study. These procedures included meeting with the informants interviewed to review recorded and summarized information from which subsequent inferences were drawn regarding project questions. This was done to ensure that the TEK was recorded and interpreted accurately during the interviews. Verification and validation exercises also served as opportunities for the research team to show the community informants the scientific data and TEK collected thus providing transparency in our efforts.

Third, although the methods developed in this study focus on blending the TEK of the Grand Bayou community informants with scientific datasets, these methods are generally

‘repeatable’, or applicable, to any proposed or ongoing restoration project that impacts a community where the population has a long history of being intricately tied to the surrounding ecosystem. This situation is the case with many of Louisiana’s coastal fishing villages, as well as fishing communities throughout the Gulf Coast. Thus, the integration methodology, as proposed, is not specific to Grand Bayou and can be applied to other areas with similar issues.

Lastly, in working with the residents as collaborators on this project, they have become more familiar with the capabilities and limitations of remotely sensed imagery. Every time the researchers visit Grand Bayou, maps generated from remotely sensed imagery were left with the residents and the researchers made an effort to explain how the maps were produced. The researchers have also fostered a relationship between community residents and the collaborating CPRA scientists associated with monitoring the study area. This relationship was non-existent prior to this study.

The hope is to create more dialog and discussion between the two groups fostering a mutual respect and knowledge transfer that will be sustained beyond the term of this study. If this goal is achieved, the Grand Bayou residents will continue to provide CPRA with ecological insight and informed suggestions, critique, and information, thus aiding the mapping process, as well as image dataset interpretation, and ultimately helping to inform the West Pointe a la Hache restoration decision-making process for the foreseeable future. In doing so, this effort will address the general lack of understanding by scientists of the information value that TEK offers, as well as start to bridge the communication gap that typically exists between scientists and traditional knowledge holders.

## **FUTURE RESEARCH RECOMMENDATIONS**

The development of the methods and GIS tools implemented in this study and the improved understanding of how TEK may be merged with scientific datasets to inform restoration decision-making make it apparent that numerous unanswered questions regarding benefit and cost aspects of knowledge integration and application for coastal restoration exist. Moreover, in order to fully test and further develop the methods and mapping products presented in this study, the results should be applied to other vulnerable coastal ecosystems that serve as livelihood bases for coastal communities. The following is a summary of proposed future directions that might expand upon the findings of this study:

1. A continual detailed monitoring of the morphology of the Grand Bayou area in order to determine effectiveness and impacts of the current and proposed restoration projects on the ecosystem, to better understand long-term versus short-term (i.e., episodic storm related) land loss trends, and to document changes for comparison to projected vulnerability identified in this research.
2. Monitoring possible major causes of land loss identified in this study, including oil canals, through subsequent research focusing on future data collection and analyses in an effort to quantify their effects.
3. Incorporation of economic analyses to determine the cost/benefit ratio associated with incorporating this type of integrated dataset into the current process as a means of justifying the additional time and cost which currently precludes it from being utilized more frequently by restoration scientists. If supportive results can be achieved, then there will be a

compelling precedent for scientists to view the cost/benefit ratio of utilizing such a method more favorably.

4. Integrate new datasets of the marsh biophysical parameters from field data acquired during the peak of the growing season, and then repeat the marsh biophysical estimated mapping process to include the new datasets. This will allow for comparison with the biophysical mapping results of this study and may improve the assessment of relative marsh health for inclusion into a revised vulnerability assessment.
5. Integrate new remotely sensed data products with greater spectral resolution into the mapping processes described in this study in an attempt to improve correlation with field data.

Additional research may be facilitated by better availability and reduced cost of finer resolution remotely sensed satellite data as more remote sensing data options become available to researchers.



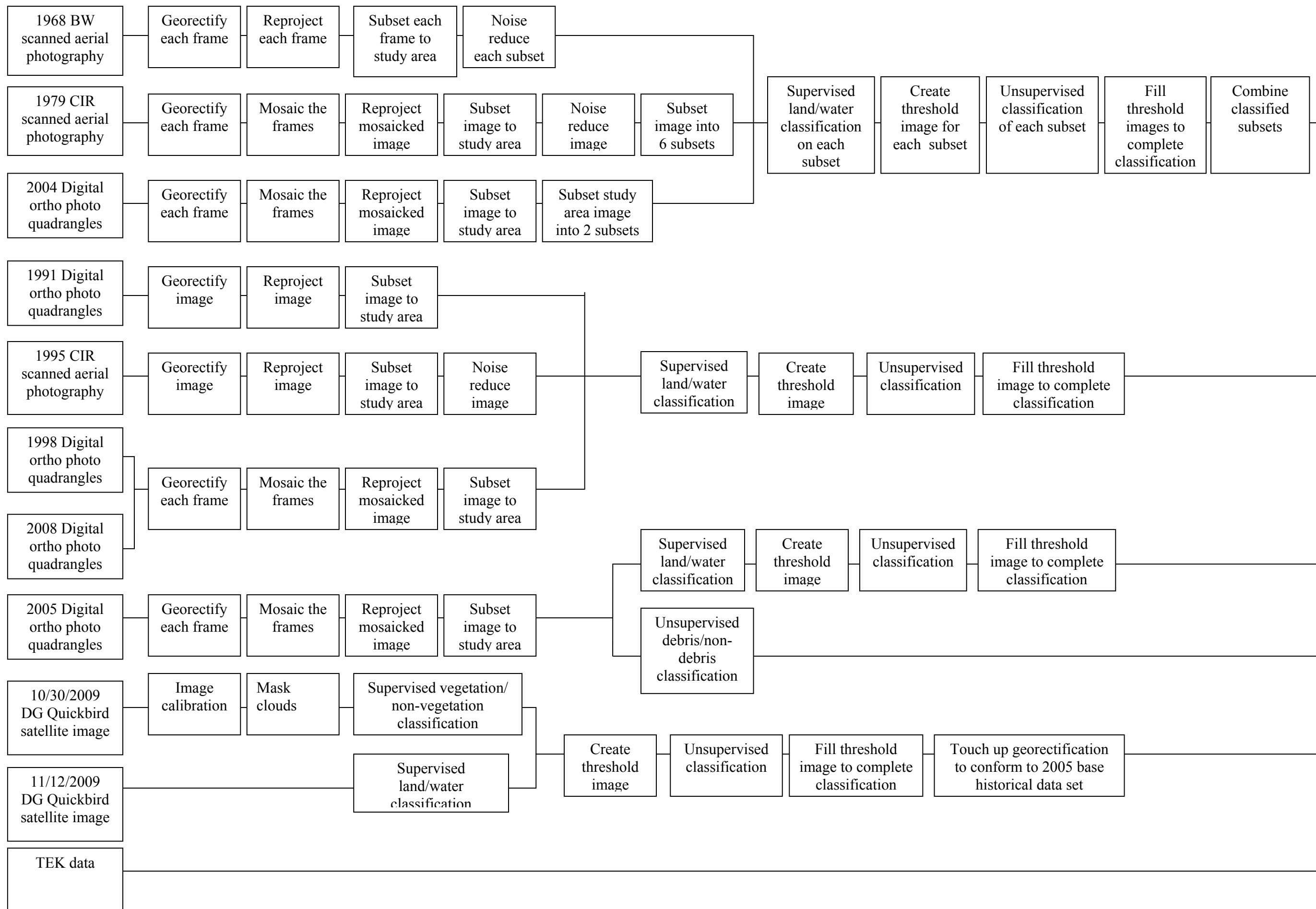
## REFERENCES

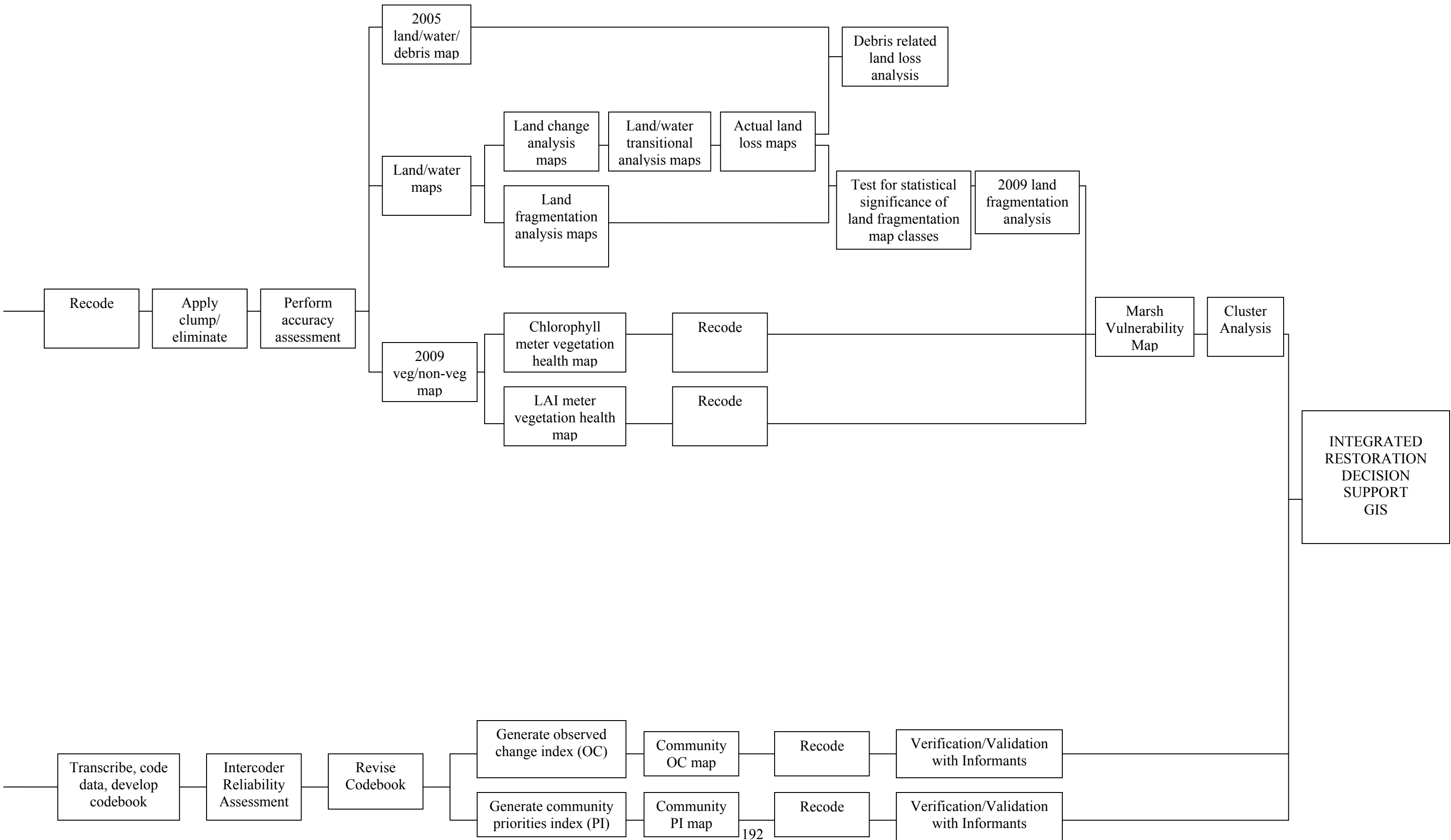
- Ballard, H. L., M. E. Fernandez-Gimenez, and V. E. Sturtevant. 2008. Integration of local ecological knowledge and conventional science: a study of seven community-based forestry organizations in the USA. *Ecology and Society*, 13(2): 37.
- Barras, J. A., S. Beville, D. Britsch, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota, and J. Suhayda. 2003. Historical and projected coastal Louisiana land changes: 1978-2050. *U.S. Geological Survey Open-File Report 03-334*, 39 p.
- Barras, J. A. 2007. Land area changes in coastal Louisiana after Hurricanes Katrina and Rita, in Farris, G. S., Smith, G. J., Crane, M. P., Demas, C. R., Robbins, L. L., and Lavoie, D. L., eds., *Science and the storms: the USGS response to the hurricanes of 2005*: U. S. Geological Survey Circular 1306, p. 98-113, <http://pubs.usgs.gov/circ/1306/pdf/c1306>
- Barras, J. A., J. C. Bernier, and R. A. Morton. 2008. Land area change in coastal Louisiana-A multidecadal perspective (from 1956 to 2006): U. S. Geological Survey Scientific Investigations Map 3019, scale 1:250,000, 14 p. pamphlet
- Bernier, J. C., R. A. Morton, and J. A. Barras. 2006. Constraining Rates and Trends of Historical Wetland Loss, Mississippi River Delta Plain, South-Central Louisiana, in *Coastal Environment and Water Quality*, Water Resources Publications, LLC, Highlands Ranch, CO, p. 371-382.
- Britsch, L. D., and J. B. Dunbar. 1993. Land loss rates: Louisiana Coastal Plain. *Journal of Coastal Research*, 9(2), pp. 324-338.
- Castillo, A., A. Torres, A. Velazquez, and G. Bocco. 2005. The use of ecological science by rural producers: a case study in Mexico. *Ecological Applications* 15(2):745-756.
- Gramling, R. and R. Hagelman. 2005. A Working Coast: People in the Louisiana Wetlands. *Journal of Coastal Research*, SI(44): pp. 112-133.
- Michot, T. C., C. J. Wells, and R. S. Kemmerer. 2004. Spatial and Temporal Distribution of Coastal Marsh Dieback in Louisiana, 2000-2003, as Determined from Aerial Surveys. Report submitted to *Coastal Restoration Division, Louisiana Department of Natural Resources* in partial fulfillment of: DNR Contract Number 2512-05-03.
- Penland, S., I. Mendelssohn, L. Wayne, and D. Britsch. 1996. Natural and Human Causes of Coastal Land Loss in Louisiana. *Coastal Studies Institute and Wetland Biogeochemistry Institute*, Louisiana State University, Baton Rouge, Louisiana.

- Turner, R. E. 1997. Wetland Loss in the Northern Gulf of Mexico: Multiple Working Hypotheses. *Estuaries*, Vol. 20, No. 1, pp. 1-13.
- Walker, J. H., J. M. Coleman, H. H. Roberts, and R. S. Tye. 1987. Wetland Loss in Louisiana. *Geografiska Annaler. Series A, Physical Geography*, Vol. 69, No. 1, pp. 189-200.

## APPENDIX A

### MAPPING PROCESS FLOW CHART





## APPENDIX B

### GRAND BAYOU PROJECT DECLARATION OF PRINCIPLES

## **Declaration of Principles, Ethics and Expectations**

*Pontchartrain Institute for Environmental Sciences, [Center for Hazard Assessment, Response and Technology](#), University of New Orleans, The Community of Grand Bayou, Center for Research on Embedded Systems Technology Team*

These principles of Participatory Action Research are based on the understanding assumption that people and processes are always changing, and that despite these changes we, as a team, will continue to work with each other. We hope, through this project to better understand ourselves and each other. We will collaborate honestly and equally, while being aware of the history which has held our worlds apart. We hope to build a bridge between the permanent community of Grand Bayou and the academic community so that all participants can share knowledge and resources, in the search for justice and truth and encourage others to do the same. We will establish a learning community through honoring all participants and respecting each other.

The principles we have agreed upon:

### **Openness and Honesty**

From the start, we will clearly explain the strengths and limitations of our diverse experiences. Such openness will help create a truly collaborative relationship. We will take care to recognize the difference between facts and opinions. We will be honest in every aspect and open to suggestions and advice from *all participants*. Additionally, we will not harbor grudges; rather we will take the initiative to communicate our feelings about the process and the information being shared.

### **Clear Communication**

Clear communication among all participants is of the utmost importance. We intend to use phone calls as the primary means of communication along with some email and meetings. Open and frequent conversation is essential for the learning community. Information must be shared with *all* members participating in the process. Each individual must take the initiative to ensure the circle of communication includes everyone who is interested or affected.

### **Commitment to doing good**

No harm should ever come to the community through the work of this project. This is especially important because outsiders, such as academics, have brought significant harm to Grand Bayou in the past. If disagreements should occur it is essential that the community's vision or well-being not be harmed. Results and information from this project will only be used in ways that will appropriately benefit all parties involved. We recognize that these benefits may come in different forms; however one member should not be getting a benefit while another is suffering a loss. We recognize that the community's willingness to work with us is a privilege, and not a right. That being the case, we will do everything in our power to continually earn the privilege



of working with the community, in part by never letting our concerns impede the community's vision. These guidelines hold true *even in situations of innocent intentions*.

### **Sharing and presenting of Research**

The community must approve the final publication, presentation or document *before* it is released. Diversity of opinions on findings will be honored. The community will be significantly involved in the writing, editing and presenting. The community will be represented in full or by representatives whenever their name is used in presentations or documents. The community will receive copies of every document in full.

### **Commitment to Resources**

We all commit to using, providing and seeking any available resources to assist the community's vision *at the direction of the community*.

### **Respect of Local Knowledge**

All team members are valued and respected for their individual and community experiences and knowledge. We will respectfully combine local traditional scientific knowledge with academic scientific knowledge. We believe that the sum of combining the two bodies of knowledge will be more complete and more useful than if the two remained separated. It is imperative to honor the community as well as their experience. We recognize that in the past traditional indigenous knowledge was exploited by outsiders; we will not repeat such discrimination. Every team member's experience and knowledge is different, yet no one's is better than anyone else's.

### **Inclusion of the Entire Community**

The learning community will include every member of the permanent, indigenous Grand Bayou community. Through various methods of communication, especially cell phones and visits, we, the learning community, will ensure that we get in touch with everyone who wants to be involved.

### **Flexibility**

We will be flexible and adaptive in all of our work, not only with the time and scheduling of meetings, but also with the process. This method will allow the collaboration to be more flexible. We will modify our work as we evaluate and reflect on what we learn. We expect our environment, our relationships and ourselves to change throughout this collaboration, a reflective process will allow us to learn from these changes.

**Reflection**

Ongoing evaluation is critical, and must be given priority in discussions and communications. The process of participatory action is one of constant reflection and analysis. We are committed to helping each other see where our work is headed and think about where we have been. We must also always check that we are adhering to these principles, and that we are asking the questions that are most important to the community and our shared vision. The process of reflection is fundamental as it ties our knowledge together, creating new understanding.

**Consideration of Time**

We recognize that the community is busy, and that time spent in collaboration is time spent away from family, work, leisure or other activities devoted to community resiliency. Research and other activities must be conducted in a manner that fits with the time schedule and needs of the Grand Bayou community. This project requires a significant time investment from all partners. We recognize that forming relationships and building trust takes time and we will not rush these processes regardless of deadlines.

**\*\*This document, while specific to our research team, can be used as a blueprint for future studies.\*\***

## APPENDIX C

### RESTORATION PRIORITY INDEX

***Community assessment of restoration priority (+1 is important/urgent, -1 is not important/not urgent, 0 mentioned but inconclusive)***

**Very important area to restore (+1)-----0-----Insignificant area (-1)**

Restoration is vital to protect the entire area—ideally all areas would be restored. Generally residents’ lifestyles are very mobile as is their work. Two sites—the Chenier/Indian Mounds and their village are immobile and fundamental to the community’s culture and livelihood.

Shrimping, fishing and trapping are highly mobile activities. Oystering is also mobile but on a fixed time scale due to annual, geographically specific leases.

**Back levee**

*Hunting and trapping +1*

RI=1/13=0.07692

**Bay Batiste**

It’s still a good area for oystering and shrimping, but not as good as before. A large island (Big Island) in the middle has disappeared.

*Land leasing/Land ownership +1*

*Oysters +1*

RI= 2/13=0.15385

**Bay Roquette**

High levels of land loss. There is no marsh left—it’s all water. Used to have to walk—the land was so solid, now you can take a big boat. Community hunters and trappers used to have camps along this bay. Still some good trapping in the area.

*Hunting and trapping +1*

*Wildlife +1*

*Cultural significance +1*

RI= 3/13=0.23076

**Bay Sans Bois**

Keeps getting bigger and bigger over time—high amounts and speed of land loss. The bay is huge now, was a small bay twenty years ago, now it’s a lake. Shrimping in this bay, not much fishing. The Texas Company Canal leads into it. Used to be forested area.

RI= 0

**Bayou Stephan**

*Generations +1*

*Cultural significance +1*

*Hunting and trapping +1*

RI=3/13=0.23077

**Bayou Traverre**

Large shrimp in this area.

*Hunting and trapping +1*

*Generations +1*

*Oysters +1*

RI=3/13=0.23077

**Beach (by the sea)**

50 years ago shrimped here. Used to be able to walk on a high levee to get here. Has basically washed away—huge amount of land. A seemingly efficient restoration project has targeted this area, restored only about 10ft width. Used to take 4 hours to get to the beach from the village, now it takes 1.5-2 hours.

*Political Action +1*

*Restoration 0*

*Money 0*

*Cultural Significance +1*

RI= 2/13=0.15385

**Chenier**

Highest place –still intact one side, the other is being eaten up. This ridge which acts as a barrier from storm surge, a bulkhead and an evacuation spot. Used to be heavily forested with lush vegetation. Solid/hard land is changing slowly compared to other areas. Contains the Indian Mounds (traditional burial grounds). Jean Lafitte used to travel along this ridge. Community used the area for gardens and hunting/trapping. Only place still with deer and other wildlife. People used to live in this area and some community members would like to again. Only area with any trees but they are dying. This area is very important to protect.

*Storms +1*

*Restoration +1*

*Farming +1*

*Hunting and trapping +1*

*Wildlife +1*

*Generations +1*

*Cultural significance +1*

RI= 7/13=0.53846

**Crane Island**

Used to be an island, now is just water. Named for the many birds which used to flock there.

*Wildlife +1*

RI= 1/13=0.07692

**Foster's Canal**

By the school. Used to have a rice field. Used to have trees, can see stumps. Empties—is dry—before a big storm.

*Storms +1*

*Farming +1*

*Cultural significance +1*

RI=  $3/13=0.23077$

**Freeport Canal**

Shrimping location.

RI= 0

**Grand Bayou Pass**

Natural bayou. Goes to the back of Empire. Large amounts of land loss.

*Restoration 0*

RI= 0

**Grand Bayou Village**

Community members have lived for centuries on Grand Bayou Way. Everyone has a strong desire to stay there. The land is owned privately by residents. They are geographically near to sport camps but the community is exclusive to permanent indigenous residents of the area. They have been offered a lot of money for their land and have refused. Due to land loss and environmental change many community members have been forced to move away. Those who remain do not consider relocation an option. The ground is relatively high and hard, and bullheaded in some areas with grass and shells and in other with beams and pilings. It is also a place for residents to dock their boats, sort their catches and meet with others. The Bayou has gotten significantly wider in the last 50 years—a lot of property has washed away. The current has gotten much faster. Residents used to have big gardens but now can't due to land loss and salt water intrusion.

*Burns +1*

*Political Action +1*

*Land leasing/Land ownership +1*

*Storms +1*

*Restoration +1*

*Farming +1*

*Hunting and trapping +1*

*Wildlife +1*

*Generations +1*

*Money+1*

*Cultural significance +1*

RI=  $11/13=0.84615$

**Grand Lake**

Used to shrimp around islands—now disappeared.

RI= 0

### **Green Island**

Previous beautiful bird sanctuary—hatching area for cranes and many other migratory birds. No longer exists.

*Wildlife +1*

RI= 1/13=0.07692

### **Gulf**

Contributes to erosion. Land is being eaten up from both ends—the Gulf is one end. Used to take 4-5 hours to get from Grand Bayou to the Gulf, now takes about 1 hour. At Empire now, getting closer and closer to Grand Bayou and the surrounding environment. Used to shrimp all the way from Grand Bayou to the Gulf. White shrimp catches have moved much closer to the Gulf. Fishing and shrimping has moved out into the Gulf. Used to stay for 6 months in the Gulf shrimping—now a few weeks. Oil canals link the Gulf with freshwater wetlands.

RI= 0

### **Indian Mounds**

Only place left. They are now, how the entire marsh used to be—hard. Important to protect. The highest point in the marsh—three mound surrounding a flat part in the center. Still have deer and other animals. Contained within the Chenier. Environment much the same as large areas used to be.

*Burns +1*

*Storms +1*

*Restoration +1*

*Farming+1*

*Hunting and trapping +1*

*Wildlife +1*

*Generations +1*

*Cultural significance +1*

RI= 8/13=0.61538

### **Jefferson Lake Canal**

Eaten up from canals cut for sulphur extraction. Blocking off this canal would help restoration efforts tremendously—land would build back up in 4-5 years. Would be one of the first projects if community initiated. Originally dug 14ft. deep with high banks on either side started digging at Wilkinson Bay. In an area with lots of canals and rigs—oil, gas and sulphur extraction. Went to political meetings in the past and encouraged closure of this canal to stop erosion.

*Political Action +1*

*Restoration +1*

*Hunting and trapping +1*

*Generations +1*

*Money 0*

RI=4/13=0.30769



**Lake Hermitage**

Restoration priority should be to close channels in this area. Used to act like a bulkhead with trees, mangroves and vegetation.

*Restoration +1*

*Hunting and trapping +1*

*Wildlife 0*

*Land ownership/Land leasing -1*

RI=1/13=0.07692

**Mississippi River**

Fast current. Contains enough sediment to rebuild the whole marsh.

RI= 0

**Myrtle Grove Canal**

*Hunting and trapping +1*

RI= 1/13=0.07692

**Old evacuation spot**

*Storms +1*

*Hunting and trapping +1*

*Cultural significance +1*

*Restoration +1*

*Generations +1*

RI=5/13=0.38462

**Pond behind the school**

*Restoration +1*

*Hunting and trapping +1*

*Cultural significance +1*

*Burns +1*

RI=4/13=0.30769

**Port Sulphur Canal**

*Hunting and trapping +1*

RI= 1/13=0.07692

**Ravine**

*Restoration +1*

*Cultural significance +1*

*Generations +1*

*Storms +1*

*Hunting and trapping +1*

*Wildlife +1*

RI=6/13=0.46154

### **Shell Canal**

RI=0

### **Siphon**

Brings only freshwater and no sediment—changes water salinity in that immediate area but does not rebuild land. The influx of freshwater doesn't stay because there are too many open areas, need to close off canals to make it effective. Won't close any spaces up. Perceived land gain in the area is just shifting sediment, or receding water levels. Not helpful or efficient as a restoration project. Killed all the nearby oyster beds due to the mass influx of freshwater. Couldn't catch a fish. Vegetation changed from salt water to freshwater grasses. Used to be willow trees in that area. Relatively firm land. On/Off decisions (regulated by the state) kill fish and vegetation in the area. Hurt the brown shrimp catch a bit.

*Political Action -1*

*Legal Action -1*

*Oysters -1*

*Money -1*

*Restoration -1*

RI=-5/13=-0.38462

### **Texas Company Canal**

Need to close off for restoration—will make a big difference. One of the biggest and oldest oil canals. Really wide now. Land loss accelerated after it was cut.

*Restoration +1*

RI= 1/13=0.07692

### **Wilkinson Bay**

Sulphur extraction canal dug all the way through this bay, because of this the land washed away twice as fast. Community used to fish and shrimp, used to have camps out in there. "Now, it's nothing there." Restoration efforts should start in this area.

*Restoration +1*

*Cultural significance +1*

RI= 2/13=0.15385

All possible codes for restoration importance:

*Burns (they have made the effort to restore themselves)*

*Political Action (area is important enough that residents assert themselves politically to protect it)*

*Legal Action (area is important enough that residents assert themselves legally to protect it)*

*Land leasing/Land ownership*

*Storms (Evacuation spots)*

*Restoration*

*Farming (contributes to sustenance and culturally important)*

*Hunting and trapping (while a mobile activity, there is so few places left with wildlife, the areas that do exist are important to protect in order to allow community members to continue this cultural activity)*

*Wildlife*

*Generations (areas with historical, cultural importance)*

*Oysters (while a dynamic operation, fishermen cannot move their sites on short notice due to annual leasing systems)*

*Money*

*Cultural significance*

$$RI = (a - b) / x$$

*RI = Restoration Index*

*a = number of codes with value of +1*

*b = number of codes with value of -1*

*x = total number of codes = 13*

Note: The only negative RI value is associated with the siphon. This is because the community considers this area a poor target area for significant restoration investment. The influx of freshwater killed their oyster beds, rendering their leases useless. It had no positive effect on their livelihood.

## APPENDIX D

### OBSERVED CHANGE INDEX

*Observed Change (+1 is positive change, -1 negative change, 0 mentioned but inconclusive)*

**Back Levee**

*Land height -1*

*Restoration +1*

*Vegitation 0*

*Water salinity +1*

$VI=1/27=0.03704$

**Bay Batiste**

It's still a good area for oystering and shrimping, but not as good as before. A large island (Big Island) in the middle has disappeared.

*Land Loss -1*

*Oysters 0*

*Shrimp 0*

*Restoration -1*

*Current -1*

$VI= -3/27 =-0.11111$

**Bay Roquette**

High levels of land loss. There is no marsh left—it's all water. Used to have to walk—the land was so solid, now you can take a big boat.

*Boat transportation -1*

*Change -1*

*Land Loss -1*

*Marsh Stability -1*

*Open areas -1*

*Speed -1*

*Water Increase -1*

$VI= -7/27 = -0.25926$

**Bay Sans Bois**

Keeps getting bigger and bigger over time—high amounts and speed of land loss. The bay is huge now, was a small bay twenty years ago, now it's a lake. Shrimping in this bay, not much fishing. The Texas Company Canal leads into it. Used to be forested area.

*Change -1*

*Early Canal Cutting -1*

*Land Loss -1*

*Open areas -1*

*Shrimp +1*

*Speed -1*

*Vegetation -1*

*Water Increase -1*

*Work -1*

$VI= -7/27 = -0.25926$

**Bayou Stephan**

*Vegetation -1*

*Restoration 0*

*Current -1*

*Water increase -1*

*Boat transportation -1*

*Current -1*

VI=-5/27=-0.18519

**Bayou Traverre**

Large shrimp in this area.

*Shrimp +1*

*Current -1*

*Open areas -1*

*Boat transportation -1*

*Vegetation +1*

*Wildlife 0*

*Marsh stability -1*

*Land height -1*

VI= -3/27 =-0.11111

**Beach (by the sea)**

50 years ago shrimped here. Used to be able to walk on a high levee to get here. Has basically washed away—huge amount of land. A seemingly efficient restoration project has targeted this area, restored only about 10ft width. Used to take 4 hours to get to the beach from the village, now it takes 1.5-2 hours.

*Boat transportation -1*

*Land Loss -1*

*Restoration +1*

*Shrimp -1*

VI= -2/27 = -0.07407

**Chenier**

Highest place –still intact one side, the other is being eaten up. This ridge which acts as a barrier from storm surge, a bulkhead and an evacuation spot. Used to be heavily forested with lush vegetation. Solid/hard land is changing slowly compared to other areas. Contains the Indian Mounds (traditional burial grounds). Jean Lafitte used to travel along this ridge. Community used the area for gardens and hunting/trapping. Only place still with deer and other wildlife. People used to live in this area and some community members would like to again. Only area with any trees but they are dying. This area is very important to protect.

*Farming -1*

*Hunting and Trapping 0*

*Land Height +1*

*Land Loss -1*

*Marsh Stability +1*

*Speed +1*

*Storms -1*

*Vegetation -1*

*Wildlife 0*

$VI = -1/27 = -0.03704$

**Crane Island**

Used to be an island, now is just water. Named for the many birds which used to flock there.

*Land Loss -1*

*Water Increase -1*

*Wildlife -1*

$VI = -3/27 = -0.11111$

**Foster's Canal**

By the school. Used to have a rice field. Used to have trees, can see stumps. Empties—is dry—before a big storm.

*Current 0*

*Farming -1*

*Vegetation -1*

$VI = -2/27 = -0.07407$

**Frank Canal**

*Shrimp -1*

*Boat transportation -1*

*Land height -1*

$VI = -3/27 = -0.11111$

**Freeport Canal**

Shrimping location.

*Shrimp +1*

*Work +1*

$VI = 2/27 = 0.07407$



**Grand Bayou Pass**

Natural bayou. Goes to the back of Empire. Large amounts of land loss.

*Land Loss -1*

VI=  $-1/27 = -0.03704$

**Grand Bayou Village**

*Land loss -1*

*Vegetation -1*

*Water increase -1*

*Speed -1*

*Wildlife -1*

*Shrimp -1*

*Work -1*

*Current -1*

*Water salinity -1*

VI=  $-9/27 = -0.33333$

**Grand Lake**

Used to shrimp around islands—now disappeared.

*Land Loss -1*

*Shrimp -1*

*Work -1*

VI=  $-3/27 = -0.11111$

**Green Island**

Previous beautiful bird sanctuary—hatching area for cranes and many other migratory birds. No longer exists.

*Land Loss -1*

*Wildlife -1*

VI=  $-2/27 = -0.07407$

**Gulf**

Contributes to erosion. Land is being eaten up from both ends—the Gulf is one end. Used to take 4-5 hours to get from Grand Bayou to the Gulf, now takes about 1 hour. At Empire now, getting closer and closer to Grand Bayou and the surrounding environment. Used to shrimp all the way from Grand Bayou to the Gulf. White shrimp catches have moved much closer to the Gulf. Fishing and shrimping has moved out into the Gulf. Used to stay for 6 months in the Gulf shrimping—now a few weeks. Oil canals link the Gulf with freshwater wetlands.

*Boat transportation -1*

*Early Canal Cutting -1*

*Land Loss -1*

*Shrimp -1*

*Water Salinity -1*

*Work -1*

VI=  $-6/27 = -0.22222$

### **Indian Mounds**

Only place left. They are now, how the entire marsh used to be—hard. Important to protect. The highest point in the marsh—three mound surrounding a flat part in the center. Still have deer and other animals. Contained within the Chenier. Environment much the same as large areas used to be.

*Change 0*

*Land Height +1*

*Marsh Stability +1*

*Wildlife +1*

$VI = 3/27 = 0.11111$

### **Jefferson Lake Canal**

Eaten up from canals cut for sulphur extraction. Blocking off this canal would help restoration efforts tremendously—land would build back up in 4-5 years. Would be one of the first projects if community initiated. Originally dug 14ft. deep with high banks on either side started digging at Wilkinson Bay. In an area with lots of canals and rigs—oil, gas and sulphur extraction.

*Early Canal Cutting -1*

*Land Gain -1*

*Land Height 0*

*Restoration -1*

*Resource Extraction -1*

*Land loss -1*

*Water increase -1*

*Open areas -1*

*Current -1*

$VI = -8/27 = -0.29630$

### **Lake Hermitage**

Restoration priority should be to close channels in this area. Used to act like a bulkhead with trees, mangroves and vegetation.

*Change -1*

*Storms -1*

*Vegetation -1*

*Restoration -1*

*Wildlife +1*

*Marsh height -1*

*Water increase -1*

$VI = -5/27 = -0.18519$

### **Mississippi River**

Fast current. Contains enough sediment to rebuild the whole marsh.

*Current 0*

*Sediment/Dirt/Soil +1*

$VI = 1/27 = 0.03704$

**Myrtle Grove Canal***Restoration +1**Land loss +1* $VI=2/27=0.07410$ **Old evacuation spot***Vegetation -1**Current -1**Water increase -1**Wildlife -1**Marsh stability -1**Water salinity -1**Dirt -1**Restoration 0**Boat transportation -1* $VI=-8/27=-0.29630$ **Pond behind the school***Marsh stability -1**Land loss -1**Land height -1**Boat transportation -1**Water increase -1**Speed -1**Vegetation -1**Wildlife -1* $VI=-8/27=-0.29630$ **Port Sulphur Canal***Restoration +1* $VI=1/27=0.03704$ **Ravine***Vegetation -1**Wildlife -1**Land loss -1**Speed -1* $VI=-4/27=-0.14815$

### **Shell Canal**

Closed up during beach restoration. Oil company cut from wetlands straight to the Gulf.  
Shrimping location.

*Early Canal Cutting -1*

*Restoration 0*

*Shrimp +1*

*Work +1*

$VI = 1/27 = 0.03704$

### **Siphon**

Brings only freshwater and no sediment—changes water salinity in that immediate area but does not rebuild land. The influx of freshwater doesn't stay because there are too many open areas; need to close off canals to make it effective. Won't close any spaces up. Perceived land gain in the area is just shifting sediment, or receding water levels. Not helpful or efficient as a restoration project. Killed all the nearby oyster beds due to the mass influx of freshwater. Couldn't catch a fish. Vegetation changed from salt water to freshwater grasses. Used to be willow trees in that area. Relatively firm land. On/Off decisions (regulated by the state) kill fish and vegetation in the area. Hurt the brown shrimp catch a bit.

*Land Gain 0*

*Marsh Stability +1*

*Open areas 0*

*Oysters -1*

*Restoration -1*

*Sediment/Dirt/Soil 0*

*Shrimp -1*

*Vegetation +1*

*Water Increase 0*

*Water Salinity +1*

*Wildlife +1*

*Current -1*

*Boat transportation -1*

*Speed +1*

$VI = 0/27 = 0$

### **Texas Company Canal**

Need to close off for restoration—will make a big difference. One of the biggest and oldest oil canals. Really wide now. Land loss accelerated after it was cut.

*Early Canal Cutting -1*

*Land Loss -1*

*Restoration -1*

*Speed -1*

*Water Increase -1*

$VI = -5/27 = -0.18519$

**Venice**

*Water salinity +1*

*Land loss -1*

$VI=0/27=0$

**Wilkinson Bay**

Sulphur extraction canal dug all the way through this bay, because of this the land washed away twice as fast. Community used to fish and shrimp, used to have camps out in there. “Now, it’s nothing there.” Restoration efforts should start in this area.

*Change -1*

*Land Loss -1*

*Shrimp -1*

*Speed -1*

*Work -1*

*Restoration -1*

*Early Canal Cutting -1*

$VI= -7/27 = -0.25926$

All possible codes for vulnerability:

*Boat transportation*

*Change*

*Current*

*Early Canal Cutting*

*Farming*

*Hunting and Trapping*

*Land Gain*

*Land Height*

*Land Loss*

*Marsh Stability*

*Open areas*

*Oysters*

*Restoration*

*Sediment/Dirt/Soil*

*Shrimp*

*Speed*

*Storms*

*Vegetation*

*Water Increase*

*Water Salinity*

*Wildlife*

*Work*

$VI = (a - b) / x$

*VI = Vulnerability Index*

*a = number of codes with value of +1*

*b = number of codes with value of -1*

*x = total number of codes = 22*

## **VITA**

Matthew Bethel was born in Jackson, Tennessee. He graduated from Greenfield High School in 1989. Matthew received a Bachelor of Science in Geography from The University of Tennessee at Martin in 1994, and a Master of Science in Geoscience from Murray State University in 1999. In 1998, he began his career as an Image Analyst and progressed as a Research Project Manager for the Institute for Technology Development at Stennis Space Center in Mississippi. In 2006, he took a position with the Pontchartrain Institute for Environmental Sciences at the University of New Orleans (UNO-PIES) as a Research Associate, and began work on his doctorate in Engineering and Applied Science with a concentration in Environmental Science there, which he completed in August 2010. Dr. Bethel is currently employed as a Research Project Manager with UNO-PIES.