ERDC/EL TR-07-2

Environmental Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Ecosystem Management and Restoration Research Program

A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Tidal Fringe Wetlands Along the Mississippi and Alabama Gulf Coast

Deborah J. Shafer, Thomas H. Roberts, Mark S. Peterson, and Keil Schmid

April 2007

Approved for public release; distribution is unlimited.

Ecosystem Management and Restoration Research Program

ERDC/EL TR-07-2
April 2007

A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Tidal Fringe Wetlands Along the Mississippi and Alabama Gulf Coast

Deborah J. Shafer

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Thomas H. Roberts

Tennessee Technological University
Department of Biology
P.O. Box 5063
Cookeville, TN 38505

Mark S. Peterson

University of Southern Mississippi
Department of Coastal Sciences
703 East Beach Drive
Ocean Springs, MS 39564

Keil Schmid

Mississippi Department of Environmental Quality
P.O. Box 10385
Jackson, MS 39289-0385

Final report

Prepared for Mississippi Department of Marine Resources
1141 Bayview Avenue, Biloxi, MS 39530

ABSTRACT: The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence.

During the Development Phase of the HGM Approach, four critical components are integrated in a Regional Guidebook for assessing the functions of a regional wetland subclass. Subsequently, during the Application Phase, end users, following the protocols outlined in the Guidebook, assess the functional capacity of selected wetlands.

This Regional Guidebook (a) characterizes the tidal fringe wetlands of the Mississippi and Alabama Gulf Coast (north-central Gulf of Mexico) reference domain, (b) provides a rationale to select functions for the regional tidal fringe subclass, (c) provides a rationale to select model variables and metrics, (d) provides a rationale to develop assessment models, (e) provides data from reference wetlands and documents their use in calibrating model variables and assessment models, and (f) outlines protocols for applying the functional indices to the assessment of tidal fringe wetland functions in the north-central Gulf of Mexico.

Corps of Engineers Research Report Summary, April 2007

Assessing Wetland Functions

A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Tidal Fringe Wetlands Along the Mississippi and Alabama Gulf Coast (ERDC/EL TR-07-2)

ISSUE: Section 404 of the Clean Water Act directs the U.S. Army Corps of Engineers to administer a regulatory program for permitting the discharge of dredged or fill material in the "waters of the United States." As part of the permit review process, the impact of discharging dredged or fill material on wetland functions must be assessed. On 16 August 1996, a National Action Plan to Implement the Hydrogeomorphic Approach (NAP) for developing Regional Guidebooks to assess wetland functions was published. This report is one of a series of Regional Guidebooks that will be published in accordance with the National Action Plan.

RESEARCH OBJECTIVE: The objective of this research was to develop a Regional Guidebook for assessing the functions of tidal fringe wetlands along the Mississippi and Alabama Gulf Coast.

SUMMARY: The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The Approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the Approach have been identified, including determining minimal effects under the Food Security Act, designing mitigation projects, and managing wetlands.

AVAILABILITY OF REPORT: The report is available at the following Web sites: *http://www.wes.army.mil/el/wetlands/wlpubs.html* or *http://libweb.wes.army.mil/index.htm*. The report is also available on Interlibrary Loan Service from the U.S. Army Engineer Research and Development Center (ERDC) *http://libweb.wes.army.mil/lib/library.htm*

About the Authors: Dr. Deborah J. Shafer is a Research Marine Biologist at the U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS. Dr. Thomas H. Roberts is a Professor in the Center for the Management, Utilization and Protection of Water Resources at Tennessee Technological University, Cookeville. Dr. Mark S. Peterson is a Professor in the Department of Coastal Sciences, Fisheries Ecology, University of Southern Mississippi, Ocean Springs, MS. Keil Schmid was formerly with the Mississippi Department of Environmental Quality, Jackson, MS. Point of Contact is Glenn G. Rhett, Ecosystem Management and Restoration Research Program Manager, U.S. Army Engineer Research and Development Center, (601) 634-3717, e-mail *Glenn.G.Rhett@erdc.usace.army.mil*.

Contents

List of Figures

List of Tables

Preface

This work was performed by the U.S. Army Engineer Research and Development Center (ERDC) under a Cooperative Research and Development Agreement with the Mississippi Department of Marine Resources (MDMR). Funding was provided by a grant from the U.S. Environmental Protection Agency, Region 4, to MDMR.

This guidebook was prepared by Dr. Deborah J. Shafer, Environmental Laboratory (EL), ERDC. Dr. Thomas H. Roberts, Tennessee Technological University, Cookeville, was the author of the section in Chapter 4 relating to wildlife utilization of tidal fringe marshes. Dr. Mark S. Peterson, University of Southern Mississippi, Ocean Springs, made major contributions to the description of the Nekton Utilization Function in Chapter 4. Keil Schmid, Mississippi Department of Environmental Quality, Jackson, MS, wrote the section in Chapter 3 describing the geology of the Mississippi-Alabama Coastal Plain. This guidebook was developed in cooperation with an Assessment Team (A-Team) of regional experts familiar with tidal fringe wetlands in Mississippi and Alabama. Leah Bray, MDMR, served as the A-Team leader. Special thanks are due to Ben Bloodworth, Utah Department of Natural Resources (formerly MDMR), who provided GIS mapping and support, contributed to the content and format of this guidebook through his numerous comments and suggestions throughout the guidebook development process, and performed a careful edit of a previous version of this guidebook. In addition, the authors are grateful to the following A-Team members who contributed their time and expertise at team meetings and/or participated in field sampling of reference wetlands: Leah Bray; Darren LeBlanc and Patric Harper, U.S. Fish and Wildlife Service; Shawn Clark, Mississippi Department of Environmental Quality; Mike Moxey, U.S. Army Engineer District, Mobile; and Leslie Turney and Randy Shaneyfelt, Alabama Department of Environmental Management. The authors also appreciate the comments and suggestions provided by several reviewers, including Dr. Mark Woodrey, Mississippi State University, and Dr. David Yozzo and Howard Horne, Barry A. Vittor and Associates, Inc.

This work was performed under the general supervision of Dr. Morris Mauney, Jr., Chief, Wetlands and Coastal Ecology Branch, EL; Dr. David J. Tazik, Chief, Ecosystem Evaluation and Engineering Division, EL, and Dr. Elizabeth C. Fleming, Director, EL.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act (CWA) Section 404 Regulatory Program permit review sequence to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including determining minimal effects under the Food Security Act, designing mitigation projects, and managing wetlands.

The HGM Approach includes four integral components: (a) the HGM Classification, (b) reference wetlands, (c) assessment models and functional indices, and (d) assessment protocols. During the Development Phase of the HGM Approach, these four components are integrated in a Regional Guidebook for assessing the functions of a regional wetland subclass. Subsequently, during the Application Phase, end users, following the assessment protocols outlined in the Regional Guidebook, assess the functional capacity of selected wetlands. Each of the components of the HGM Approach and the Development and Application Phases is discussed below. More extensive treatment of these topics can be found in Brinson (1993, 1995, 1996), and Smith et al. (1995).

The advantage of the HGM approach is that a given site may be assessed for its entire suite of functions or a subset of functions, depending upon the ultimate management objective. The HGM approach requires basic information on the site that can be generated without significant expense. Knowledge about the relationships between form and function, upon which these models are based, can also be used to assist with planning habitat restoration and/or creation efforts and allows for the emphasis to be placed on the entire suite of functions or selected functions.

On 16 August 1996 a National Action Plan (NAP) to implement the Hydrogeomorphic Approach was published (National Implementation Team 1996). The NAP was developed cooperatively by the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highway Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS). Publication of the NAP was designed to outline a strategy and promote the development of Regional Guidebooks for assessing the functions of regional wetland subclasses using the

HGM Approach; to solicit the cooperation and participation of Federal, State, and local agencies, academia, and the private sector in this effort; and to update the status of Regional Guidebook development.

The sequence of tasks necessary to develop a Regional Guidebook outlined in the NAP was used to develop this Regional Guidebook (see Development Phase, Chapter 2). The National Guidebook for Application of Hydrogeomorphic Assessment to Tidal Fringe Wetlands (Shafer and Yozzo 1998) and the Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Northwest Gulf of Mexico Tidal Fringe Wetlands (Shafer et al. 2002) served as the starting point for the development of this guidebook for tidal fringe wetlands of the Mississippi and Alabama Gulf Coast region. A series of workshops, attended by fisheries biologists, soil scientists, wildlife biologists, and plant ecologists with extensive knowledge of regional tidal fringe wetlands, were held in Biloxi, MS, at the offices of the Mississippi Department of Marine Resources. Based on the results of these workshops, a regional wetland subclass was defined and characterized, a reference domain was defined, wetland functions were selected, model variables were identified, and conceptual assessment models were developed. Subsequently, field work was conducted to collect data from reference wetlands. These data were used to revise and calibrate the conceptual assessment models presented in this document.

The objectives of this Regional Guidebook are to (a) characterize the tidal fringe wetlands of the north-central Gulf of Mexico reference domain, (b) provide a rationale to select functions for the regional tidal fringe subclass, (c) provide a rationale to select model variables and metrics, (d) provide a rationale to develop assessment models, (e) provide data from reference wetlands and document their use in calibrating model variables and assessment models, and (f) outline the necessary protocols for applying the functional indices to the assessment of tidal fringe wetland functions in the north-central Gulf of Mexico.

This document is organized in the following manner. Chapter 1 outlines the background, objectives, and organization of the document. Chapter 2 provides a brief overview of the major components of the HGM Approach and the Development and Application Phases required to implement the approach. Chapter 3 characterizes the tidal fringe subclass in the north-central Gulf of Mexico in terms of geographical extent, climate, geomorphic setting, hydrology, vegetation, soils, and other factors that influence wetland function. Chapter 4 discusses each of the wetland functions, model variables, and functional indices. This discussion includes a definition of the function, a quantitative, independent measure of the function for the purposes of validation, a description of the wetland ecosystem and landscape characteristics that influence the function, a definition and description of model variables used to represent these characteristics in the assessment model, a discussion of the assessment model used to derive the functional index, and an explanation of the rationale used to calibrate the index with reference wetland data. Chapter 5 outlines the steps of the assessment protocol for conducting a functional assessment of tidal fringe wetlands in the north-central Gulf of Mexico. Appendix A lists the team members involved in the development of this HGM assessment protocol. Appendix B provides copies of the field forms needed to collect field data. Appendix C summarizes functions, assessment models, variables, and variable measures. Appendix D contains the summary data collected at reference wetlands. Appendix E provides examples of how to measure selected assessment variables. Appendix F provides supplemental information.

While it is possible to assess the functions of tidal fringe wetlands using only the information contained in Chapter 4 and Appendix D, it is suggested that potential users familiarize themselves with the information in Chapters 1 to 3 prior to conducting an assessment.

2 Overview of the Hydrogeomorphic Approach

Hydrogeomorphic Classification

Wetland ecosystems share a number of common attributes including relatively long periods of inundation or saturation, hydrophytic vegetation, and hydric soils. Despite these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic situations and exhibit a wide range of physical, chemical, and biological characteristics and processes (Cowardin et al. 1979, Mitsch and Gosselink 2000). The variability of wetlands makes it challenging to develop assessment methods that are both accurate (i.e., sensitive to significant changes in function) and practical (i.e., can be completed in the relatively short time frame available for conducting assessments). Existing "generic" methods, designed to assess multiple wetland types throughout the United States, are relatively rapid, but lack the resolution necessary to detect significant changes in function. However, one way to achieve an appropriate level of resolution within the available time frame is to reduce the level of variability exhibited by the wetlands being considered (Smith et al. 1995).

The HGM Classification was developed specifically to accomplish this task (Brinson 1993). It identifies groups of wetlands that function similarly using three criteria that fundamentally influence how wetlands function: geomorphic setting, water source, and hydrodynamics. Geomorphic setting refers to the landform and position of the wetland in the landscape. Water source refers to the primary water source in the wetland such as precipitation, overbank floodwater, or groundwater. Hydrodynamics refers to the level of energy and the direction that water moves in the wetland. Based on these three criteria, any number of "functional" wetland groups can be identified at different spatial or temporal scales. For example, at a continental scale, Brinson (1993) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Table 1 (Smith et al. 1995). In many cases, the level of variability in wetlands encompassed by a continental scale hydrogeomorphic class is still too great to develop assessment models that can be rapidly applied while being sensitive enough to detect changes in function at a level of resolution appropriate to the Section 404 review process. For example, at a continental geographic scale the depression class includes wetlands as diverse as California vernal pools, prairie potholes in North and South Dakota, playa lakes in the high plains of Texas, kettles in New England, Carolina bays in the southeast, and cypress domes in Florida.

Table 1
Hydrogeomorphic Wetland Classes at the Continental Scale

HGM Wetland Class	Definition
Depression	Depression wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depression wetlands may have any combination of inlets and outlets or lack them completely. Potential water sources are precipitation, overland flow, streams, or groundwater/ interflow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the center of the depression. The predominant hydrodynamics are vertical fluctuations that range from diurnal to seasonal. Depression wetlands may lose water through evapotranspiration, intermittent or perennial outlets, or recharge to groundwater. Prairie potholes, playa lakes, vernal pools, and cypress domes are common examples of depression wetlands.
Tidal Fringe	Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with riverine wetlands where tidal current diminishes and river flow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and riverine classes is where bidirectional flows from tides dominate over unidirectional flows controlled by floodplain slope of riverine wetlands. Because tidal fringe wetlands frequently flood and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, overland flow to tidal creek channels, and evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh. *Spartina alterniflora* salt marshes are a common example of tidal fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. In some cases, these wetlands consist of a floating mat attached to land. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bidirectional, usually controlled by water-level fluctuations resulting from wind or seiche. Lacustrine wetlands lose water by flow returning to the lake after flooding and evapotranspiration. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands.
Slope	Slope wetlands occur in association with the discharge of groundwater to the land surface or sites with saturated overland flow with no channel formation. They normally occur on sloping land ranging from slight to steep. The predominant source of water is groundwater or interflow discharging at the land surface. Precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by downslope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturated subsurface flows, surface flows, and by evapotranspiration. Slope wetlands may develop channels, but the channels serve only to convey water away from the slope wetland. Slope wetlands are distinguished from depression wetlands by the lack of a closed topographic depression and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands.
Mineral Soil Flats	Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large floodplain terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and seepage to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage due to impermeable layers (e.g., hardpans), slow lateral drainage, and low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become organic soil flats. They typically occur in relatively humid climates. Pine flatwoods with hydric soils are an example of mineral soil flat wetlands.
Organic Soil Flats	Organic soil flats, or extensive peatlands, differ from mineral soil flats in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves, but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid climates. Raised bogs share many of these characteristics but may be considered a separate class because of their convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are examples of organic soil flat wetlands.

(Continued)

Table 1 (Concluded)	
HGM Wetland Class	**Definition**
Riverine	Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank flow from the channel or subsurface hydraulic connections between the stream channel and wetlands. Additional sources may be interflow, overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. In headwaters, riverine wetlands often intergrade with slope, depressional, poorly drained flat wetlands, or uplands as the channel (bed) and bank disappear. Perennial flow is not required. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater (for losing streams), and evapotranspiration. Peat may accumulate in off-channel depressions (oxbows) that have become isolated from riverine processes and subjected to long periods of saturation from groundwater sources. Bottomland hardwoods on floodplains are an example of riverine wetlands.
Source: Smith et al. (1995).	

To reduce both inter- and intra-regional variability, the three classification criteria are applied at a smaller geographic scale to identify regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying these regional subclasses (Stewart and Kantrud 1971, Golet and Larson 1974). Regional subclasses, like the continental classes, are distinguished on the basis of geomorphic setting, water source, and hydrodynamics. In addition, certain ecosystem or landscape characteristics may also be useful for distinguishing regional subclasses in certain regions. For example, depression subclasses might be based on water source (i.e., groundwater versus surface water) or the degree of connection between the wetland and other surface waters (i.e., the flow of surface water in or out of the depression through defined channels). Tidal fringe subclasses might be based on salinity gradients (Shafer and Yozzo 1998). Slope subclasses might be based on the degree of slope, landscape position, source of water (i.e., interflow versus groundwater), or other factors. Riverine subclasses might be based on water source, position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Examples of potential regional subclasses are shown in Table 2, Smith et al. (1995), and Rheinhardt et al. (1997).

Regional Guidebooks include a thorough characterization of the regional wetland subclass in terms of its geomorphic setting, water sources, hydrodynamics, vegetation, soil, and other features that were taken into consideration during the classification process.

Table 2
Potential Regional Wetland Subclasses in Relation to Geomorphic Setting, Dominant Water Source, and Hydrodynamics

Geomorphic Setting	Dominant Water Source	Dominant Hydrodynamics	Potential Regional Wetland Subclasses	
			Eastern USA	Western USA/Alaska
Depression	Groundwater or interflow	Vertical	Prairie pothole marshes, Carolina bays	California vernal pools
Fringe (tidal)	Ocean or Estuary	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
Fringe (lacustrine)	Lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake marshes
Slope	Groundwater	Unidirectional, horizontal	Fens	Avalanche chutes
Flat (mineral soil)	Precipitation	Vertical	Wet pine flatwoods	Large playas
Flat (organic soil)	Precipitation	Vertical	Peat bogs; portions of Everglades	Peatlands over permafrost
Riverine	Overbank flow from channels	Unidirectional, horizontal	Bottomland hardwood forests	Riparian wetlands

Reference Wetlands

Reference wetlands are the wetland sites selected to represent the range of variability that occurs in a regional wetland subclass as a result of natural processes and disturbance (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as cultural alteration. The reference domain is the geographic area occupied by the reference wetlands (Smith et al. 1995). Ideally, the geographic extent of the reference domain will mirror the geographic area encompassed by the regional wetland subclass; however, this is not always possible due to time and resource constraints.

Reference wetlands serve several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of function across the suite of functions selected for a regional wetland subclass. Second, they establish the range and variability of conditions exhibited by model variables and provide the data necessary for calibrating model variables and assessment models. Finally, they provide a concrete physical representation of wetland ecosystems that can be repeatedly observed and measured.

Reference standard wetlands are the subset of reference wetlands that perform the suite of functions selected for the regional subclass at a level that is characteristic in the least-altered wetland sites in the least-altered landscapes. Table 3 outlines the terms used by the HGM Approach in the context of reference wetlands.

Table 3
Reference Wetland Terms and Definitions

Term	Definition
Reference domain	The geographic area from which reference wetlands representing the regional wetland subclass are selected (Smith et al. 1995).
Reference wetlands	A group of wetlands that encompass the known range of variability in the regional wetland subclass resulting from natural processes and disturbance and from human alteration.
Reference standard wetlands	The subset of reference wetlands that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human-altered wetland sites in the least human-altered landscapes. By definition, the functional capacity indices for all functions in reference standard wetlands are assigned a value of 1.0.
Reference standard wetland variable condition	The range of conditions exhibited by model variables in reference standard wetlands. By definition, reference standard conditions receive a variable subindex score of 1.0.
Site potential (mitigation project context)	The highest level of function possible, given local constraints of disturbance history, land use, or other factors. Site potential may be less than or equal to the levels of function in reference standard wetlands of the regional wetland subclass.
Project target (mitigation project context)	The level of function identified or negotiated for a restoration or creation project.
Project standards (mitigation context)	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

Assessment Models and Functional Indices

In the HGM Approach, an assessment model is a simple representation of a function performed by a wetland ecosystem. It defines the relationship between one or more characteristics or processes of the wetland ecosystem or surrounding landscape and the functional capacity of a wetland ecosystem. Functional capacity is simply the ability of a wetland to perform a function compared to the level of performance in reference standard wetlands.

Model variables represent the characteristics of the wetland ecosystem and surrounding landscape that influence the capacity of a wetland ecosystem to perform a function. Model variables are ecological quantities that consist of five components (Schneider 1994): (a) a name, (b) a symbol, (c) a measure of the variable and procedural statement for quantifying or qualifying the measure directly or calculating it from other measurements, (d) a set of values (i.e., numbers, categories, or numerical estimates) that are generated by applying the procedural statement, and (e) units on the appropriate measurement scale. Table 4 provides several examples.

Model variables occur in a variety of states or conditions in reference wetlands. The state or condition of the variable is denoted by the value of the measure of the variable. For example, tree basal area, the measure of the tree biomass variable, could be large or small. Similarly, recurrence interval, the measure of overbank flood frequency variable, could be frequent or infrequent. Based on their condition (i.e., value of the metric), model variables are assigned a variable subindex. When the condition of a variable is within the range of conditions exhibited by reference standard wetlands, a variable subindex of 1.0 is assigned. As the condition deviates from the reference standard condition (i.e., the range of conditions under which the variable occurs in reference standard wetlands), the variable subindex is assigned based on the defined relationship between model variable condition and functional capacity. As the condition of a variable deviates from the conditions exhibited in reference standard wetlands, it receives a progressively lower subindex reflecting its decreasing contribution to functional capacity. In some cases, the variable subindex drops to zero. For example, when no trees are present, the subindex for tree basal area is zero. In other cases, the subindex for a variable never drops to zero. For example, regardless of the condition of a site, Manning's roughness coefficient n will always be greater than zero.

Table 4
Components of Example Model Variables

Name (Symbol)	Measure / Procedural Statement	Resulting Values	Units (Scale)
Redoximorphic Features (V_{REDOX})	Status of redoximorphic features/ visual inspection of soil profile for redoximorphic features	Present Absent	Unitless (nominal scale)
Floodplain Roughness (V_{ROUGH})	Manning's roughness coefficient n. Observe wetland characteristics to determine adjustment values for roughness component to add to base value	0.01 0.1 0.21	Unitless (interval scale)
Tree Biomass (V_{TBA})	Tree basal area/measure diameter of trees in sample plots (cm), convert to area (m^2), and extrapolate to per hectare basis	5 12.8 36	m^2/ha (ratio scale)

Model variables are combined in an assessment model to produce a Functional Capacity Index (FCI) that ranges from 0.0 to 1.0. The FCI is a measure of the functional capacity of a wetland relative to reference standard wetlands in the reference domain for the particular function measured. Wetlands with an FCI of 1.0 perform the function at a level that is sustainable and characteristic of reference standard wetlands. A decrease in the FCI usually indicates that the capacity of the wetland to perform the function is less than that which is characteristic of reference standard wetlands. In some cases, however, higher levels of function may occur under conditions that are considered unsustainable or atypical of reference standard wetlands. For example, high values for V_{EDGE}, the variable that measures the ratio of marsh-water interface to total marsh area, are considered to indicate reference standard conditions and would be assigned a variable subindex of 1.0. Very high values for V_{EDGE} are characteristic of subsiding or drowning marshes, an unsustainable condition, and would therefore be assigned a subindex value less than 1.0, even though these marshes may be highly productive in terms of fisheries utilization over the short term.

Assessment Protocol

The final component of the HGM Approach is the assessment protocol. The assessment protocol is a series of tasks, along with specific instructions, that allow the end user to assess the functions of a particular wetland area using the functional indices in the Regional Guidebook. The first task is characterization, which involves describing the wetland ecosystem and the surrounding landscape, describing the proposed project and its potential impacts, and identifying the wetland areas to be assessed. The second task is collecting the field data for model variables. The final task is analysis, which involves calculation of functional indices.

Development Phase

The Development Phase of the HGM Approach was carried out by an interdisciplinary team of experts known as the Assessment Team, or A-Team. The product of the Development Phase is a Regional Guidebook for assessing the functions of a specific regional wetland subclass. In developing a Regional Guidebook, the A-Team completed the following major tasks. After organization and training, the first task of the A-Team was to classify the wetlands within the region of interest into regional wetland subclasses using the principles and criteria of the Hydrogeomorphic Classification (Brinson 1993, Smith et al. 1995). Next, focusing on the specific regional wetland subclass selected, the A-Team developed an ecological characterization or functional profile of the subclass.

The A-Team then identified the important wetland functions, conceptualized assessment models, identified model variables to represent the characteristics and processes that influence each function, and defined metrics for quantifying model variables. Next, reference wetlands were identified to represent the range of variability exhibited by the regional subclass. Field data were then collected from the reference wetlands and used to calibrate model variables and verify the conceptual assessment models. Finally, the A-Team developed the assessment protocols necessary for regulators, managers, consultants, and other end users to apply the indices to the assessment of wetland functions. The following list provides the detailed steps involved in this general sequence:

Task 1: Organize the A-Team

a. Identify A-Team members.
b. Train A-Team in the HGM Approach.

Task 2: Select and Characterize Regional Wetland Subclass

a. Identify/prioritize regional wetland subclasses.
b. Select regional wetland subclass and define reference domain.
c. Initiate literature review.
d. Develop preliminary characterization of regional wetland subclass.
e. Identify and define wetland functions.

Task 3: Select Model Variables and Metrics and Construct Conceptual Assessment Models

a. Review existing assessment models.
b. Identify model variables and metrics.
c. Define initial relationship between model variables and functional capacity.
d. Construct conceptual assessment models for deriving FCIs.

e. Complete Pre-calibrated Draft Regional Guidebook (PDRG).

Task 4: Conduct Peer Review of Pre-calibrated Draft Regional Guidebook

a. Distribute PDRG to peer reviewers.
b. Conduct interdisciplinary, interagency workshop of PDRG.
c. Revise PDRG to reflect peer review recommendations.
d. Distribute revised PDRG to peer reviewers for comment.
e. Incorporate final comments from peer reviewers on revisions into the PDRG.

Task 5: Identify and Collect Data from Reference Wetlands

a. Identify reference wetland field sites.
b. Collect data from reference wetland field sites.
c. Analyze reference wetland data.

Task 6: Calibrate and Field Test Assessment Models

a. Calibrate model variables using reference wetland data.
b. Verify and validate (optional) assessment models.
c. Field test assessment models for repeatability and accuracy.
d. Revise PDRG based on calibration, verification, validation (optional), and field testing results into a Calibrated Draft Regional Guidebook (CDRG).

Task 7: Conduct Peer Review and Field Test of Calibrated Draft Regional Guidebook

a. Distribute CDRG to peer reviewers.
b. Field test CDRG.
c. Revise CDRG to reflect peer review and field test recommendations.
d. Distribute CDRG to peer reviewers for final comment on revisions.
e. Incorporate peer reviewers' final comments on revisions.
f. Publish Operational Draft Regional Guidebook (ODRG).

Task 8: Technology Transfer

a. Train end users in the use of the ODRG.
b. Provide continuing technical assistance to end users of the ODRG.

Application Phase

The Application Phase involves two steps. The first is using the assessment protocols outlined in the Regional Guidebook to carry out the following tasks:

a. Define assessment objectives.
b. Characterize the project site.
c. Screen for red flags.
d. Define the Wetland Assessment Area (WAA).
e. Collect field data.
f. Analyze field data.

The second step involves applying the results of the assessment, the FCI, to the appropriate decision-making processes of the permit review sequence, such as alternatives analysis, minimization, assessment of unavoidable impacts, determination of compensatory mitigation, design and monitoring of mitigation, comparison of wetland management alternatives or results, determination of restoration potential, or identification of acquisition or mitigation sites.

3 Characterization of Tidal Fringe Wetlands in the North-Central Gulf of Mexico Regional Subclass

Introduction

This Regional Guidebook was developed to assess the functions of tidal fringe wetlands in the north-central Gulf of Mexico along the Mississippi and Alabama coasts. For the purposes of this approach, the term tidal fringe wetlands applies only to vegetated habitats occupying the intertidal zone of marine, estuarine, or riverine systems. Specifically, these wetlands occur along the fringe of drowned river valleys, barrier islands, lagoons, and other coastal waterways, receive their water primarily from marine or estuarine sources, and are affected by bidirectional tidal action. Included in this group are wetlands commonly known as intertidal marshes, salt marshes, forested riverine swamps, and mangrove swamps, corresponding to the emergent, scrub-shrub, and forested wetland class designations used by Cowardin et al. (1979). The dominant hydrodynamic is bidirectional water flow generated by tidal action. Additional water sources may be riverine flow, groundwater discharge, precipitation, and overland flow. Tidal fringe wetlands lose water by tidal exchange, saturated overland flow to tidal creek channels, and evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are protected from shoreline wave erosion by intervening areas of low marsh. *Spartina alterniflora* salt marshes are a common example of tidal fringe wetlands.

By definition (Cowardin et al. 1979), the entire intertidal zone includes the vertical range between the extreme annual high- and low-water levels of spring tides. Spring tides are tides of greater-than-average range that occur around the times of new and full moon. However, the north-central Gulf of Mexico has small (< 1 m) to microtidal (< 0.5 m) meteorologically dominated (wind) mixed tides. Therefore, wind tides as well as lunar tides must be considered in relation to the classification of north-central Gulf Coast tidal-fringe wetlands. Along coastal rivers, tidal wetlands extend horizontally to the upstream limits of tidal influence and may or may not be exposed to fluctuating salinity (e.g., tidal swamps and freshwater marshes).

Early in the development of these models, regional tidal fringe wetland subclasses were proposed based on differences in elevation and salinity (Shafer and Yozzo 1998). Low marshes occupy the vertical range from the extreme low water levels of spring tides up to the mean daily high water zone and are frequently flooded because of their low elevation and proximity to open water. High marshes occupy the vertical range between the mean daily high water zone up to the mean annual high water zone of spring high tides and are infrequently flooded because of their higher elevation and distal location from open bay/estuary waters. In the field, differences between these proposed subclasses were often difficult to identify and delineate. Usually, except where abrupt elevation changes occur, distinct boundaries do not exist and transitional zones may show only subtle changes in plant assemblages as one moves higher in elevation and away from sources of salt water. Also, topographic irregularity (mounds, ridges, swales, depressions, etc.) and altered hydrologic characteristics (levees, roads, ditches, drains, water-control structures) often result in uncharacteristically diverse or somewhat atypical plant assemblages. Similarly, since many tidal marsh plant species are tolerant of salinities ranging from saline to fresh, separation of wetland subclasses along a salinity gradient based on vegetation characteristics is not always reliable. Since many of the model variables focus on geomorphological or landscape characteristics, separation of wetland subclasses based on elevation and salinity within this reference domain did not seem justified.

According to Smith et al. (1995), the reference domain is the geographic area occupied by the reference wetland sites. For the purposes of this guidebook, the reference domain is defined as those tidal wetlands occurring within the boundaries of Hancock, Harrison, and Jackson Counties in Mississippi and Mobile and Baldwin Counties in Alabama.

Description of the Regional Subclass

Geology and geomorphology

The geological units that form the surface of coastal counties in Mississippi and Alabama range in age from the late Pliocene Epoch (3.4 million years ago) to the present. The oldest unit that is exposed in the area that roughly includes the HGM Tidal Fringe reference domain is the Citronelle Formation. It consists mostly of sand and silt, with some gravel. This unit was deposited in coalescing river floodplains (Otvos 1985) on the broad coastal plain from southern Louisiana to Florida.

Following the Pliocene, coastal deposits during the Pleistocene Epoch (1.6 million to 10,000 years) were related to warm interglacial and cooler glacial periods. The earliest Pleistocene alluvial deposits formed before the warm Sangamon interglacial period. They form a narrow, discontinuous terrace Gulfward of the Citronelle Formation intermediate in elevation between the higher Citronelle and the younger, lower elevation Prairie terrace near and at the present shoreline elevation. During the Sangamon interglaciation, sea level rose as high as 20 to 25 feet above the present. Pleistocene surface formations of this period include the fluvial Prairie deposits that formed level floodplains and the ridge-forming Gulfport coastal barrier formations. They are preceded and underlain by the muddy-sandy, fossil-rich Biloxi Formation, deposited in nearshore Gulf, bay, and lagoonal settings. The Prairie Formation continued to be deposited in the coastal plain after the Sangamon sea level subsided. This unit, in most cases, underlies the present marshes in Mississippi and Alabama. The Gulfport Formation formed a wide belt of beach ridges representing a Sangamon age Gulf shoreline. It includes fine to medium sand, which is often humate-stained. Humate is a dark brown to black organic-rich amorphous matter that formed after deposition and impregnated the lower Gulfport sand intervals. The peak of the ice age between fifteen to sixty thousand years ago brought dry conditions to the northern Gulf coast, as shown by large remnant dune hills in Alabama, Florida, and southeast Louisiana.

The recent Holocene Epoch has seen a continued rise in sea level from its very low late-glacial stand about twenty thousand years ago. This rise gradually drowned coastal river valleys and prevented coarse stream sediments from directly reaching the coast. Holocene sediments filled the coastal estuaries and built up locally wide marshlands, rich in organic matter. These deposits consist mostly of sandy fine-grained silts and clays with significant organic material (marshes). Coastal deposits (beaches and dunes) are formed primarily by erosion of sandy parent material (Prairie and Gulfport Formations) and by longshore drift on the barrier islands. The barrier islands in Mississippi and Alabama are recent features (less than five thousand years old) that are nurtured by sand carried alongshore by wave transport from northwest Florida. The islands are generally shifting westward by erosion on their east end and accretion on their west end. The formation of the Mississippi St. Bernard delta south of Mississippi about four thousand years ago surrounded and trapped the western barrier islands in Mississippi and Louisiana in wide expanses of tidal marshes that are heavily eroding today.

Subsidence of the land surface increases westward and southward, toward the thick, abandoned Mississippi delta lobes in Louisiana. The western part of the Mississippi coast is experiencing higher subsidence rates than in Alabama. Fine-grained, highly saturated deposits (marshes) also have a stronger tendency toward subsidence, which results in the encroachment of coastal waters and erosion of the marshlands. The Alabama coastal marshes experience considerably less compactional subsidence. Apart from shoreline erosion along their bayward fringes, and the ongoing very slow encroachment from global sea level rise, they are nearly stable. Subsidence is offset in areas where new sediment enters the system and is evident in areas with thick Holocene deposits. A general reduction in sediment to coastal depositional systems, however, has resulted in a trend toward drowned coastal areas and shoreline retreat.

Climate

The climate within the reference domain is relatively homogeneous. The average annual temperature is 68 °F. In winter, the average temperature is 50 ºF, and summer averages are in the low 80 ºF range. The large water mass of the Gulf of Mexico has a moderating effect on temperatures. Near the coast, the number of days over 90 ºF is only 55 annually; this increases to more than 100 just a few miles inland. The mean annual rainfall averages around 152 to 165 cm. Most precipitation falls from November through June, and thunderstorms occur on average 70 to 80 days per year. Fall months are usually the driest.

From May through September, southerly winds created by the Bermuda High create a warm, humid, semitropical climate. Afternoon thunderstorms are frequent, and may be accompanied by strong winds. Tropical storms and hurricanes also occur during this period, and can produce significant damage from high winds, storm surge, heavy rainfall, and erosion of coastal areas. These storms can deliver more than 20 inches of rainfall in just a few days, resulting in widespread coastal flooding.

During the cold season, periods of cold temperatures alternate with bursts of warm, tropical air. Cold fronts can produce large, sudden drops in temperatures, although these cold temperatures seldom last for more than a few days (adapted from Southern Regional Climate Center (2005); *http://www.srcc.lsu.edu/southernClimate/atlas/msdescription*).

Hydrology

Tides in this region are typically diurnal, i.e., one high and one low tide daily, with an average range of 0.37 to 0.52 m. The mean low water level in coastal Mississippi is 0.25 m (Wieland 1994). However, meteorological conditions, such as tropical storms and seasonally varying wind patterns, can cause tides to deviate significantly from predicted astronomical levels (Stout 1984). Beginning in May, tidal heights rise above mean annual levels and remain elevated until December. This coincidence of higher sea level and southerly winds during the summer months can cause even high marsh areas to remain flooded for extended periods of time (Provost 1973).

There is considerable annual and seasonal variation in the rainfall pattern. Of the average annual precipitation, 55 percent usually falls between April and September (Smith et al. 1981, Smith 1975, Cole and Dent 1964, Hickman and Owens 1980). Combined precipitation and stream discharge generally exceed evapotranspiration rates (Christmas 1973).

Freshwater runoff and riverine sediment inputs along the Mississippi-Alabama Gulf coast are significant. Along the Mississippi coast, two major rivers, four smaller rivers, and numerous small bayous with a combined drainage area of more than 100,000 square miles empty into Mississippi Sound (Wieland 1994, Isphording et al. 2000). In Alabama, the Mobile River system accounts for 95 percent of the freshwater input to the Mobile Bay estuary (Schroeder et al. 1990). The Mobile River Basin is the sixth largest in the nation, with an area of approximately 44,000 square miles (McPherson et al. 2003).

Mixing of fresh water with saline Gulf waters produces gradients in salinity ranging from low-salinity conditions near the mouths of rivers and bayous to higher salinity areas near the coastal barrier islands. Salinity zones for Gulf marine and estuarine habitats were defined by Wieland (1994) according to the average salinity at the bottom of the water column (Table 5). In tidal wetlands, these salinity gradients are reflected by the plant communities typical of each zone, as described in the following section.

Table 5
Marine and Estuarine Salinity Zones

Salinity Zone	Average Salinity (ppt)
Freshwater	0
Oligohaline	7.6
Mesohaline	12.4
Polyhaline (low)	22.1
Polyhaline (high)	29.9

Source: Wieland (1994).

Vegetation Communities

This guidebook was developed for application in saline, brackish, and intermediate marshes of the north-central Gulf of Mexico. Tidal fresh wetlands are not included in the reference domain, since they differ in many of the characteristics used to assess these wetlands. Tidal fresh marshes represent only a very small proportion (1 percent) of tidal wetlands in Mississippi (Eleuterius 1973). The following tidal marsh vegetation types are described based on information provided in Eleuterius (1972), Stout (1984), and Wieland (1994).

Saline marsh. Saline marshes are typically located adjacent to open water bodies such as bays and estuaries. Their salinity levels are the highest, usually falling in the mesohaline or polyhaline range. One of the most obvious characteristics of saline marshes is the distinct patterns of plant zonation (Figure 1). Two plant species are dominant, *Spartina alterniflora,* which occurs in nearly pure stands, and *Juncus roemerianus*, which borders the *S. alterniflora* zone. In the lower elevation zones, *J. roemerianus* and *S. alterniflora* grow in their most robust forms, as evidenced by their greater height and density. The upper elevations of the saline marsh show a reduction in the *S. alterniflora* habitat and a decrease in density of *J. roemerianus*. In these areas *Limonium carolinianum* and *Symphyotrichum tenuifolium* are often found scattered within the *J. roemerianus* and *S. alterniflora* stands. Brackish water plant species, such as *Spartina patens*, *S. cynosuroides, Schoenoplectus (syn. Scirpus*) *americanus* and *S. robustus,* frequently occur intermixed with *J. roemerianus*. The submerged aquatic *Ruppia maritima* sometimes occurs in shallow open water areas adjacent to the marsh shoreline.

Saline marshes are the only ones that may include areas known as salt flats. These areas are not generally inundated and are located upland of the *Juncus* zone. During long periods of exposure, salt concentrations in the upper soil horizon can become very high (> 30 ppt) (Wieland 1994). Salt flats lack the tall, dense vegetation of other tidal marsh zones and are dominated by only those few plant species able to tolerate the hypersaline soil conditions. These include *Salicornia virginica*, *Salicornia bigelovii, Batis maritima, Distichlis spicata*, and *Suaeda linearis*. Soils with extremely high salinity may be barren and devoid of vascular plants. In Mississippi, salt flats are most common on Deer Island, and in the Bangs Lake area of Jackson County (Eleuterius 1972).

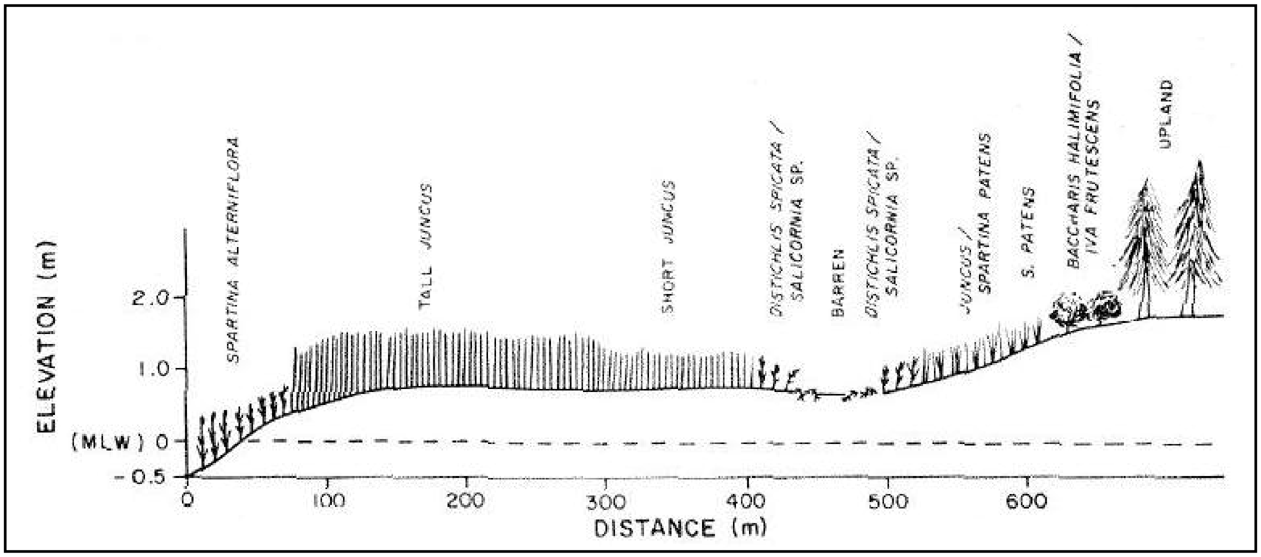

Figure 1. Typical saline marsh profile on a low energy shoreline (from Stout 1984).

Brackish marsh. Brackish marshes generally occur in association with freshwater input from coastal rivers and bayous. Salinity levels are usually within the mesohaline or oligohaline range. There are several major differences between saline marsh and brackish marsh plant community composition and structure. First, there is a gradual decrease and eventual loss of the low-elevation *Spartina alterniflora* zone. *Spartina cynosuroides* is increasingly abundant and may entirely replace *S. alterniflora* in the lowest elevations. This decline in *S. alterniflora* is accompanied by an increase in density of *J. roemerianus* and total species richness. *Limonium carolinianum, Schoenoplectus americanus,* and *S. robustus* also occur in brackish marshes, but are reduced in abundance compared to saline marshes. Freshwater species also occurring in brackish marshes include *Iris virginica*, *Sium suave, Hymenocallis occidentalis, Lythrum lineare, Ludwigia sphaerocarpa*, *Osmunda regalis* var. *spectabilis, Crinum americanum, Sagittaria lancifolia*, and *Bidens frondosa*. *Spartina patens* typically forms a zone between the *J. roemericanus* zone and the upland shrub-scrub border. A typical brackish marsh profile is illustrated in Figure 2.

Intermediate marsh. Intermediate tidal marshes are generally adjacent to riverine systems; salinity levels are oligohaline or near fresh water. The intermediate marsh plant community has higher species diversity than saline or brackish marshes and is composed of both brackish and freshwater species. *S. alterniflora* is absent in intermediate marshes, as are the well-defined plant zonation patterns evident in saline and brackish marshes. Dominant or common plants include *J. roemerianus*, *Phragmites australis*, *Cladium mariscus* ssp. *jamaicense*, *Schoenoplectus tabernaemontani*, *Iris virginica*, and *Panicum virgatum*. The freshwater species listed in the preceding paragraph as occurring in brackish marshes are more common and are distributed throughout intermediate marshes. Intermediate marshes differ from saline and brackish marshes, however, in the absence of *Spartina patens*, *S. cynosuroides*, *Schoenoplectus americanus* and *S. robustus*. On levees and higher areas of the marsh, *P. australis* can occur in almost pure stands.

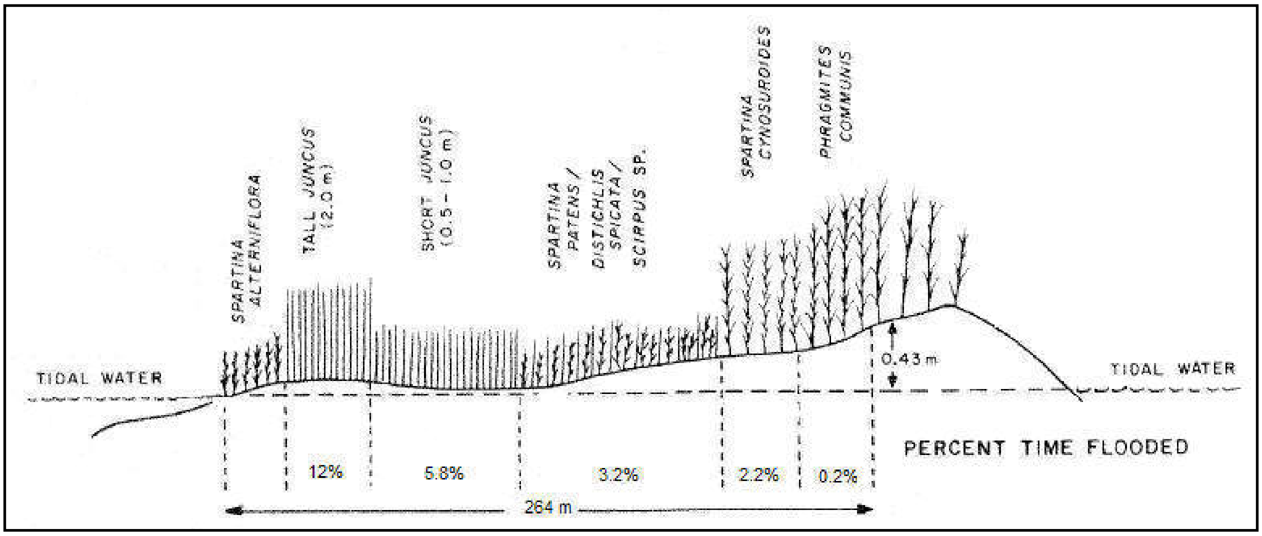

Figure 2. Typical brackish marsh profile (from Stout 1984).

Soils

Tidal fringe wetlands in the Gulf Coast region have soils that formed on flood basin, coastal marsh, and beach sediments deposited near bays and the Gulf of Mexico. In Hancock County, Mississippi, the reference wetlands were located in two soil associations: Handsboro-Bohickert, which are nearly level, very poorly drained, mucky and clayey soils, on tidal marshes that are flooded daily by tidal waters; and Atmore-Beauregard-Escambia, which are nearly level to gently sloping, moderately well drained to poorly drained silty and loamy soils on broad wet upland flats and low ridges (Smith et al. 1981). In Harrison County, Mississippi, the reference wetlands were located in three soil associations: Eustis-Latonia-Lakeland, which are somewhat excessively drained and excessively drained soils that are sandy throughout and well-drained soils that have a loamy subsoil; Handsboro, which are very poorly drained organic soils; and Handsboro-St. Lucie, which are very poorly drained organic soils and excessively drained sandy soils (Smith 1975). Soil associations in Jackson County, Mississippi, include Rains-Lynchburg-Plummer-Goldsboro, which are level or nearly level, poorly drained loamy soils; and Tidal, which are level, wet land (Cole and Dent 1964). In Mobile County, Alabama, the reference wetlands are located in Axis-Lafitte and Bayou-Escambia-Harleston soil associations, which are nearly level, very poorly to moderately well drained soils, loamy mineral soils and organic soils, formed in loamy marine and fluvial sediments (Hickman and Owens 1980). Baldwin County, Alabama, soil series include the Lakewood, St. Lucie, and Leon associations. The Lakewood and St. Lucie series are well-drained sandy soils that occur in uplands. Leon mucks are poorly drained soils that occur within reference wetlands. In many areas, the St. Lucie and Leon series are so interspersed that it is difficult to map them separately (McBride and Burgess 1964).

Anthropogenic alterations

For many years, tidal wetlands were viewed as having little value. Consequently, many thousands of acres of tidal wetlands were "converted" to more "productive" uses (Stout 1984). Stout and de la Cruz (1981) estimated that prior to 1980 more than 4,040 hectares (9,978 acres) of tidal wetlands in Mississippi Sound (11.5 percent) had been dredged to create open water or filled to create uplands. In Mobile Bay, more than 22 percent of the total marsh area (1,596 hectares) had been lost by 1979 due to dredging activities alone (Stout 1984). These are likely underestimates since data were incomplete and only large projects were included. In addition, small channels connecting private property to natural waterways have been dredged in all areas of the Gulf Coast. The dredged material was usually placed in marsh areas. While most individual efforts are small in nature, their cumulative impact is considerable.

In Alabama, construction of the Mobile Bay Causeway is thought to have had a profound impact on tidal wetlands by altering circulation and sedimentation patterns in Mobile Bay. However, assessing these impacts has proved difficult because of a lack of data on the ecological conditions prior to the causeway's construction in the 1920s. Although bridges span the Tensaw, Apalachee, and Blakeley Rivers, sections of elevated roadway crossing the marshlands effectively function as dams, restricting fresh water flow from the rivers into the bay as well as the movement of saline water from the bay up into the delta. Areas with restricted circulation have likely become shallower, fresher, and more isolated, while flow rates and water depths are probably increased in the channels that remain open (Fearn et al. 2005).

Tourism is a multimillion dollar industry along the Gulf Coast, promoting the natural resources, history, and man-made beaches of the area. A relatively new component of the tourist industry, gambling casinos have the potential to greatly impact the coastline because of jurisdictional and legal requirements for the location of the gaming facilities. In some cases, this has resulted in the filling or dredging of tidal wetlands to provide suitable locations for casino facilities.

Major water-using industries in the Gulf Coast region include food, pulp and paper, chemicals, natural gas, and other petroleum products. Because of their proximity to industrialized areas, tidal fringe marshes have the potential to become contaminated by pulp-mill effluents, oil spills, and surface runoff (Stout 1984). In large doses, these contaminants can cause widespread mortality of many marsh species; in smaller amounts, chronic sublethal effects have been documented. There is a wealth of literature on the effects of chemical contaminants on marsh biota, and this literature will not be reviewed here. In general, the wetland assessment models developed as part of the HGM Approach are not well-suited to the assessment of potential impacts of chemical contaminants. If this situation is present, an alternative approach, such as an ecological risk assessment, should be used.

4 Wetland Variables, Functions, and Assessment Models

Variables

The following variables are used to assess the functions performed by north-central Gulf of Mexico tidal fringe marshes in Mississippi and Alabama:

a. Total Percent Vegetative Cover of Native Emergent Wetland Species
b. Mean Height of Tallest Herbaceous Vegetation Strata
c. Percentage Cover by Woody Plant Species
d. Percentage Cover by Invasive or Exotic Species
e. Wetland Plant Indicator Status
f. Aquatic Edge
g. Hydrologic Regime
h. Nekton Habitat Diversity
i. Wildlife Habitat Diversity
j. Mean Marsh Width
k. Wave Energy Exposure
l. Adjacent Land Use
m. Wetland Patch Size

Total Percent Vegetative Cover of Native Emergent Wetland Species (V_{COVER})

This variable is used in the functions Wave Energy Attenuation, Biogeochemical Cycling, Provide Habitat for Tidal Marsh-Dependent Wildlife, and Maintain Characteristic Plant Community Structure and Composition.

This variable is defined as the mean total percentage cover of native non-woody marsh species. For the purposes of variable measurement, marsh species are herbaceous plants that have a wetland indicator status of obligate wetland (OBL) or facultative wetland (FACW). Low values may indicate a number of different undesirable conditions including (a) a subsiding or deteriorating marsh, (b) presence of toxins or other pathological condition, (c) altered hydrology or fill, or (d) incorrect elevation range in created marshes.

This variable should be measured during the growing season using the following procedure:

(1) Select one or more representative areas within the site for sampling. Beginning at the edge of a shoreline or tidal creek, establish one or more transects perpendicular to the shoreline or along the hydrologic gradient (e.g., increasing elevation). If there are multiple vegetation community types within the WAA, the transect should intersect each vegetation community to ensure a representative sample.

(2) Using a standard 1-m^2 frame, estimate total percentage cover of native nonwoody marsh (OBL or FACW) species using the Braun-Blanquet cover class categories (Table 6) (Mueller-Dombois and Ellenberg 1974). Both live and standing dead emergent plant material should be included. Tidal creeks and other areas where water depths are too deep to support the growth of emergent vegetation should be excluded. The number of transects and plots will depend on the size and heterogeneity of the site; a minimum of 10 plots per transect are recommended for all except the smallest sites.

Table 6
Braun-Blanquet Cover Class Categories

% Cover	Cover Class	Cover Class Midpoint
> 75	5	87.5
50-75	4	62.5
25-50	3	37.5
5-25	2	15.0
<5	1	2.5

(3) Calculate the total percentage cover of each plot by summing the cover class midpoints (Table 6) for each species, then divide by the number of plots sampled to obtain the mean percentage cover of the study area.

(4) Using Table 7, determine the variable subindex that corresponds to the mean percentage cover estimate.

Table 7
Relationship Between Mean Percentage Emergent Marsh Vegetation Cover (V_{COVER}) and Functional Capacity

% Cover	Variable Subindex
> 70	1.0
61-70	0.8
51- 60	0.6
41-50	0.4
31- 40	0.2
11-30	0.1
<11	0.0

Mean Height of Tallest Herbaceous Vegetation Strata (V_{HEIGHT})

This variable is used only in the function Provide Habitat for Tidal Marsh-Dependent Wildlife.

Although wetlands within the subclass differ in plant species composition and other characteristics, there are several common features that influence habitat quality for the target marsh-dependent wildlife species and presumably many other vertebrates. Marshes should be dominated by robust vegetation that is tall enough not to be inundated by normal tides. For wildlife species that breed in tidal marshes, vegetation height can be a major factor influencing nesting success.

This variable is defined as the mean height of the dominant plants within the tallest zone of the emergent marsh plant community. In saline and brackish tidal marshes within the reference domain, dominant species typically include *J. roemerianus*, *Spartina alterniflora*, *S. cynosuroides*, or *Schoenoplectus* spp. Based on data from the literature and from reference standard sites, a subindex of 1.0 is assigned when mean height of dominant emergent vegetation is at least 100 cm (values from Kale (1983) and Post and Greenlaw (1994) describing high-quality habitat for the *Ammodramus maritimus* (Seaside Sparrow). A subindex value of 0.0 is assigned to sites in which mean values are 60 cm or less (approximately the minimum value Oney (1954) reported for *Rallus elegans* (Clapper Rail) nesting sites). At sites in which the mean height is between 60 cm and the minimum reference standard height, the relationship between canopy height and the capacity to support a characteristic wildlife population is assumed to be linear.

It is important that this variable be measured during the growing season since use of senescent plants to estimate height will typically result in lower subindex values for this variable. This variable is measured using the following procedure:

(1) This variable measure employs a stratified sampling design based on plant community zonation. First, identify the tallest species assemblages present within the WAA. In brackish and saline marshes within the subclass, this zone will typically be dominated by *J. roemerianus*, *S. alterniflora*, *S. cynosuroides*, or *Schoenoplectus* spp. If *Phragmites* is present, it should be included in the height measurements, but only in proportion to its distribution within the WAA.

(2) Within 1-m^2 plots, measure the height in centimeters (rounded to the nearest 5 cm) at which the bulk of the biomass occurs (i.e., the mean or most frequently occurring height). Record this value.

In plots composed of mixed species assemblages of tall, robust plants, record only one value for height, corresponding to the most frequently occurring height of the entire species assemblage. Do not include the height of low-growing species that occur within the same plot, such as *Distichlis spicata*.

Although standing dead stems may be used to estimate the maximum height obtained during peak biomass periods, measurement of this variable during winter and early spring is not recommended.

(3) Repeat this procedure for each plot and average the results from all plots. At least 10 plots are recommended for most sites, but this number can change depending on the degree of variability within the WAA.

(4) Using Figure 3, determine the variable subindex that corresponds to the mean vegetation height.

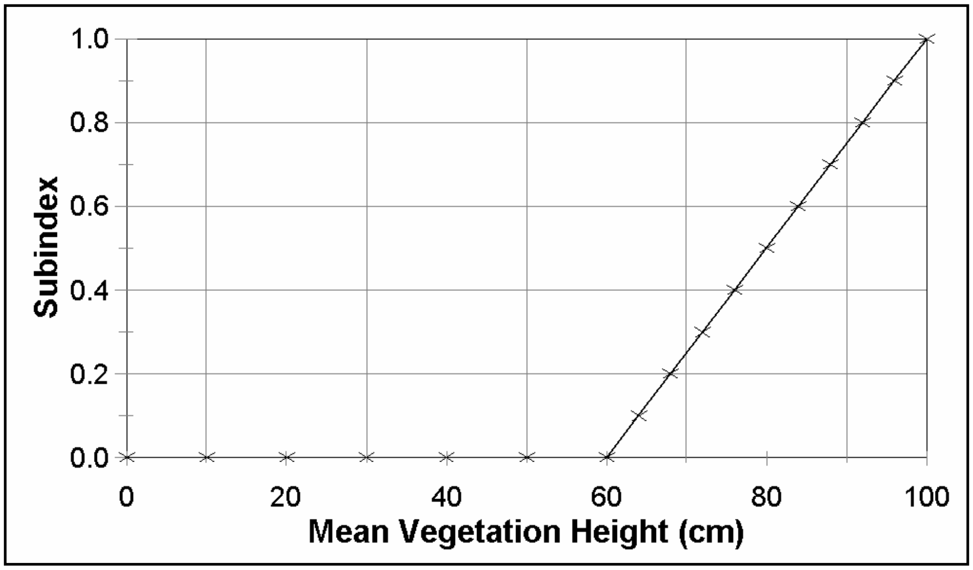

Figure 3. Relationship between mean vegetation height and functional capacity

Percentage Cover by Woody Plant Species (V_{WOODY})

This variable is used only in the function Maintain Characteristic Plant Community Structure and Composition.

Since tidal marshes are typically dominated by emergent herbaceous vegetation (i.e., grasses, sedges, and rushes), a high proportion of cover by woody plant species is considered an indicator of site alteration and degradation. Although shrub-scrub and other woody species commonly occur as a narrow fringe near the upland perimeter of tidal marshes, increasing dominance of these species can occur as a result of hydrological alterations such as filling or other activities that reduce the frequency and extent of tidal flooding. These alterations may also change hydrological characteristics of the site from one dominated by tidal flows to one dominated by freshwater runoff and precipitation, facilitating the invasion of species more typical of freshwater wetlands (i.e., *Acer rubrum* (red maple), *Taxodium distichum* (bald cypress). This variable serves to downgrade the value of the functional index as the proportionate contribution of woody plant species increases. Table 8 lists examples of woody plant species that may occur within the regional subclass.

Table 8
Partial List of Woody Plant Species That May Occur in Tidal Marshes Within the Regional Subclass[1].

Scientific Name	Common name
Acer rubrum	Red maple
Baccharis halimifolia	Eastern baccharis
Ilex decidua	Possum haw
Ilex vomitoria	Yaupon
Iva frutescens	Jesuit's bark
Morella cerifera	Wax myrtle
Nyssa spp.	Black gum, water tupelo
Taxodium distichum	Bald cypress
Triadica sebifera	Chinese tallow

[1] Additional species may be added to this list.

Measure this variable using the following procedure:

(1) Using the Braun-Blanquet cover class categories (Table 6), visually estimate the percentage of the entire site that is covered by woody plants (shrub-scrub and tree species) (Table 8). Since these species are usually not well represented in small 1-m^2 plots, it is best to visually estimate the percentage cover of the entire site using aerial photography.

(2) Assign a variable subindex based on Table 9.

Table 9
Relationship Between Percentage Cover by Woody Plant Species (V_{WOODY}) and Functional Capacity

% Woody Cover	Variable Subindex
0-5	1.0
6-10	0.8
11-20	0.6
21-30	0.4
>30	0.2

Percentage Cover by Invasive or Exotic Species (V_{EXOTIC})

This variable is used only in the function Maintain Characteristic Plant Community Structure and Composition.

The presence of non-native or invasive species is considered an indicator of site degradation. This variable serves to downgrade the value of the functional index as the proportionate contribution of non-native or invasive species increases. Table 10 lists those introduced or potentially invasive species that may occur within the regional subclass.

Table 10
Non-native or Invasive Species That May Occur Within the Regional Subclass[1]

Scientific Name	Common name	Designation
Alternanthera philoxeroides	Alligatorweed	Alabama Class C noxious weed
Imperata cylindrica	Cogongrass	Alabama Class A noxious weed; Mississippi noxious weed
Ipomoea purpurea	Tall morning glory	Introduced
Panicum repens	Torpedograss	Alabama Class C noxious weed
Phragmites australis	Common reed	Alabama Class C noxious weed
Triadica sebifera	Chinese tallow	Mississippi noxious weed
Typha latifolia	Broadleaf cattail	Invasive

Source: Wieland (1994), USDA PLANTS Database (2005).
[1] Additional species may be added to this list.

The two species encountered most frequently were *Alternanthera philoxeroides* and *Phragmites australis*. Both species are listed in Alabama as Class C noxious weeds (USDA PLANTS database (2005)). *A. philoxeroides* (alligatorweed) is an obligate wetland plant that was introduced from South America around the turn of the century (Spencer and Coulson 1976). It can grow either terrestrially or as a floating aquatic, and is capable of forming thick mats that clog waterways and out-compete native plants. Although *P. australis* is native to the Gulf Coast region, there is evidence of a cryptic invasion of North America over the last century by an aggressive genotype that is capable of displacing native populations (Saltonstall 2002). At present, there is no reliable indicator to conclusively determine whether Gulf Coast populations of *P. australis* are native or introduced (Saltonstall 2002). However, the presence of this species is generally considered an indicator of site disturbance or stress due to hydrologic alteration, increased soil salinity, or excess nutrients (Marks et al. 1994, Saltonstall 2002).

For all reference wetlands sampled in the reference domain, the percentage cover by introduced or invasive species ranged from 0 to 86 percent. The Blakeley River site was dominated by *P. australis* with a mean percent cover of 86 percent. Sites that exhibited a high percentage cover by *A. philoxeroides* included Alabama Department of Natural Resources (49 percent) and Daphne Bayfront Park (35 percent). See Appendix D for additional data from other reference sites.

Measure this variable using the following procedure:

(1) Using the Braun-Blanquet cover class categories, visually estimate the percentage of the entire site that is covered by non-native or invasive plant species (Table 10). For some species, such as *A. philoxeroides*, this may be accomplished using the same 1-m^2 plots used in the assessment

of native emergent species. However, for some larger species, such as *P. australis*, that are often not well-represented in small 1-m^2 plots, it is best to visually estimate the percentage cover of the entire site using aerial photography. If there is uncertainty regarding the most appropriate technique for measurement of this variable, use the method that results in the highest value for percentage cover of invasive or exotic plants.

(2) Assign a variable subindex based on Table 11.

Table 11
Relationship Between Percentage Cover by Non-native or Invasive Plant Species (V_{EXOTIC}) and Functional Capacity

% Exotic Cover	Variable Subindex
0-5	1.0
6-10	0.8
11-20	0.6
21-30	0.4
31-50	0.2
> 50	0.1

Wetland Plant Indicator Status (V_{WIS})

This variable is used only in the function Maintain Characteristic Plant Community Structure and Composition.

In tidal marshes, the most common types of site alteration involve changes in site elevation (excavation and filling), and altered hydrology (restricted tidal flow caused by the presence of culverts, weirs, dams, etc.). Filling increases the site elevation, which reduces the depth and duration of tidal flooding as well as flooding frequency. Alterations that restrict normal tidal hydrology can also result in reduced hydroperiod. Both of these can affect the plant community composition in tidal marshes by increasing the dominance of those species that are able to tolerate drier conditions. Therefore, the plant community may gradually shift from one dominated primarily by wetland species (OBL and FACW), to one with a larger component of facultative (FAC) and facultative upland (FACU) plant species.

Measure this variable using the following procedure:

(1) Using the Braun-Blanquet cover class categories, visually estimate the percentage of each plot that is occupied by plants with a wetland indicator status of FAC or FACU. Table 12 provides a few examples: for more detailed information please see the USDA PLANTS online database. For some species, this may be accomplished using the same 1-m^2 plots used in the assessment of other plant community parameters.

However, for some larger species, such as *Baccharis halimifolia*, that may not be well-represented in small 1-m^2 plots, it is best to visually estimate the percentage cover of the entire site using aerial photography, if necessary. If there is uncertainty regarding the most appropriate technique for measurement of this variable, use the method that results in the highest value for percentage cover of FAC or FACU plant species.

(2) Sum the cover class midpoints of FAC/FACU species for all plots.

(3) Sum the cover class midpoints of emergent herbaceous wetland plants (OBL or FACW) for all plots.

(4) Divide the sum cover class midpoints of FAC/FACU species by the sum of the cover class midpoints of emergent herbaceous wetland plants and multiply by one hundred.

(5) Assign a variable subindex based on Table 13.

Table 12
Partial List of FAC and FACU Plants Found in North-Central Gulf of Mexico Tidal Fringe Marshes[1]

Scientific Name	Common Name	Wetland Indicator Status
Ampelopsis arborea	Peppervine	FAC+
Ampelopsis cordata	Heart-leaf peppervine	FAC+
Ambrosia artemisiifolia	Annual ragweed	FACU
Baccharis halimifolia	Eastern baccharis	FAC
Ilex vomitoria	Yaupon	FAC
Morella cerifera	Small wax myrtle	FAC+
Panicum virgatum	Switchgrass	FAC+
Panicum amarum	Bitter panic grass	FAC
Rubus trivialis	Southern dewberry	FAC

Source: Wieland (1994), USDA PLANTS database.
[1] Additional species may be added to this list.

Table 13
Relationship Between Percentage Cover of Nonwetland Plants (Wetland Indicator Status = FAC or FACU) (V_{WIS}) and Functional Capacity

% Cover Nonwetland species	Variable Subindex
0-1	1.00
2-4	0.75
5-10	0.50
>10	0.25

Aquatic Edge (V_{EDGE})

This variable is used in the functions Nekton Utilization Potential and Provide Habitat for Tidal Marsh-Dependent Wildlife.

It should be noted that in previous HGM guidebooks for the assessment of tidal fringe wetlands, the variable V_{EDGE} was defined to include both tidally connected and tidally unconnected edge. Since features with tidally unconnected edge were not common within this reference domain, this variable has been redefined to include only tidally connected edge. Tidally connected edge includes the vegetated shorelines of embayments, estuaries, and tidal rivers, channels, and creeks. Examples of tidally unconnected edge not included are the edges of isolated ponds and depressions within the marsh interior and stretches of unvegetated shorelines (i.e., sandy beaches).

With the availability of digital imagery produced from aerial photography, it is possible to obtain measurements of tidally connected edge using Geographic Information System (GIS) software. Measurements of edge may be subject to large variations depending on the scale of measurement used, however. Therefore, it is crucial that the scale of measurement be the same for all sites if sites are to be compared. The measurement scale should also be chosen so that relatively small water bodies and patches of marsh are visible. At a scale of 1 cm = 48 m (1:4800 or 1 in. = 400 ft), water bodies and patches of marsh as small as 1 m in diameter may be detected.

A GIS-based analysis of digital imagery is recommended as the method of choice for estimating the relative amount of tidally connected edge among several sites. However, most regulatory personnel who are involved in routine wetland assessments may not have access to GIS software or time available for detailed GIS measurements of each site. Therefore, a simple pattern recognition technique is proposed as an alternative, based on the degree of landscape complexity of a site. This approach has been used in other rapid assessment techniques, such as the Wetland Evaluation Technique (WET) (Adamus et al. 1991), and the Wetland Value Assessment (WVA) (Coastal Wetlands Planning, Protection, and Restoration Act Environmental Work Group 1998).

Measure or estimate V_{EDGE} using one of the following techniques:

(1) *Qualitative Measure*: Using aerial photography at a scale of 1 cm = 48 m (1 in. = 400 ft) , assign a subindex value for the site using the qualitative descriptions provided in Table 14. See the pictorial key in Appendix E for specific examples.

(2) *Quantitative Measure*: Using GIS and aerial photography at the same scale, measure all visible marsh/water interfaces, including edges of tidal creeks (both banks), creeks, and open bay shoreline. Determine the total marsh area in hectares, and express the total amount of edge in meters as a function of total marsh area. Assign a subindex value using the data in Table 14.

Table 14 **Estimating V_{EDGE} Based on the Amount of Marsh/Water Interface Present**			
Site Description	**Qualitative Estimate**	**Quantitative Measure (m/ha)**	**Subindex**
1) Well-developed tidal drainage network present (Figures E-1 and E-2) or 2) Very narrow fringe marsh that lacks tidal creeks. One lengthwise shoreline that represents at least 40 percent of the total perimeter is exposed to tidal waters. (e.g., Daphne Bayfront Park) or 3) Other geomorphic configuration with a large amount of shoreline relative to total area (i.e., small island or narrow peninsula) (Figures E-3 and E-4)	High	$\geq$ 225	1.0
Simple tidal drainage network (may consist of one or more small channels) that are well-distributed across the total WAA area (Figures E-5 and E-6)	Moderate-High	175-224	0.7
Tidal creeks may be lacking, or if present, drain only a small proportion of the total WAA area (Figure E-7, E-8, and E-9)	Moderate-Low	100-175	0.5
Shoreline is generally linear or smooth curvilinear without embayments or convolutions. Tidal creeks typically absent. The area of marsh is large relative to shoreline length (Figure E-10)	Low	<100	0.3
No tidally connected vegetated marsh-water interface present in WAA (Figure E-11)	Absent	0	0.0

Hydrologic Regime (V_{HYDRO})

This variable is used in the functions Biogeochemical Cycling and Nekton Utilization Potential.

Since it is not practical to install and monitor water level recorders at each wetland assessment area, evaluation of this variable is based on the degree of hydrologic alteration present. This variable is assigned a default value of 1.0 if no hydrologic alteration exists and the site is open to free exchange of tidal waters.

Estimate a value for the hydrologic regime using the following method:

(1) Visually inspect the site and determine if there is any evidence of hydrological alteration, berms, culverts, fill, or other alterations that affect normal tidal hydrology. The value of the variable subindex V_{HYDRO} is assumed to be 1.0 unless any of these altered conditions are present.

(2) Match site condition with variable subindex value from Table 15.

Table 15
Relationship Between Hydrologic Regime (V_{HYDRO}) and Functional Capacity

Site Description	Variable Subindex
Site is open to free exchange of tidal waters. Lower edges of vegetated marsh surface are flooded on a regular basis as evidenced by wrack lines, watermarks, etc. No obvious hydrologic alteration, fill, or restrictions present.	1.0
Minor hydrologic alteration or restriction present (i.e., presence of low-elevation berm, which is frequently overtopped by high-tide events or has multiple breaches or large culverts; presence of some fill that raises a small portion (<20 percent of marsh area) of marsh surface above normal tidal flooding zone).	0.75
Moderate hydrologic alteration present (i.e., presence of high-elevation berm, which is infrequently overtopped by high-tide events or has a single opening, breach, or small culvert; greater extent of fill (>20 percent) that raises portions of marsh surface elevation above normal tidal flooding zone).	0.50
Severe hydrologic alteration; site receives tidal floodwaters only during extreme tide events (i.e., surface elevation of marsh is above normal tidal flooding zone; blocked culvert, etc.).	0.25
Site is isolated from tidal exchange. The principal source of flooding is water sources other than tidal action (i.e., precipitation or groundwater). *Note: If this condition exists, use of another wetland assessment model should be strongly considered unless the site was a tidal wetland prior to hydrologic modification.*	0.00

Nekton Habitat Diversity (V_{NHD})

This variable is used only in the function Nekton Utilization Potential.

Habitat diversity is a measure of the heterogeneity of a site, based on comparison of the number of habitats actually present at a site relative to the number of possible habitats known to occur in the appropriate regional subclass. Different marsh vegetation types (i.e., low-, mid-, high-marsh), water bodies (e.g., tidal creeks and channels), physical structures (e.g., oyster reefs), and the presence of submerged aquatic vegetation in adjacent subtidal areas all contribute to the habitat complexity of a site, and may affect utilization by resident and nonresident nekton species. Since it is highly unlikely that all possible habitat types can be detected from aerial photos of the site, a field visit will be required to obtain the data necessary to calculate this variable.

A total of eight possible different habitat types were identified in reference wetlands within the reference domain (Table 16). Based on the conditions observed at reference standard sites, a variable subindex of 1.0 is assigned if at least five of these habitat types are present onsite or within 30 m of the site perimeter. Assign a variable subindex based on Figure 4.

Table 16 Possible Nekton Habitat Types
Low marsh (i.e., daily tidal flooding)
High marsh (i.e., irregular tidal flooding)
Intertidal creeks/channels
Subtidal creeks/channels
Ponds or depressions (temporary or permanent)
Shallow (< 1 m) sand or mudflats
Submerged aquatic vegetation
Oyster reef

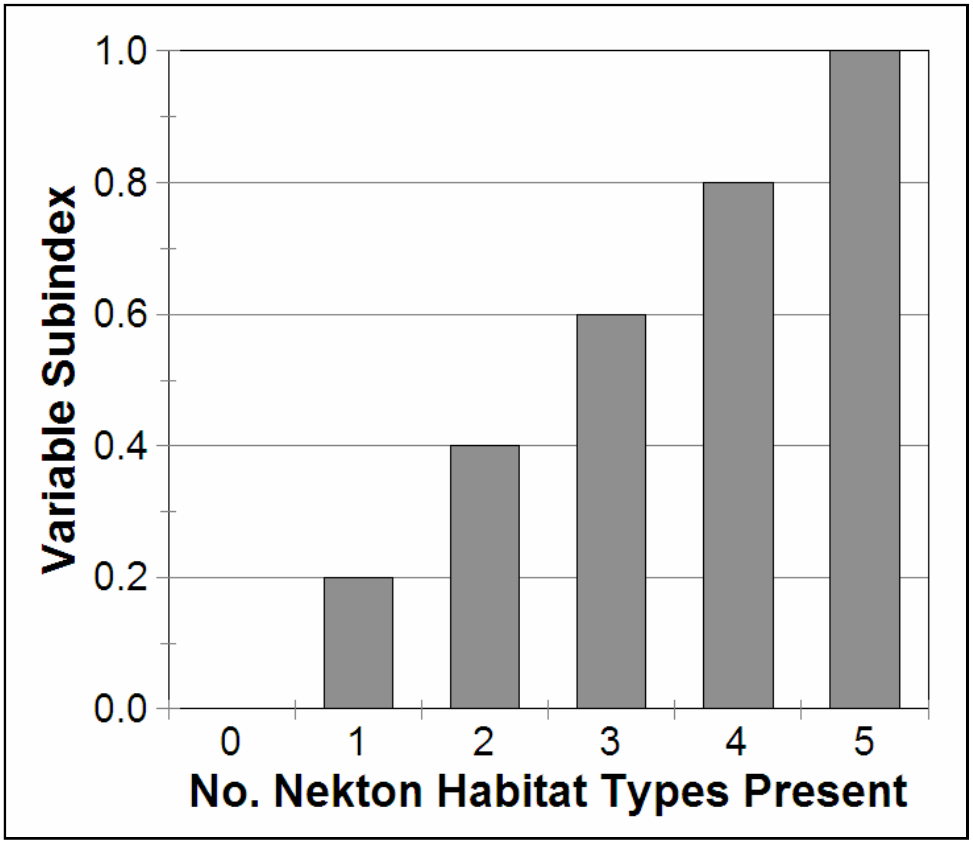

Figure 4. Relationship between nekton habitat complexity and functional capacity

Wildlife Habitat Diversity (V_{WHD})

This variable is used only in the function Provide Habitat for Tidal Marsh-Dependent Wildlife.

Numerous references emphasize the importance of community complexity, and it is logical to assume that areas in which all the typical plant associations or zones are present provide higher quality habitat than areas in which one or more are lacking. Although most high-quality marshes are dominated by the more robust lower zones, the presence of the high marsh (i.e., zones dominated by *S. patens* and *S. spartinae* in saline marshes) contributes to improved quality habitat. These areas are used as foraging habitat and serve as refuges during periods of higher-than-average tides. Naturally vegetated upland areas adjacent to the marsh also can provide this function.

This variable is a measure of the occurrence of habitat types known to support selected marsh-dependent wildlife species within the WAA. Separate variables have been defined for V_{NHD} (nekton habitat diversity) and V_{WHD} (wildlife habitat diversity) to reflect differential usage of available habitats by these faunal groups. Habitat diversity is important because wildlife use and obtain different resources from different community types. Especially important in marshes within the reference domain is the presence of both the irregularly flooded lower zone and seldom-flooded higher zones. The lower zones typically are dominated by taller vegetation and thus provide cover for marsh-dependent wildlife for the majority of the year (Eddleman and Conway 1995, Post and Greenlaw 1994). The higher zones may not provide cover routinely, but can be critical during periods of high tides.

This variable should help to identify sites that have been degraded by human activity or are not providing the greatest level of this function possible for the hydrogeomorphic setting present. As an example, coastal marshes that have been subject to hydrologic alteration or fill may be composed almost entirely of high marsh habitat, with little low marsh habitat available. Created coastal marshes often lack tidal access, aquatic edge, tidal channels, and ponds.

Measure V_{WHD} using the following procedure:

(1) Identify the total number of habitat types listed in Table 17 that are present within the WAA or adjacent to the WAA perimeter.

(2) Assign a variable subindex based on Table 18.

Table 17 **Wildlife Habitat Types**
Tall, robust herbaceous vegetation that is at least irregularly flooded (i.e.,*S. alterniflora, S. cynosuroides, J. roemerianus, Typha* spp., *Schoenoplectus* spp.) **Required**.
Short herbaceous vegetation that is infrequently flooded (i.e., *S. patens, S. spartinae, Distichlis spicata, Borrichia frutescens, Batis maritima*)
Intertidal creek banks and mudflats that are exposed at low tide
Naturally vegetated upland (forested, shrub-scrub, or dense herbaceous) buffer with a minimum width of 30 m adjacent to the WAA perimeter.

Table 18 Relationship Between Number of Wildlife Habitat Diversity (V_{WHD}) and Functional Capacity	
Wildlife Habitat Types	**Variable Subindex**
1) WAA lacks tall, robust, herbaceous vegetation as described in Table 17 or 2) Tall, robust vegetation community occurs only in a narrow (<10 m) fringe that represents a small proportion of the total plant community within the WAA	0.0
WAA contains large patches of tall, robust, herbaceous vegetation, plus any one of the other habitat types listed above	0.35
WAA contains large patches of tall, robust, herbaceous vegetation, plus any two of the other habitat types listed above	0.70
At least 50 percent of the WAA is dominated by tall, robust, herbaceous vegetation; and all three of the other habitat types identified in Table 17 are also present	1.0

Mean Marsh Width (V_{WIDTH})

This variable is used only in the Wave Energy Attenuation function.

This variable describes the distance that water must travel across intervening tidal fringe wetland (distance from the shoreline). Large expansive marshes are more effective than narrow fringing marshes at dissipating the effects of wave energy because wave energy diminishes as the crest moves landward across the marsh surface.

Measure average marsh width using the following procedure:

(1) Using a recent aerial photo or direct field survey, establish a baseline within the WAA that runs roughly parallel to the shoreline and/or perpendicular to the topographic gradient.

(2) Within the WAA boundaries, draw a series of regularly spaced transects perpendicular to this baseline, running from the edge of the shoreline to the nearest upland (Figure 5). Measure the lengths of each transect, sum the lengths, and divide by the total number of transects to calculate the average width of the marsh in meters. The number of transects is determined by the length of the baseline (Table 19). Transects should be placed to capture the full range of variability in marsh width.

(3) Assign a variable subindex based on Table 20.

In Mississippi and Alabama tidal marshes, reference marsh widths ranged from less than 35 m to more than 17,000 m (Appendix D, Table D3). Sites with mean widths >500 m were treated as outliers and were excluded from further analysis. Based on the range of values at reference standard sites, a variable subindex of 1.0 is assigned to average marsh widths greater than or equal to 100 m (Table 20). The lower limit of the curve was established based on the recommendations of Knutson et al. (1990).

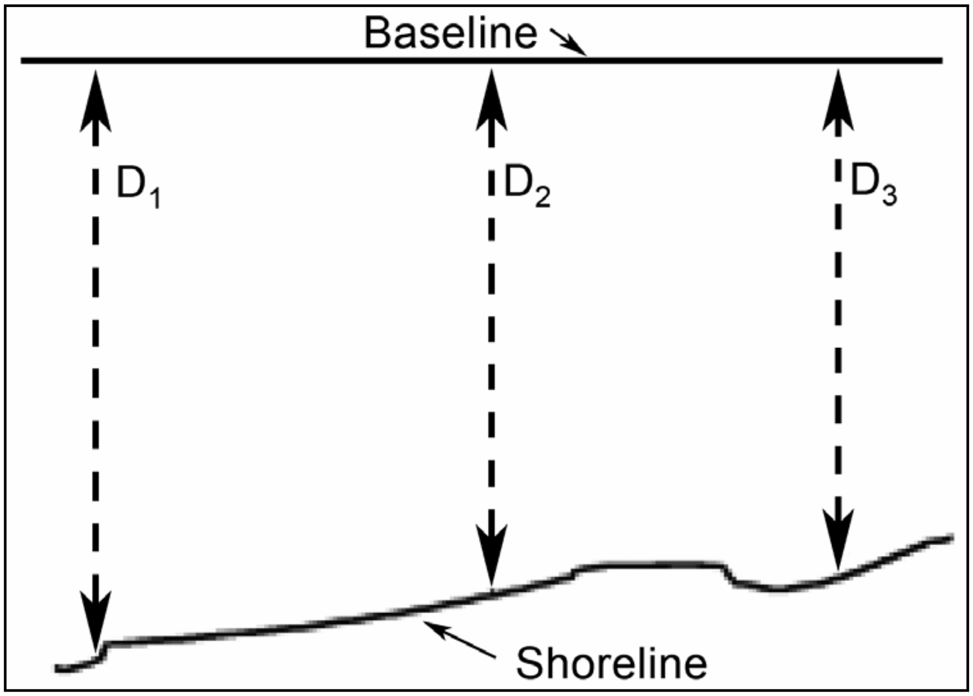

Figure 5. Using transects to measure mean marsh width

Table 19 **Number of Transects for Estimating Mean Marsh Width**	
Baseline Length, m	**Number of Transects**
< 300	3
300-1,500	5
1,500-3,000	7
>3,000	9

Table 20 **Relationship Between Mean Marsh Width (*V_{WIDTH}*) and Functional Capacity**	
Mean Marsh Width, m	**Variable Subindex**
$\geq$ 100	1.0
50-99	0.8
30-49	0.6
11-29	0.4
$\leq$ 10	0.2

Wave Energy Exposure (V_{EXPOSE})

This variable is used only in the Wave Energy Attenuation Function.

Relative exposure indices (REI) calculated by Keddy (1982) include estimates of wind speed and duration as well as fetch distances, and can provide a biologically meaningful and quantitative method for exploring relationships between wave energy regime and sediment type, vegetation community composition, epibenthic faunal communities, and seagrass bed structure (Keddy 1982, Pihl 1986, Fonseca and Bell 1998). These indices were modified for use in the Regional Guidebook for Northwest Gulf of Mexico tidal fringe wetlands (Shafer et al. 2002). However, measurement of this variable was computationally intensive. In this Regional Guidebook, a simple qualitative approach for classifying the landscape setting of each site is used. In this approach, users will classify tidal fringe wetlands as high, moderate, or low exposure based on the geomorphic setting, fetch distance, and the potential for erosion by wind- and vessel-generated wave energy. This classification is based on the geomorphic setting of the contiguous tidal fringe wetland within which the WAA is located. Sites with high exposure are assigned a subindex of 1.0 since reference standard sites were typically located on the open coast. Because of their geomorphic setting, these sites will have the greatest opportunity to perform this function. Sites that have no exposed shorelines along the edges of bays, tidal creeks, or rivers lack the opportunity to perform this function.

Estimate wave energy exposure using the following procedure:

(1) Using a recent aerial photo or direct field survey, identify the contiguous tidal fringe wetland occupied by the WAA. Qualitatively assess the degree of wave exposure of all shorelines bordering bodies of tidally connected open water by matching site conditions with the descriptions provided in Table 21. If the wetland is bordered by shorelines in more than one geomorphic setting, assign a subindex based on the highest level of exposure present.

(2) Using the values in Table 21, assign a variable subindex based on the geomorphic setting and site condition.

Table 21 **Relationship Between Wave Energy Exposure (V_{EXPOSE}) and Functional Capacity**		
Site Description	**Exposure**	**Variable Subindex**
Geomorphic Setting: Low-Energy Interior Marsh These wetlands have one or more shorelines located along the edges of protected coves or embayments (concave shoreline) or along the edge of a small tidal creek not used by commercial boat traffic.	Low	0.3
Geomorphic Setting: Moderate-Energy Interior Marsh These wetlands have one or more shorelines located along the edges of large tidal creeks or rivers that are used by recreational and/or commercial boat traffic.	Moderate	0.6
Geomorphic Setting: Open Bay or Estuary These wetlands have one or more shorelines located directly along the edges of an estuary or bay (e.g., Mississippi Sound, Mobile Bay). Shoreline is generally linear, exposed to relatively high wind and wave energy, with long fetch distances, or adjacent to navigation channel that is frequently used by recreational or commercial boat traffic.	High	1.0
Geomorphic Setting: Zero-Energy Interior Marsh These wetlands have no shorelines exposed to wind or wave energy present (uncommon).	None	0.0

Adjacent Land Use ($V_{LANDUSE}$)

This variable is used only in the Biogeochemical Cycling function.

This variable estimates the potential for impairment of biogeochemical cycling functions by inputs of nutrients, metals, petroleum products, and other pollutants via stormwater runoff from adjacent land uses. Calculation of pollutant loading rates into the wetland is beyond the scope of a rapid assessment method such as this. Therefore, a simplified approach based on the proportion of the wetland perimeter occupied by various land use types is proposed. The land use types are adapted from van der Valk (2002).

Measure this variable using the following procedure:

(1) Determine the percentage of the total WAA perimeter that is bounded by each of the land use types listed in Table 22. Percentages may be rounded to the nearest 5 percent.

(2) Assign a subindex value for $V_{LANDUSE}$ based on the descriptions in Table 23.

Table 22 Description of Land Use Types	
Land Use Category	**Description**
Undeveloped naturally vegetated areas or open water	a) Open water: Shoreline is at least 100 m from navigation channel, if present. b) Terrestrial: > 75% of total area is naturally vegetated forested or grassy uplands or wetlands.
Mostly agricultural	More than 50% of the total area is occupied by cropland.
Mostly developed	a) Open water: Harbors, ports, and marinas b) Terrestrial: More than 40% of the total area is developed (i.e., residential, commercial, or industrial areas; also includes point sources such as golf courses, wastewater treatment plant outfalls, feedlots, etc.)
Mixed use	a) Open water: areas where the shoreline is within 100 m of a navigation channel. b) Terrestrial: Does not fit any of the above categories, may include low-density rural residential, unpaved roads, etc.

Table 23 Relationship Between Adjacent Land Use ($V_{LANDUSE}$) and Functional Capacity	
Proportion of Wetland Perimeter	**Variable Subindex**
>95% of WAA perimeter is bounded by undeveloped naturally vegetated areas or open water	1.0
70-95% of WAA perimeter is bounded by undeveloped natural areas	0.8
< 70% of WAA perimeter is bounded by undeveloped naturally vegetated areas or open water, but <50% is bounded by agricultural or mostly developed areas	0.6
50-75% of WAA perimeter is bounded by agricultural or mostly developed areas	0.4
>75% of WAA perimeter is bounded by agricultural or mostly developed areas	0.2
Note: See Table 22 for specific definitions of land use types.	

Wetland Patch Size (V_{SIZE})

This variable is used only in the function Provide Habitat for Tidal Marsh-Dependent Wildlife.

Size of the patch within which the WAA occurs has to be considered relative to its ability to support wildlife. Many species will not use small patches of habitat, even if the conditions within them are favorable. For the target species in the subclass, minimum area recommendations vary somewhat. For example, Lewis and Garrison (1983) concluded that 2 ha is the minimum amount of habitat required for Clapper Rail survival and reproduction, whereas Gutzwiller and Anderson (1987) chose a value of 0.04 ha of contiguous habitat for the *Cistothorus palustris* (Marsh Wren). This latter value included open water as well as emergent vegetation, and was described as the size necessary to support a breeding pair, not a population. Estimates of Seaside Sparrow home ranges vary (Post et al. 1983, Post and Greenlaw 1994), but are intermediate between these values. A mean area of 0.16 ha was the smallest home range reported for any of the southern populations studied (Post et al. 1983). In this model, a value of

0.04 ha was chosen as the minimum area necessary to be evaluated, and sites smaller than this receive an FCI of 0.0. Although it is smaller than the values thought to be necessary for the Clapper Rail and Seaside Sparrow, those larger values are mean sizes and in the case of the Clapper Rail are based on the ability to support a breeding population. All three of the marsh-dependent species are known to occur in very small marshes, and in some instances may have very small home ranges (for example, some Seaside Sparrows have home ranges as small as 0.02 ha (Post et al. 1983)).

This variable is measured using the following procedure:

(1) Using aerial photography, GIS tools, or other means, delineate the boundaries of the contiguous tidal fringe wetland in which the WAA is located. For the purpose of this measurement, shorelines of open bays and rivers should be considered as boundaries, but areas containing tidal creeks should be included within the contiguous wetland boundaries.

(2) Using GIS or other means, calculate the area (in hectares) within these boundaries. In some situations, the WAA may encompass the entire wetland patch and the WAA size and wetland patch size will be equal.

(3) Assign a variable subindex value for V_{SIZE} according to Table 24.

Table 24
Relationship Between Wetland Patch Size (V_{SIZE}) and Functional Capacity

Wetland Patch Size, ha	Variable Subindex
< 0.04	0.1
0.04-0.2	0.25
0.21-0.5	0.50
0.51 - 2	0.75
> 2	1.0

Functions

The following functions performed by north-central Gulf of Mexico tidal fringe marshes were selected for assessment:

a. Wave Energy Attenuation
b. Biogeochemical Cycling
c. Nekton Habitat Utilization
d. Provide Habitat for Marsh-Dependent Wildlife
e. Characteristic Plant Community Structure and Composition

Each of these functions is discussed in the following sequence:

- **Definition:** defines the function and identifies an independent quantitative measure that can be used to validate the functional index.

- **Rationale for selecting the function**: provides the rationale for why a function was selected and discusses onsite and offsite effects that may occur as a result of diminished or atypical functional capacity.

- **Characteristics and processes that influence the function**: describes the characteristics and processes of the wetland and the surrounding landscape that influence the function and lay the groundwork for the description of model variables.

- **FCI**: describes the assessment model from which the FCI is derived and discusses how model variables interact to influence functional capacity.

Function 1: Wave Energy Attenuation

Definition

This function assesses the ability of a wetland to attenuate wind- and vessel-generated wave energy. It is influenced by several factors, including landscape position, marsh width, and vegetation cover. A quantitative unit of measure of this function would be change in mean wave height per meter of marsh surface.

Rationale for selecting the function

Vegetated intertidal wetlands provide a measure of protection against the destructive effects of wave energy associated with storm surges, wind-generated waves, and vessel wakes. The ability of marsh vegetation to stabilize sediments and reduce shoreline erosion has long been recognized by coastal engineers (U.S. Army Corps of Engineers 1954), and some of the first planted salt marshes were established for this purpose (Webb 1982). Significant anthropogenic changes such as construction of navigation channels through wetlands (i.e., the Gulf Intracoastal Waterway), subsidence resulting from groundwater extraction and oil and gas extraction, and alteration of natural sedimentation patterns due to flood control structures have accelerated erosion of wetlands in some areas. Erosion rates along some areas of Mississippi Sound, such as Point aux Chenes, Point Clear, and St. Joseph Point, may average as much as 2 to 3 m/year (Otvos 1976).

Characteristics and processes that influence the function

The wave climate at any given site is influenced by fetch, shoreline geometry, wind speed and duration, sediment grain size, water depth, and proximity to boat traffic (Knutson et al. 1981, Knutson and Inskeep 1982, Knutson and Woodhouse 1983). A number of methods can be used for evaluating wave climate, but many of these are beyond the scope of a rapid assessment method such as this one. Knutson et al. (1981) devised a simple, rapid method that included measures of average and longest fetch distances, sediment grain size, and shoreline geometry characteristics. The REIs calculated by Keddy (1982) include estimates of wind speed and duration as well as fetch distances, and have been shown to be highly correlated with sediment grain size parameters. The REIs provide a biologically meaningful and quantitative method for exploring relationships between wave energy regime and sediment type, vegetation community composition, epibenthic faunal communities, and seagrass bed structure (Keddy 1982, Pihl 1986, Fonseca and Bell 1998).

The potential for shoreline erosion due to vessel traffic will depend on the magnitude of the waves produced, traffic frequency, and the distance between the shoreline and the passing ships (Knutson and Woodhouse 1983). The height of waves produced by a ship is dependent primarily on the ship's velocity; other factors such as hull design, draft, and water depth will also have a lesser effect. Limited data suggest that wave heights are reduced by 25 to 50 percent at a distance of 150 m (Sorenson 1973).

Large expansive marshes are more effective at dissipating the effects of wave energy than narrow fringing marshes because wave energy diminishes as the crest moves landward across the marsh surface. Marsh width generally depends on regional geomorphologic characteristics, tidal range, and slope of the shoreline. The loss of wave energy is directly related to marsh width (Knutson et al. 1990); however, field experiments on wave dissipation in *S. alterniflora* marshes have demonstrated that this relationship is nonlinear (Knutson et al. 1982). Based on a survey of marshes planted for shoreline erosion control, a minimum marsh width of at least 10 m was recommended by Knutson et al. (1990).

The ability of a tidal wetland to attenuate wave energy is a function of the frictional resistance characteristics of the vegetation, surface obstructions or microtopography, and marsh width (Knutson et al. 1990). Emergent stems function as a flexible baffle to dampen wave energy and detain water. Stems may also trap organic debris ranging in size from leaves and twigs to logs. Trapped debris may induce additional drag and decrease water velocity. Miller (1988) used Manning's roughness coefficient to characterize frictional resistance attributed to intertidal marsh vegetation. A Manning's n of 0.06 was assigned for short *S. alterniflora* in a South Carolina salt marsh; *J. roemerianus* was assigned a Manning's n of 0.125, and is, therefore, considered more effective in dissipating tidal surges. *S. alterniflora* may reduce wave heights by as much as 71 to 94 percent and wave energy by 92 to 100 percent, while the roots of marsh vegetation serve to bind the marsh substrate (Wayne 1976, Knutson et al. 1990).

Although previous guidebooks developed protocols for estimating Manning's n values for tidal fringe wetlands (Shafer et al. 2002), in practice, the characteristics of the vegetation community contribute the greatest effect to roughness of the marsh surface in Gulf Coast tidal fringe wetlands. Therefore, a simple measure of percentage cover by emergent marsh plant species is used as a surrogate measure of the frictional resistance of the site to wave energy. Belowground plant roots and rhizomes also play an important role in sediment stabilization, particularly during the winter months when the aboveground portions may be significantly reduced. Collection and processing of belowground samples require more time and effort than are typically available for a rapid assessment technique such as this one. Therefore, this component is not included as a model variable at this time, but could be considered if time and resources were available.

In the model, the capacity of a tidal fringe wetland to attenuate wave energy is based on the landscape position of the wetland, mean marsh width, and percentage vegetative cover. The variable V_{EXPOSE} represents the opportunity for a wetland to perform this function based on its geomorphic setting. The variables marsh width and percentage vegetative cover represent site characteristics that affect the function, and are combined in an additive equation. The average of these two variables is used with the landscape variable V_{EXPOSE} in a multiplicative equation, indicating that low values for either will serve to downgrade the level of function.

Functional capacity index

The following variables are used in the assessment model for the function Wave Energy Attenuation:

a. Mean Marsh Width
b. Wave Exposure
c. Mean Percentage Cover Emergent Marsh Vegetation

The assessment model for calculating the FCI is as follows:

$$FCI = \left[\frac{\left(3 \times V_{WIDTH} + V_{COVER}\right)}{4} \times V_{EXPOSE} \right]^{1/2}$$

Function 2: Biogeochemical Cycling

Definition

This function describes the ability of a tidal wetland to receive, transform, and export various elements and compounds through natural biogeochemical processes. A quantitative measure of this function is mass of elements or compounds, both dissolved and particulate, transformed per unit area per unit time (g/m^2/year).

Rationale for selecting the function

This function includes those onsite characteristics that were included in the Nutrient and Organic Carbon Exchange Potential functions of the Northwest Gulf of Mexico Tidal Fringe Regional HGM (Shafer et al. 2002). Since many characteristics governing exchange and retention of nutrients and organic carbon are the same as for other dissolved and particulate elements and compounds, other biogeochemical functions are assumed to be covered by the function as well. This guidebook differs from Shafer et al. (2002) in that a landscape measure for surrounding land use is added to address the potential for offsite characteristics such as nutrient loading and pollution to alter characteristic biogeochemical processes.

Tidal nutrient fluxes are important in maintaining the high levels of primary productivity characteristic of tidal wetlands. In turn, the large stores of plant material produced supply organic carbon in a wide variety of forms for consumption or accumulation within the system or export to the adjoining estuary or littoral fringe. These systems may either import or export nutrients and organic carbon, depending on specific geomorphologic characteristics, time of year, marsh age, and other factors. Characterizing the magnitude and direction of nutrient and organic carbon fluxes in tidal wetlands is important in determining the wetland's ability to mediate water quality and to maintain characteristic plant communities. The latter is particularly relevant to newly created or developing tidal wetlands, where nutrient limitation often dictates project success or failure.

Characteristics and processes that influence the function

Elements and compounds can enter tidal wetlands by tidal exchange, precipitation, upland runoff, and groundwater flow. Once in the wetland, they may be deposited on the bottom, adsorbed to particles, or taken up and fixed in the tissues of rapidly growing vascular plants. These substances may be incorporated or otherwise transformed by microbial assemblages associated with the complex of surfaces provided by the sediment, live plants, litter, and detritus.

This model considers primarily exchanges and transformation of elements and compounds mediated by surface water flows from both tidal and upland sources. The potential for groundwater input is not specifically addressed, since nutrient exchange in marshes characterized by tidal ranges of less than 1 m occurs primarily within marsh surface waters (Childers et al. 1993). Because the embayments of the north-central Gulf of Mexico region are microtidal (< 0.5 m) to low tidal (< 1 m) and larger tidal ranges are associated only with infrequent meteorological events, it is assumed that subsurface water exchanges can be ignored for regional applications.

Odum (1974) proposed that nutrient inputs via tidal waters were important in maintaining the characteristic high productivity of *S. alterniflora* in creekside salt marshes. This occurs as a result of direct infiltration of nutrient-laden surface waters, horizontal recharge driven by rise and fall of the tide, and in some cases, vertical recharge from below the root zone. Salt marsh vegetation is primarily nitrogen limited, with ammonium nitrogen being the form most readily available in interstitial waters for uptake by plant roots. Phosphorus is abundant in saline waters and marsh soils, and is generally not considered a limiting nutrient in salt or brackish marsh systems. Numerous studies have attributed variation in *S. alterniflora* growth form to gradients in chemical and physical characteristics of tidal marshes, including nutrient availability (Valiela and Teal 1974, Broome et al. 1975; DeLaune and Pezeshki 1988). This is particularly true for developing or created salt marshes. Other workers suggest that, in mature marshes, edaphic factors affecting nutrient uptake are the primary determinants of *Spartina* growth form. Variables known to stress plants (high soil salinity and sulfide concentrations, waterlogging, low dissolved oxygen) reduce the uptake efficiency of nitrogen at the root-pore water interface, especially when multiple stressors are present.

Previous efforts to characterize nutrient exchanges in tidal marshes have yielded varying results, and seasonal differences in nutrient exchange are often pronounced. The relative contribution of dissolved versus particulate matter is still largely unknown because of the difficulty in estimating leaching rates from decomposing macrophytes and other sources (phytoplankton, benthic algae). Wolaver et al. (1983) observed strong seasonal trends in tidal exchanges of nitrogen and phosphorus in a Virginia salt marsh, with considerable export of dissolved organic nitrogen during fall and a net import of phosphorus during most of the year. Aurand and Daiber (1973) observed a net import of inorganic nitrogen for a Delaware salt marsh over a single year, and Stevenson et al. (1977) reported a yearly net export of nitrogen and phosphorus from a Chesapeake Bay tidal marsh. Hackney and De la Cruz (1979) determined that a single tidal creek near Bay St. Louis, Mississippi, was responsible for a net import of particulate organic matter (38.32 kg/year). The authors suggested that individual creeks may actually serve to dampen long-term oscillations in detrital availability to nearshore waters rather than providing a constant source of detrital material.

Biogeochemical processes within the wetland are also affected by offsite inputs from the surrounding drainage area. Eutrophication caused by anthropogenic nutrient enrichment of coastal ecoystems has been a major concern for resource managers for the last few decades. The effects of nutrient enrichment include stimulation of primary production by algae and phytoplankton and depletion of oxygen, which can lead to hypoxia (Deegan 2002). Nutrient enrichment can also cause shifts in plant species distribution and zonation in mixed species tidal wetlands, resulting in increased dominance of *S. alterniflora* at the expense of other tidal marsh species (Pennings et al. 2002). Recent research has shown that anthropogenic eutrophication may cause shifts in benthic invertebrate and fish community food webs that are manifested long before actual loss of the habitat occurs (Deegan 2002). Furthermore, the cumulative effects of nutrient enrichment on a landscape scale may cause increased or decreased rates of subsidence, although these predictions have not yet been tested (Deegan 2002). Highly developed or industrial watersheds may also serve as sources of metals, hydrocarbons, and other toxins that may be deposited in wetland sediments, posing risks for benthic organisms that inhabit them. As predators consume these organisms, food web dynamics may be altered through accumulation of toxins in the tissues of higher trophic level organisms. The accumulation of toxins in animal tissues may reduce growth and fecundity, and may render them unsuitable for consumption as food.

Within a drainage basin, land use is a primary factor affecting stormwater runoff characteristics. Land use determines the types and amounts of ground cover, impervious surface, and automobile traffic, which have a direct effect on the water quality of stormwater runoff generated (Harper 1998). The pollutant loading rates calculated for land use categories in central and south Florida by Harper (1998) illustrate that multifamily and high-intensity commercial land uses have the highest loading rates for nitrogen and phosphorus, caused primarily by their large proportion of impervious surfaces. Similarly, commercial, industrial, and highway land use types have the highest potential loading rates for metals such as lead and zinc (Harper 1998).

Loading rates for nutrients and pollutants into a particular watershed or wetland can be estimated by multiplying the area of the watershed occupied by various land use categories times the potential contribution of pollutants associated with each land use type, often known as export coefficients. For a review and summary of published export coefficients for various land use types, see Lin (2004) and the sources cited within. However, calculation of wetland loading rates is beyond the scope of a rapid assessment method such as this. Therefore, a simplified approach based on the proportion of the wetland perimeter occupied by various land use types is proposed.

A number of potentially important factors are not considered in the present index. Nutrient exchange capacity in tidal wetlands may be considered a function of sediment grain size and organic content, factors that are often associated with marsh age. Older, well-developed marshes are generally characterized as having fine-grained, nutrient-rich organic soils; these systems tend to export nutrients to the adjacent estuary. In contrast, newly developed marshes characterized by coarse, sandy soils generally lack well-developed nutrient pools and are devoid of binding sites associated with soil organic matter. In these younger wetlands, direct nutrient limitation is important and a net import of nutrients generally occurs. This has been demonstrated by fertilization experiments in salt marshes (Broome et al. 1975, Osgood and Zieman 1993) in which *S. alterniflora* plants in newly developed marshes exhibited an enhanced growth response relative to plants in older marshes. Another factor is decomposition rates, which can vary seasonally among plant species and even between different parts of the same plant. Decomposition of labile, broad-leaved emergent vegetation, such as *Peltandra virginica* or *Sagittaria* spp., occurs more rapidly than breakdown of salt marsh species such as *S. patens* or *J. roemerianus*, which are characterized by high carbon:nitrogen ratios, and thus decompose gradually (Odum and Heywood 1978). Water and air temperature are key determinants of the rate of organic matter decomposition. Microbial activity associated with decomposing marsh vegetation is mediated by temperature decreases in winter. The rate of decomposition of detrital material is inversely related to particle size. Large fragments of plant tissue are broken down rapidly by invertebrate grazers, either via passage through the gut or mechanical fragmention by chewing. Storm events are not considered here; however, they are certainly responsible for the transport of considerable amounts of suspended organic and inorganic materials in tidal marsh systems.

Functional capacity index

The following variables are used in the assessment model for the function Biogeochemical Cycling:

a. Hydrologic Regime
b. Mean Percentage Cover of Native Emergent Marsh Vegetation
c. Surrounding Land Use

The assessment model for calculating the FCI is

$$FCI = \left[V_{HYDRO} \times V_{COVER} \times V_{LANDUSE}\right]^{1/3}$$

Biogeochemical processes in tidal systems are mediated by physical, chemical, and biological factors. Many of these factors are either poorly understood or beyond the scope of a rapid assessment method such as this one. The variables chosen for this functional index represent those factors that are both practical to estimate or measure and are presumed to affect biogeochemical processes in tidal systems. These variables include hydrologic regime (V_{HYDRO}), percentage vegetative cover of emergent plants (V_{COVER}), and surrounding land use ($V_{LANDUSE}$). V_{HYDRO} assesses the potential for alteration of the normal tidal flooding regime, when water comes in contact with the microbial films covering sediment, live plant, and litter surfaces, and infiltration of nutrients to the root zone may occur. V_{COVER} is included as an indicator of the potential for organic carbon production, degradation, and export, both in dissolved and particulate form. $V_{LANDUSE}$ is included as an indicator of the potential for the wetland biogeochemical processes to be altered by offsite inputs from anthropogenic sources.

Function 3: Nekton Utilization Potential

Definition

This function describes the potential utilization of a marsh by resident and seasonally occurring nonresident adult or juvenile fish and macrocrustacean species. A quantitative measure of this function would be abundance (or biomass) of resident nekton per square meter.

Rationale for selecting the function

Tidal marshes provide forage habitat, spawning sites, and a predation refuge, and serve as a nursery for resident and nonresident fishes and macrocrustaceans. These organisms use tidal marshes or adjacent subtidal shallows either year-round or during a portion of their life history as nurseries. A number of ecologically and economically important nekton species are dependent on the availability of suitable tidal marsh habitat. The ubiquitous killifishes (*Fundulus* spp.), grass shrimp (*Palaemonetes* spp.), and gobies (*Gobiosoma* spp., *Gobionellus* spp., *Microgobius* spp., etc.) are characteristic residents of Atlantic and Gulf coast intertidal wetlands. In contrast, estuarine-dependent species such as the penaeid shrimp (*Farfantepenaeus* spp., *Litopenaeus* spp.), the blue crab (*Callinectes sapidus*), the sciaenids (*Cynoscion* spp., *Sciaenops ocellatus*, *Leiostomus xanthurus*, *Micropogonias undulatus*, and *Bairdiella chrysoura*, etc.), and others use tidal marshes and shallow, subtidal bottoms as nurseries. These organisms are consumed by nektonic and avian predators and are considered to represent an important link in marsh-estuarine trophic dynamics.

Previous HGM guidebooks for the assessment of tidal fringe wetlands (Shafer and Yozzo 1998, Shafer et al. 2002) have included separate functions for resident and nonresident nekton utilization, based on differences in the life history and marsh utilization patterns of these two groups. Although the remaining water in shallow, water-filled depressions and rivulets within the marsh interior (e.g., unconnected marsh edge) may provide a low-tide refuge for resident species (Kneib and Wagner 1994, Kneib 1997), nonresident nekton are typically restricted to the edges of tidally connected channels and bayshores that provide an avenue of retreat to deeper water on ebb tides. The only difference between the Resident Nekton Utilization and Nonresident Nekton Utilization assessment models in previous HGM tidal fringe guidebooks is the ratio of tidally connected versus unconnected marsh edge, as measured by the variable V_{OMA} (Opportunity for Marsh Access). Although these shallow pools and water-filled depressions within the marsh interior (unconnected edge) are a common feature in Texas, Louisiana, and Atlantic tidal marshes, they are uncommon in Mississippi and Alabama (Stout 1984). Therefore, the A-Team decided to consolidate both resident and nonresident nekton utilization into a single function.

Characteristics and processes that influence the function

The importance of tidal marshes as habitat for both resident and nonresident nekton species is one of the most often cited functions of this wetland subclass. Most evidence suggests that resident organisms (e.g., killifishes, grass shrimps) utilize the entire marsh surface across the range from low to high elevations, but that the dense vegetation characteristic of high marsh habitats may offer greater protection from natant predators than low marshes. However, resident nekton are also widely distributed throughout the lower intertidal marsh early and late in the tidal cycle in Louisiana and Mississippi (Rozas and Reed 1993, Fulling et al. 1999, Hendon et al. 2000), and may use these areas as staging areas prior to marsh flooding. Resident nekton can make extensive use of high marsh when spring tide conditions facilitate access to the upper intertidal zone. Several resident killifish species, including *Fundulus grandis, F. similis, F. pulverus,* and *Adinia xenica*, rely on availability of high intertidal marsh, coincident with spring tidal events, for use as spawning sites (Greeley and MacGregor 1983, Greeley 1984, Greeley et al. 1986, Greeley et al. 1988). Killifishes also use tidal marshes for foraging sites; as Rozas and LaSalle (1990) noted, the Gulf killifish (*F. grandis*) consumed more prey when they had access to the marsh surface than when they were confined to subtidal areas by low tides. These foraging activities also indicate that killifishes export carbon in the form of increased body size from the upper marsh to the intertidal marsh on every tide. Evidence suggests this may be true for saltmarsh topminnow (*F. jenkinsi;* Fulling et al. 1999, Peterson et al. 2003), which also follow the tide in Mississippi and Alabama tidal marshes.

Unlike resident nekton that use intertidal wetlands for most of their life histories, nonresident nekton are more restricted in their access to these areas. Most seasonally occurring, nonresident nekton (e.g., sciaenids, penaeid shrimps, etc.) found in tidal marshes originate from subtidal habitats (mainstream and large distributary channels, deepwater bay or ocean) that are linked to marshes by the tidally connected drainage system. These tidal channels are used as staging areas for both resident and nonresident nekton at low tide and represent corridors between the marsh surface and deeper, subtidal habitats (Rozas et al. 1988). Nonresident nekton, in part because of body size, access the marsh almost exclusively through the tidal channel system on rising tides or during “northerns” (seasonal fronts approaching from the north), typically using the marsh-edge (about 1 m into the vegetation) areas as habitat for foraging and escape from larger predators. These organisms utilize the interior marsh surface only during longer, higher tides, and usually vacate all tidal channels during tidal exposure (Stout 1984, Rozas and Reed 1993, Peterson and Turner 1994, Fulling et al. 1999). Although resident nekton may occupy residual waters in tidal channels within or adjacent to the marsh, nonresident nekton tend not to remain in shallow microhabitats and must retreat to deeper water on most ebb tides. Use of tidal marshes by nonresident nekton may also be enhanced when the marsh is associated with adjacent subtidal seagrass habitat (e.g., *Ruppia maritima*), as penaeid postlarvae and juvenile densities are higher in seagrass than tidal marsh or sand/mud bottoms (Howe et al. 1999, Howe and Wallace 2000).

Although a number of factors are believed to determine utilization of these areas by resident and nonresident nekton, these variables are often difficult to quantify and may not necessarily be supported by available research. The variables used in the model are based on documentation in the primary literature from the Gulf and Atlantic coasts. The model includes the following factors: habitat complexity, access to and availability of aquatic edge, and the hydrologic regime. It is assumed that the potential utilization of a site by resident and nonresident nekton will change as a direct function of each of these variables.

Since nekton are able to access the surface of the marsh only when it is flooded, the potential utilization of a site by these species is directly related to the length of time that the marsh surface is inundated. Transient species may have to wait longer for sufficient water to accumulate before they access the marsh surface, and must vacate the marsh surface earlier than resident nekton on falling tides. Individual species may vary considerably in the degree to which they use the flooded intertidal marsh surface; however, it appears that maximum utilization (in terms of abundance and species richness) occurs at slack high water (Kneib and Wagner 1994). In particular, tidal marshes of Mississippi and Alabama are influenced by northerns, which push water out of the bays/bayous as they approach from the north and once they pass, push water back into tidal marsh habitat, typically for a longer duration and flood intensity (Rozas 1995, Zapfe 2002). Northerns are unpredictable, vary in intensity and frequency, and thus cannot be modeled within the framework of a rapid assessment technique such as this one.

Functional capacity index

The following variables are used in the assessment model for the function Nekton Utilization Potential:

a. Aquatic Edge
b. Hydrologic Regime
c. Nekton Habitat Diversity

The assessment model for calculating the functional capacity index is:

$$FCI = \frac{\left(V_{EDGE} + V_{HYDRO} + V_{NHD}\right)}{3}$$

Function 4: Provide Habitat for Tidal Marsh-Dependent Wildlife

Definition

This function is defined as the capacity of a coastal fringe marsh to provide critical life requisites to selected components of the vertebrate wildlife community. This model is intended to represent the general habitat quality of coastal fringe wetlands for species of avifauna, herpetofauna, and mammals commonly associated with the subclass. A potential independent, quantitative measure of this function would be density estimates from surveys and population censuses using techniques appropriate for the species. Call counts using tape-playback (Tomlinson and Todd 1973) can be used for rails, but surveys should be conducted multiple times because the proportion of birds that respond varies with population size, stage of nesting, time of day, and weather (Meanley 1985, Eddleman 1989, Conway et al. 1993). Seaside Sparrows and Marsh Wrens are best sampled by using plots as described in Wakeley (1987), point counts as described in Ralph et al. (1995), or strip transects as described in Emlen (1971). More recently, a standardized point survey protocol for counting marsh-dependent bird species has been developed by Conway (2004).

Rationale for selecting the function

Coastal fringe marshes provide habitat for a variety of vertebrate wildlife including fish, birds, mammals, and reptiles. Teal (1986) stated that one of the most important functions of salt marshes is to provide habitat for migrant and resident bird populations. Three marsh-dependent birds—the Clapper Rail, Seaside Sparrow, and Marsh Wren—were chosen as the focus of this function because they have very strong associations with specific portions of the subclass and because they use multiple components of the marsh ecosystem (i.e., the plant community and physical features such as the substrate, pools, or tidal creeks). The Clapper Rail and Seaside Sparrow are found almost exclusively in salt or brackish marshes; the Marsh Wren also uses these communities, but also is common in tidal freshwater marshes.

The use of a few species around which to construct assessment models is consistent with the concept of *indicator species* (i.e., species that are closely associated with specific ecosystems) (Graul et al. 1976). The ecological foundation for this approach is that the maintenance of the indicator species at desired levels is indicative of a healthy ecosystem (Bolen and Robinson 2003). In fact, Post and Greenlaw (1994) stated, “As a maritime wetland specialist, the seaside sparrow represents a potentially valuable *indicator* of continued ecological integrity of certain types of coastal marshes and has already proven sensitive to habitat modification in Florida." A related concept is that of *life form associations* (Thomas et al. 1979), which presume species that use similar resources in a similar way would be affected similarly by modifications to or activities within the ecosystem. It is assumed that knowledge of the population levels of the indicator species using the coastal fringe subclass as their primary habitat would provide insight into the overall quality of habitat for other marsh-dwelling wildlife species.

Some wildlife species inhabiting tidal marshes are important game animals (e.g., mallard (*Anas platyrhynchos*) and American wigeon (*A. americana*)), whereas the muskrat (*Ondatra zibethicus*) and raccoon (*Procyon lotor*) are valuable furbearers. The American alligator (*Alligator mississippiensis*) is harvested for both its skin and meat. Many of the birds that commonly use coastal fringe wetlands, especially larger species such as ospreys, herons, egrets, and Roseate Spoonbills (*Ajaia ajaia*) provide recreational opportunities for birdwatchers, nature enthusiasts, and wildlife photographers.

Several of the species that inhabit coastal fringe marshes are not common, and a few are state or federally listed as threatened or endangered. For example, the Wood Stork (*Mycteria americana*), a species that feeds extensively in both saltwater and freshwater marshes, is listed as endangered federally in five southern states including Alabama. Seaside Sparrows are relatively common in many coastal areas, but some races have become endangered locally due to cumulative loss of habitat. This occurred on the eastern coast of Florida with the Dusky Seaside Sparrow (*A. m. nigrescens*), which became extinct in 1987 (Post and Greenlaw 1994).

The majority of wildlife species that utilize the subclass have neither commercial nor recreational value, but simply are ecologically important members of the ecosystem. For example, the rice rat (*Oryzomys palustris*) and other small mammals play a key role in marsh trophic cycles, providing food for several species of avian and mammalian predators. Many of the vertebrates that use the marsh ecosystem are highly mobile and serve as a transfer mechanism for nutrients and energy to adjacent terrestrial or aquatic ecosystems. Some of the larger vertebrates, including the muskrat and nutria (*Myocastor coypus*), consume copious amounts of forage and at high densities may have significant impacts on marsh vegetation structure.

Overview of the wildlife community

Within the reference domain, species from four vertebrate classes (in addition to fish) commonly use coastal fringe marshes for shelter and as breeding or foraging areas. These include Aves, Mammalia, Amphibia, and Reptilia. Hubbard and Gidden (1997) found that relatively few terrestrial vertebrates depend on salt marshes of the northern Florida Gulf Coast, although many species are common or incidental visitors. They also noted that the number of vertebrate species feeding or living in the marshes increases landward as the marshes change from saline to brackish to fresh.

Birds constituted the largest group with 69 species associated with salt and brackish marshes in Alabama (Stout 1984). Six orders, including Falconiformes (hawks, vultures, and their allies), Gruiformes (rails, cranes, and their allies), Charadriiformes (sandpipers, plovers, and their allies), Ciconiiformes (herons, egrets, and their allies), Anseriformes (dusks, geese, and swans), and Passeriformes (perching birds such as sparrows, wrens, and blackbirds) were represented. Wiegert and Freeman (1990) included a few other species that occurred in similar tidal habitats along the southeastern Atlantic coast, and it is likely that some of these also use coastal marshes within the reference domain. The majority of the species mentioned in Stout (1984) and Wiegert and Freeman (1990) are seasonal residents, migrants, or occasional visitors; and the number of birds that use the subclass as their primary habitat is limited. Hubbard and Gidden (1997) listed only 15 species with strong associations to tidal marsh systems in northern Florida; of these, only the Clapper Rail and Seaside Sparrow were found almost exclusively within the tidal fringe ecosystem. Others including the Marsh Wren, Virginia Rail (*Rallus limicola*), Sora Rail (*Porzana carolina*), and Least Bittern (*Ixobrychus exilis*) are marsh specialists, but are not restricted to tidal fringe marshes. Wading birds such as the Snowy Egret (*Egretta thula*) and Tricolored Heron (*E. tricolor*), although common in tidal fringe marshes, also use many other types of wetlands and open water habitats. A complete list of birds reported to use tidal marshes along the Gulf Coast (Stout 1984, Hubbard and Gidden 1997) is found in Appendix F.

Mammals that use the subclass constitute a much smaller group with only 12 species listed by Stout (1984) and 11 by Hubbard and Gidden (1997). These included members of the orders Rodentia (rats, mice, and allies), Lagomorpha (rabbits and hares), Carnivora (weasels, cats, and their allies), Artiodactyla (deer and allies), and Xenarthra (armadillos and allies). The majority are rodents and carnivores. The muskrat, nutria, marsh rabbit (*Sylvilagus palustris*), cotton rat (*Sigmodon hispidus*), rice rat, and white-tailed deer (*Odocoileus virginianus*) all live within the marsh proper or at the interface between the marsh and adjacent upland habitat. Others including the raccoon, red fox (*Vulpes vulpes*), and nine-banded armadillo (*Dasypus novemcinctus*) are primarily upland-dwelling species that sometimes use the marsh for foraging. Roberts (1991) found the house mouse (*Mus musculus*) in many coastal marshes in Florida, and it is likely that this species also is common within the reference domain.

Reptiles are uncommon in coastal fringe marshes, and only five species were listed by Stout (1984) as occurring in *Juncus* marshes. These included the American alligator (*Alligator mississippiensis*), Mississippi diamondback terrapin (*Malaclemys terrapin pileata*), Alabama red-bellied turtle (*Pseudemys alabamensis*), Florida cooter (*P. floridana floridana*), and Gulf salt marsh water snake (*Nerodia clarkii*). Hubbard and Gidden (1997) listed four additional snakes including the cottonmouth (*Agkistrodon piscivorus*) that are found in brackish and tidal freshwater marshes.

Amphibians are the least common of the vertebrates that inhabit tidal fringe marshes in the reference domain; none are adapted to the salt marsh zone. Hubbard and Gidden (1997) included the green tree frog (*Hyla cinerea*) and leopard frog (*Rana utricularia*) as inhabitants of brackish and tidal freshwater marshes in Florida’s northern Gulf Coast.

Stout (1984), Teal (1986), Wiegert and Freeman (1990), and Mitsch and Gosselink (2000) are all good sources of additional information regarding wildlife communities of coastal fringe marshes.

Characteristics and processes that influence the function

Members of the vertebrate wildlife community within the reference domain have adapted to a characteristic hydrologic regime and its resultant plant community composition and structure. Hydrology and the plant community in turn directly influence the development of a characteristic benthic community upon which many vertebrate wildlife species depend. Thus, all activities within or adjacent to the wetland that influence hydrology and plant community characteristics strongly influence the wildlife community.

Reference standard coastal fringe marshes within the reference domain are quite diverse and commonly contain different plant communities or associations dominated by one or a few species. For example, salt marshes in the northern Gulf of Mexico commonly have four distinct *zones* (smooth cordgrass (*S. alterniflora*), black needlerush (*J. roemerianus*), salt flat, and high meadow) (Stout 1984). These zones result from elevation changes, substrate differences, tidal amplitude, and other factors, and are consistent within the subclass (Clewel 1997). Tidal freshwater marshes are much more diverse and complex because of the reduction in salt stress (Mitsch and Gosselink 2000). Bulltongue (*Sagittaria lancifolia*), maidencane (*Panicum hemitomom*), and cutgrass (*Zizaniopsis miliacea*) are dominants or co-dominants in the three major associations in some Louisiana tidal freshwater wetlands (Visser et al. 1998). Other authors describe different communities or zones that range from relatively flood intolerant species found on natural levees to floating aquatic vegetation (Clewell 1997, Mitsch and Gosselink 2000). The plant community model in this guidebook provides detailed information regarding the composition of coastal fringe marshes within the reference domain.

One of the reasons that reference standard marsh communities are complex is the presence of tidal creeks caused by irregularities across the marsh surface, causing water to carve defined channels (Chapman 1960). These creeks are dynamic, and channel locations may change over time caused by sedimentation or other factors. Creeks and channels are present in both young and old natural marshes (Mitsch and Gosselink 2000) and have a pronounced effect on the plant community due to their influence on elevation, salinity, and other factors. For example, tall *S. alterniflora* typically grows along shorelines and tidal creeks, whereas short-form plants typically are found farther from the channels (Clewell 1997). Stout (1984), Clewell (1997), and Mitsch and Gosselink (2000) all provide a good overview of tidal marsh wetlands.

Regardless of marsh type (i.e., saline, brackish, or fresh), community composition and diversity are major factors that contribute to overall habitat quality of a site. Composition is important because certain species of plants are more valuable for providing food and cover resources than others; diversity is important because resource needs vary with seasons, weather conditions, and tidal regimes. For Atlantic Coast Clapper Rail populations, smooth cordgrass

(*S. alterniflora*) probably is the most important (Eddleman and Conway 1995), but Adams and Quay (1958) reported that early spring nesting often occurs in areas dominated by black needlerush (*J. roemerianus*). They speculated that this possibly was due to the better cover it provided at that time of the year. In most salt marshes within the reference domain, black needlerush is the dominant plant species. Based on recent field surveys along the Mississippi Gulf Coast, the majority of Clapper Rail nests were found in areas dominated by *J. roemerianus*. Clapper Rail nests were also observed in areas dominated by other plant communities, such as mixed *S. alterniflora Juncus, Cladium/ S. cynosuroides, Sagittaria* spp.*/Spartina cynosuroides* (Mark Woodrey, Research Biologist, unpublished data).

Seaside Sparrows prefer to nest in grasses including smooth cordgrass (Post and Greenlaw 1994), but in some instances, have been found to use other species. Two reasons cordgrass may be especially important for many birds are the high concentration of arthropods it supports (Davis and Gray 1966, Post et al. 1983) and the fact that it produces more seeds than other salt marsh species (Post and Greenlaw 1994). The Marsh Wren is less of a habitat specialist than the Clapper Rail or Seaside Sparrow; and cattails (*Typha* spp.), bulrushes (*Scirpus* spp.), phragmites (*Phragmites australis*), sawgrass (*Cladium jamaicense*), cordgrass, and needlerush all have been utilized as habitat (Kroodsma and Verner 1997). Regardless, this species also seems to benefit from community diversity. Verner and Engelsen (1970) found that nests were located primarily in cattails, but birds moved into bulrush-dominated areas later in the year as the marsh became drier. Leonard and Picman (1987) found that nesting success was lower in homogenous cattail marshes than in more diverse ones that also included *Phragmites* and bulrushes.

Portions of the marsh ecosystem commonly referred to as the high marsh community often are dominated by low-growing halophytic plants and may not provide as high a quality habitat for many wildlife species as the lower zones dominated by the more robust cordgrass and needlerush. These areas can, however, be critical at certain times and can contribute significantly to overall site quality. For example, Clapper Rails move into the high marsh during periods of high tides (especially in winter) when the vegetation in the lower cordgrass and needlerush zones are overtopped (Lewis and Garrison 1983). In marshes where the vegetation frequently is overtopped by tides, these higher areas may even be used for nesting by the rails and other species (T. H. Roberts, personal observation). In Florida, such areas were often dominated by Jesuit's bark (*Iva frutescens*), seaside tansy (*Borrichia frutescens*), and associated species (Roberts 1991). In some instances, the high marsh may even be preferred over the lower cordgrass or needlerush zones. In one Florida study, most Seaside Sparrow nests were located preferentially in saltgrass (*Distichlis spicata*) and glasswort (*Salicornia* spp.) although cordgrass and needlerush were present (Post and Greenlaw 1994). Post (1974) speculated that sparrows sometimes are displaced from the needlerush zone by rice rats and do not use the cordgrass zone because of its greater susceptibility to flooding. Adjacent upland habitat also can be important in marshes in which the higher zones are very limited or lacking entirely (T. H. Roberts, personal observation). For such habitat to be useful to marsh-dwelling wildlife, it must be able to provide concealment; thus lawns, golf courses, and other highly manicured areas are not acceptable.

Determining the exact composition of the marsh ecosystem that provides the highest quality wildlife habitat is difficult, but indications are that marshes in which several plant associations or zones are present provide the highest quality habitat. It also appears that communities do not have to be represented equally. Hon et al. (1977) described *typical* (presumably good) Clapper Rail habitat in Georgia as being composed of 79 percent cordgrass, 20 percent needlerush, and the remainder either salt flat or salt meadow. These exact values should not be overemphasized, but simply should be viewed as an illustration of the general makeup of high-quality marshes. However, it should also be recognized that these proportions are not representative of the irregularly flooded, *Juncus*-dominated marshes within the reference domain. Most reference standard wetlands in the north-central Gulf of Mexico reference domain are dominated by the more robust species with the shorter, more sparsely vegetated zones composing a much smaller percentage of the total (see "Plant Communities" in Chapter 3). While species composition and relative abundance may vary even among high-quality sites, it seems especially important that both the high and low zones are present.

In addition to species composition, structural aspects of the plant community have also been shown to be important in influencing wildlife habitat quality (Wilson 1974, Rotenberry 1985). In salt marshes along the Atlantic and Gulf Coasts, both marsh cordgrass and black needlerush develop characteristic growth forms that vary throughout the marsh complex and have been described by Kruczynski et al. (1978), Anderson and Treshow (1980), and Stout (1984). The two forms, *tall* and *short*, are thought to be a response to frequency of inundation, salinity, soil texture, and possibly other factors (Stout 1984). In general, both species become shorter toward the uplands. Mitsch and Gosselink (2000) described the tall form of *Spartina* as 100 to 300 cm tall and the short form as 17 to 80 cm tall. Eleuterius and Caldwell (1981) reported that the mean height of tall *Juncus* in Mississippi marshes was 142 cm whereas that of the short form was only 26 cm.

For most wildlife species that use coastal fringe wetlands, the different portions of the marsh (e.g., the short and tall forms of cordgrass and needlerush in salt marshes and the short and tall communities in the freshwater marshes) have differential value to wildlife. In general, marsh vegetation tall enough not to be overtopped by high tides seems to be important relative to use by the three marsh-dependent birds targeted in this model. Oney (1954) found the majority of Clapper Rail nests in marsh cordgrass stands in which the height of the vegetation was between 61 and 122 cm. Nests were also found in portions of marshes with taller vegetation, but no nests were found where the short form of marsh cordgrass predominated. Eddleman and Conway (1995) reported that the nests of Clapper Rails along the east coast are typically found in areas in which the marsh cordgrass is of *medium height*, but did not provide measurements. No studies in the Gulf Coast region have reported the height of Clapper Rail nests above the ground. Studies along the Atlantic Coast reported most nests to be 20 to 35 cm above the ground (Kozicky and Schmidt 1949, Stewart 1951). Seaside Sparrows in Florida constructed their nests in areas in which the height of the vegetation is 100 cm (Post and Greenlaw 1994). Kale (1983) described prime habitat (not specifically for nesting) for Seaside Sparrows as being greater than 1 m in height. Marsh Wrens also tend to select taller vegetation for nesting.

Verner (1965) reported that mean nest heights varied from 76 to 93 cm above the ground in cattail and bulrush marshes. In salt marshes, preferred habitat is tall cordgrass (>2 m) adjacent to creeks and rivers or somewhat shorter vegetation (1.0 to 1.5 m) elsewhere (Kale 1965). Marsh Wren nests typically are placed 30 to 91 cm above standing water or high tides (Bent 1948).

The density (or percentage ground cover) of the vegetation in the more robust zones of the marsh is also an important factor that influences use by wildlife species associated with the subclass. Areas in which plant density is not sufficient to provide concealment or protection are not used (an exception may be as occasional foraging habitat) by any of the target species. Unfortunately, relatively few studies have been conducted in which cover values have been quantified. One study in Florida does provide some insight relative to the Clapper Rail, but sample sizes were small and should be viewed cautiously. Roberts (1991) found that all marshes in which the canopy cover was 48 percent or greater (and in which other factors such as height were acceptable) were used by Clapper Rails. Lewis and Garrison (1983) did not consider point-specific canopy cover values in their Habitat Suitability Index (HSI) model for the Clapper Rail, but instead used a photograph-based approach to identify the percentage of the assessment area that was "covered by persistent emergent or shrub wetlands." The term *covered* in this context differs from values that might be measured at a specific location (i.e., within a specific sampling area such as a square meter). Similarly, Post and Greenlaw (1994) did not specify density or cover values that they considered optimum for Seaside Sparrows. They did describe optimum habitat as being "expanses of medium to high cordgrass with a turf of clumped, residual stems." The photographs they included of presumably high-quality habitat depict completely vegetated marshes in which the density or cover values would be described as *dense*. A few studies of Marsh Wren habitat requirements also suggest that relatively dense cover is desirable. Gutzwiller and Anderson (1987) concluded that erect, closely spaced vegetation with sufficient strength was needed to support the large nest that the species constructs. The lowest mean percentage cover of emergent vegetation in marshes used by territorial male wrens was 50 percent; cover in other marshes ranged from 57 percent to 100 percent. Gutzwiller and Anderson (1987) selected a value of 50 percent cover as the minimum acceptable in the HSI model for the species.

The banks of tidal creeks and other nonvegetated or sparsely vegetated portions of the marsh provide different and essential resources for the Clapper Rail, Seaside Sparrow, and many other species of wildlife. As an example, the Clapper Rail typically nests in the cordgrass and needlerush zones, but forages throughout the entire marsh ecosystem. Much of its foraging activity is conducted within mudflats and along the banks of tidal creeks, ditches, bayous, or shorelines (Lewis and Garrison 1983). Additionally, some subspecies of Clapper Rails have been found to select nest sites near creeks, ditches, or other tidal areas (Lewis and Garrison 1983, Meanley 1985), although one study in Louisiana concluded that there was no discernible pattern relative to creeks. Lewis and Garrison (1983) concluded that the highest quality habitat was provided by areas in which at least 25 percent of the vegetated portion of marsh was within 15 m of creeks or other tidal features. These same types of openings have also been found to be important to Seaside Sparrows. Post and Greenlaw (1994) noted that one of the requirements of a breeding population of sparrows was the presence of openings such as pool and creek edges where the birds can forage on open mud or at the bases of rooted vegetation. Optimum habitat is thought to be areas in which nest-centered territories and feeding habitat are contiguous (Post 1974).

Other common avian species found in coastal marshes also benefit from the presence of tidal creeks and other openings, possibly to a greater extent than either the Clapper Rail or Seaside Sparrow. Most of the shorebirds feed on benthic invertebrates, and most members of this group feed in the intertidal zone, in creeks, in salt flats, or on sandy berms (Stout 1984). They seldom, if ever, forage in densely vegetated portions of the marsh. They benefit from a complex of channels, pools, and other openings because different species feed in water of different depths; thus they partition resources efficiently and avoid competition with other species. Smaller species such as the Snowy Plover (*Charadrius alexandrinus*) and the majority of the migrant sandpipers (*Caladris* spp.) typically prefer sandy shorelines at the edges of a marsh or creek, whereas longer-legged species such as the American Oystercatcher (*Haematopus palliates*) and Greater Yellowlegs (*Tringa melanoleuca*) can forage in areas of deeper standing water. Wading birds such as Great Egret (*Ardea alba*) and Snowy Egret (*Egretta thula*) typically prefer somewhat deeper open water areas in creeks and pools where fish and other prey can become concentrated during low tides (T. H. Roberts, personal observation).

Marshes should be dense enough to provide secure cover, and for some species including the Marsh Wren, closely spaced plants are a necessity for successful construction of nests. Percentage emergent marsh cover in reference standard sites typically ranges from 70 to 100 percent. These values would be considered “dense” vegetation stands and are similar to the value recommended as optimum habitat for marsh wrens (Gutzwiller and Anderson 1987). Therefore, a subindex of 1.0 is assigned when mean cover of emergent marsh vegetation is at least 70 percent. On the lower end of the scale, there was less information upon which to base subindex values. Roberts (1991) and Gutzwiller and Anderson (1987) estimated that sites in which mean percentage cover values were 48 to 50 percent provided minimally acceptable cover for the Marsh Wren and the Clapper Rail, although sites with lower cover values may be occasionally used as forage areas.

Functional capacity index

The following variables are used in the assessment model for the function Provide Habitat for Tidal Marsh Dependent Wildlife:

a. Wetland Patch Size
b. Mean Height of Emergent Marsh Vegetation
c. Mean Percentage Cover of Native Emergent Marsh Vegetation
d. Aquatic Edge
e. Wildlife Habitat Diversity

The assessment model for calculating the FCI is as follows:

$$FCI = \left\{ V_{SIZE} \times \left[\frac{\left(V_{HEIGHT} + V_{COVER} \right)}{2} \right] \times \left[\frac{\left(V_{EDGE} + V_{WHD} \right)}{2} \right] \right\}^{1/3}$$

Function 5: Maintain Characteristic Plant Community Structure and Composition

Definition

This function describes the ability of a wetland to support a native plant community of characteristic species composition. Community composition of tidal wetlands in the region is so varied that there is no suite of species that may be considered characteristic of a reference standard. Therefore, the variables included in this function are intended to assess potential shifts in plant community composition that may have occurred as a result of hydrologic alterations and other disturbances.

Rationale for selecting the function

The vegetative community is one of the fundamental components of both terrestrial and wetland ecosystems. In tidal wetlands, alterations that affect either the surface elevation or the tidal flooding regime can result in changes in species composition. Changes in the plant species composition and structure may profoundly affect the entire suite of physical, chemical, and biological processes occurring within a site. Although some of these attributes have already been considered through the incorporation of these variables into many of the other functional indices, maintenance of a characteristic native plant community was deemed sufficiently important to warrant separate consideration.

The high productivity of coastal marshes and the physical structure that is one expression of that productivity are the basis for the transformations of matter and energy referred to as wetland functions. Plant biomass and production are similarly important in support of animal assemblages.

Characteristics and processes that influence the function

The number of plant species that are able to exist in salt marshes is limited by environmental stress factors such as the duration, frequency, and depth of flooding and high pore water salinity levels. Salt marsh vegetation is typically dominated by grasses (Poaceae) and sedges (Cyperaceae) or a combination of these families. The plants typically occur in well-defined zones dominated by a single species or species association. Tidal fringe marshes lack the complex multilayered structure characteristic of forested communities; although a scrub-shrub component may exist, it usually occurs at the upland edges or on elevated hummocks and occupies only a small proportion of the total area. The spatial extent of the major zones of vegetation is largely determined by elevation and the resultant effect on the tidal flooding regime.

The high productivity of coastal marshes has long been recognized (Sather and Smith 1984). Although the combination of long periods of soil saturation and variable salinities excludes most plants, those that can tolerate the conditions are the beneficiaries of nutrient subsidy and waste removal afforded by periodic flooding and emersion. The result is a potential for high primary productivity. Although many factors clearly influence primary productivity (e.g., nutrient availability, sediment properties, soil aeration), percentage cover of herbaceous wetland plants is included as a model variable as a measure of the standing stock of plant material on a site. It is assumed that standing crop is a sensitive integrator of all other influences on primary production and is the primary factor that most directly defines the potential of a site for primary production. Furthermore, direct measurement of nutrient availability and edaphic features, or at the other extreme, of primary productivity itself, is beyond the scope of applications of this methodology.

For wetlands of the same type, it is generally assumed that more pristine, less modified sites will exhibit plant community composition very similar to the saline, brackish, and intermediate marsh types described in Chapter 3. In tidal marshes, the most common types of site alterations involve changes in site elevation (excavation and filling) and altered hydrology (restricted tidal flow due to the presence of culverts, weirs, dams, etc.). These changes affect the salinity regime, flooding frequency, and flooding duration, and may cause an increase in the extent of brackish species such as *Typha domingensis*, at the expense of more salt-tolerant species such as *S. alterniflora* (Sinicrope et al. 1990). Filling increases the site elevation, which reduces the depth and duration of tidal flooding, as well as flooding frequency. Alterations that restrict normal tidal hydrology can also result in reduced hydroperiod. These activities can affect the plant community composition in tidal marshes by reducing the percentage cover of typical herbaceous plant species, increasing the dominance of those species able to tolerate drier conditions, or facilitating the introduction and spread of non-native or invasive species (Marks et al. 1994). Alterations that restrict tidal flow may also shift the hydrology of the site from one dominated by bidirectional tidal flows to one dominated by freshwater runoff and precipitation. This may facilitate the invasion of the site by those plant species more typical of freshwater wetlands (e.g., bald cypress, red maple). Such conditions may also allow the introduction and spread of non-native or invasive species, such as *Phragmites australis* (Roman et al. 1984).

Functional capacity index

The following variables are used in the assessment model for the function Maintain Characteristic Plant Community Structure and Composition:

a. Total Percent Vegetative Cover of Native Emergent Wetland Species
b. Percentage Cover by Invasive or Exotic Species
c. Wetland Plant Indicator Status
d. Percentage Cover by Woody Plant Species

The assessment model for calculating the FCI is as follows:

$$FCI = \left[Minimum \left(V_{COVER} \text{ or } V_{EXOTIC} \text{ or } V_{WIS} \text{ or } V_{WOODY} \right) \right]$$

These variables are intended to downgrade the value of the function as a result of (a) abnormally low cover by emergent herbaceous wetland plant species, which may result from a number of different causes (V_{COVER}), (b) presence of exotic or invasive species (V_{EXOTIC}), (c) a shift in plant community composition towards the drier end of the spectrum (V_{WIS}), or (d) increasing proportion of cover by woody plant species (V_{WOODY}). Since any of these conditions could contribute to site degradation, the value of the functional index is set to the lower of the four variable subindices.

5 Assessment Protocol

Introduction

Previous sections of this Regional Guidebook provide background information on the HGM Approach and document the variables, measures, and models used to assess the functions of tidal fringe wetlands in the north-central Gulf of Mexico. This chapter outlines a protocol for collecting and analyzing the data necessary to assess the functional capacity of a wetland in the context of a Section 404 permit review or similar assessment scenario.

The typical assessment scenario is a comparison of preproject and postproject conditions in the wetland. In practical terms, this translates into an assessment of the functional capacity of the WAA under both preproject and postproject conditions and a subsequent determination of how the FCIs have changed as a result of the project. Data for the preproject assessment are collected under existing conditions at the project site, while data for the postproject assessment are normally based on the conditions that are expected to exist following proposed project impacts. A conservative and well-documented approach is required in defining postproject conditions. This recommendation is based on the often-observed lack of similarity between predicted and actual postproject conditions.

This chapter discusses each of the tasks required to assess tidal fringe wetlands in the north-central Gulf of Mexico:

a. Define assessment objectives.
b. Characterize the project area.
c. Screen for red flags.
d. Define the wetland assessment area(s).
e. Collect field data.
f. Analyze field data.
g. Apply assessment results.

Define Assessment Objectives

Begin the assessment process by clearly identifying the purpose of conducting the assessment. This may be as simple as stating, “The purpose of this assessment is to determine how the proposed project will impact wetland functions." Often, there will be multiple purposes for conducting the assessment. Other potential objectives include (a) comparing several wetlands as part of an alternatives analysis, (b) identifying specific actions that could be taken to minimize project impacts, (c) documenting baseline conditions at the wetland site, (e) determining mitigation requirements, (f) determination of mitigation success, or (g) evaluating the effects of a wetland management technique. Defining the purpose will facilitate communication and understanding between the people involved in conducting the assessment and will make the purpose clear to other interested parties. In addition, it will help to establish the approach that is taken. The specific approach will vary depending on whether the project is a Section 404 permit review, an Advanced Identification (ADID), a Special Area Management Plan (SAMP), or some other scenario.

Characterize the Project Area

Characterizing the project area involves describing the project area in terms of climate, surficial geology, geomorphic setting, tidal flooding regime, vegetation, soils, land use, proposed impacts, and any other characteristics and processes that have the potential to influence how wetlands at the project area perform functions. The characterization should be written and should be accompanied by maps and figures that show project area boundaries, buildings, jurisdictional wetlands, the WAA, proposed impacts, roads, ditches, streams, soil types, plant communities, threatened or endangered species habitats, and other important features.

In order to characterize a project area, recent true-color or color-infrared aerial photographs or digital ortho-photo quadrangle imagery will be needed. Topographic and National Wetlands Inventory maps, tide tables, and bathymetric charts are not required, but may also be helpful.

Screen for Red Flags

Red flags are those features within or near the project area to which special recognition or protection has been assigned on the basis of objective criteria (Table 25).

Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a proactive attempt to determine if the wetlands or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of wetland function. The assessment of wetland functions may not be necessary if the project is unlikely to occur as a result of a red flag feature. For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of wetland functions may be unnecessary since the project may be denied or modified strictly based on the impacts to threatened or endangered species habitat. A list of some species of special concern known to occur within the reference domain is provided in Appendix F.

Table 25
Red Flag Features and Respective Program/Agency Authority

Red Flag Features	Authority[1]
Native lands and areas protected under American Indian Religious Freedom Act	A
Hazardous waste sites identified under CERCLA (Superfund) or Resource Conservation and Recovery Act (RCRA)	I
Areas protected by a Coastal Zone Management Plan	B, E, L
Areas providing Critical Habitat for Species of Special Concern	B, C, F
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or floodprone areas	J
Areas with structures or artifacts of historic or archeological significance	A, D, G
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	B, D
National wildlife refuges and special management areas	B, C, D
Areas identified in the North American Waterfowl Management Plan	C
Areas identified as significant under the Ramsar treaty	C
Areas supporting rare or unusual plant communities	C, F
Areas designated as Sole Source Groundwater Aquifers	I
Areas protected by the Safe Drinking Water Act	I
City, County, State, and National Parks	C, F, L, D, G
Areas supporting threatened or endangered species	B, C, E, F, I
Areas with unique geological features	D
Areas protected by the Wild and Scenic Rivers Act	C, D
Areas protected by the Wilderness Act	C, D

[1] Program Authority/Agency
A = Bureau of Indian Affairs
B = National Marine Fisheries Service
C = U.S. Fish and Wildlife Service
D = National Park Service
E = State Coastal Zone Office
F = State Department of Natural Resources, Fish and Game, etc.
G = State Historic Preservation Officer
H = State National Heritage Offices
I = U.S. Environmental Protection Agency
J = Federal Emergency Management Administration
K = Natural Resources Conservation Service
L = Local Government Agencies

Define the Wetland Assessment Area

The WAA is an area of wetland within a project area that belongs to a single regional wetland subclass and is relatively homogeneous with respect to the site-specific criteria used to assess wetland functions (i.e., hydrologic regime, vegetation structure, topography, soils, successional stage, etc.). In many project areas, there will be just one WAA representing a single regional subclass (Figure 6). However, as the size and heterogeneity of the project area increase, it is more likely that it will be necessary to define and assess multiple WAAs or partial WAAs (PWAA) within a project area.

At least three situations necessitate defining and assessing multiple WAAs within a single project area. The first situation exists when spatially separate patches of the same regional subclass occur within the project area (Figure 7). The second exists when wetlands belonging to more than one regional subclass occur within the project area (Figure 8). A third situation exists when a physically contiguous wetland area of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, project impacts or other types of disturbance, hydrologic alteration, or other factors that translate into a significantly different value for one or more of the site-specific variable measures (Figure 9). These differences may be the result of natural variability or anthropogenic alteration. Designate each of these areas as a separate WAA and conduct a separate assessment on each area.

There are elements of subjectivity and practicality in determining what constitutes “significant” differences in portions of the WAA. Field experience with the regional wetland subclass under consideration should provide a sense of the range of variability that typically occurs and the background necessary to make reasonable decisions about defining multiple WAAs. In general, differences resulting from natural variability should not be used as a basis for dividing a contiguous wetland into multiple WAAs. However, areas that differ with respect to hydrologic alterations, dredge and fill operations, project impacts, or other disturbances caused by rare and destructive natural events (e.g., hurricanes) should be assessed separately.

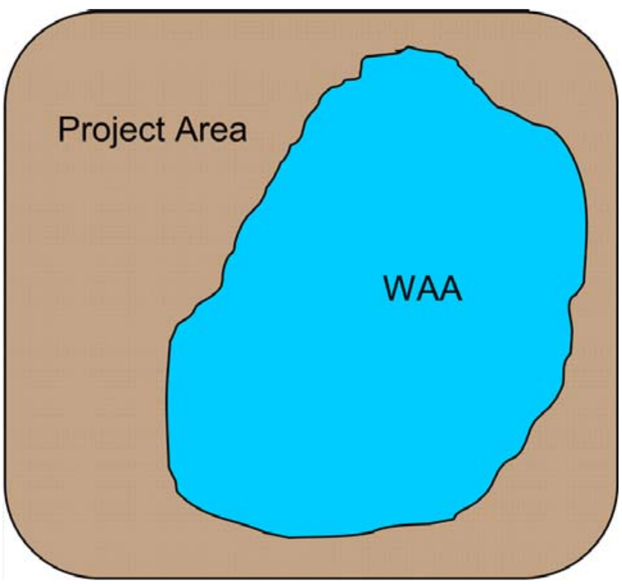

Figure 6. A single WAA within a project

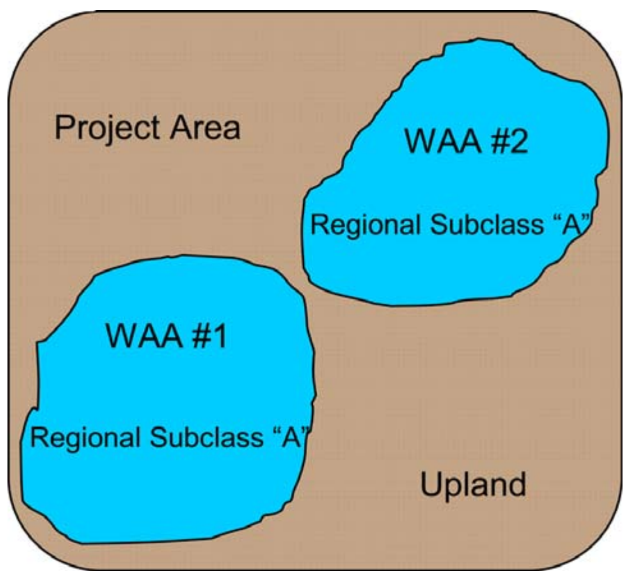

Figure 7. Spatially separated WAAs from the same regional subclass within a project

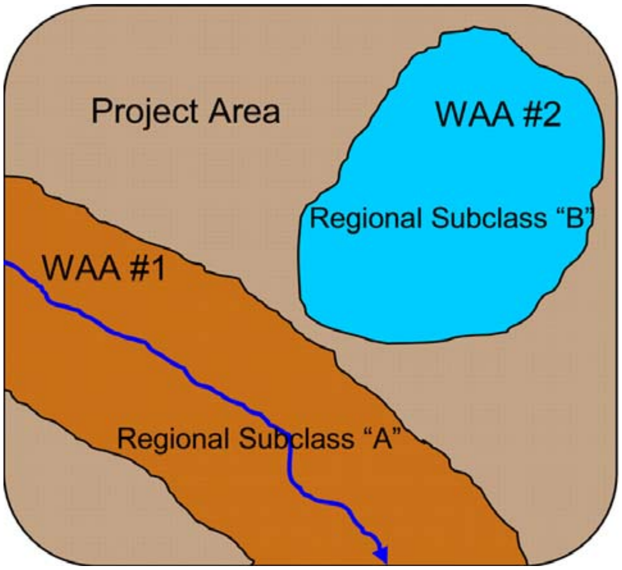

Figure 8. More than one regional subclass within a project area

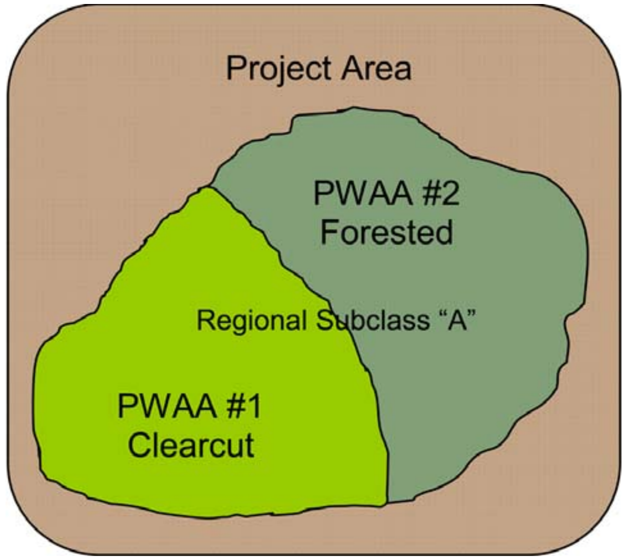

Figure 9. PWAAs defined on the basis of differences in site-specific characteristics

Data Collection

The following equipment is necessary to measure or estimate values for model variables:

a. A 1-m^2 quadrat (e.g., PVC square) for estimating plant percentage cover

b. Recent color infrared or true-color aerial photographs or digital orthophoto quadrangle imagery at a scale of approximately 1 cm = 48 m (1:4800 or 1 in. = 400 ft)

c. Measuring stick marked in centimeters

d. GIS software or non-SI area grid for measuring patch size

e. Access to U.S. Department of Agriculture (USDA) online PLANTS database or other source for determining plant wetland indicator status

f. Field data sheets (Appendix B)

Although this method is designed for use by those without access to GIS mapping software, use of a computer mapping software package such as ArcView or ArcInfo will greatly facilitate the measurement of some model variables. Although not required, National Wetlands Inventory maps, regional bathymetry charts, and tide tables may also be useful for planning field site visits. See descriptions of individual variables for specific details of variable measurement.

Using the detailed variable descriptions and methods provided in Chapter 4 and Appendix C, measure or estimate values for each variable. Landscape scale variables are best measured in the office using GIS software, while others will require a field site visit.

Data Analysis and Application

Once measures have been obtained for all variables, assign a subindex value to each variable using the figures and tables in Chapter 4 and Appendix C. Using the appropriate mathematical formula for each functional assessment model, calculate a FCI for each function. Like the subindex values for each individual variable, the FCI value will range between 0 and 1. Multiply the FCI for each function by the total size of the WAA to calculate the number of Functional Capacity Units (FCUs) for each function (Smith et al. 1995).

To evaluate project-related impacts, at least two assessments will generally be needed. The first assessment results in the number of FCUs provided by the site in its preproject condition. The second assesses the number of FCUs provided by the site in a postproject state, based on proposed project plans and the associated changes to each of the model variables. The difference between the preproject and postproject conditions, expressed in numbers of FCUs, represents the potential loss of functional capacity due to project impacts. Similarly, in a mitigation scenario, the difference between current condition and final condition with mitigation actions implemented and successfully completed, represents the potential gain in functional capacity as a result of restoration activities. However, since the mitigation project is unlikely to become fully functional immediately upon completion, a time lag must be used to account for the time necessary for the mitigation site to achieve full development.

For more detailed information on calculation of FCUs and their use in project assessments, see Smith et al. (1995). Sample spreadsheets that can be used to help evaluate the impacts of wetland projects and estimate mitigation requirements are available on the web at *http://el.erdc.usace.army.mil/wetlands/datanal.html*. The spreadsheets were developed by Frank Hanrahan based on concepts presented by the U. S. Fish and Wildlife Service (1980) and King and Adler (1992).

References

Adams, D. A., and Quay, T. L. (1958). “Ecology of the clapper rail in southeastern North Carolina,” *Journal of Wildlife Management* 22(2), 149-156.

Adamus, P. R., Clairain, E. J., Jr., Smith, R. D., and Young, R. E. (1991). “Wetland evaluation technique (WET),” Technical Report WRP-DE-01, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Anderson, C. M., and Treshow, M. (1980). “A review of environmental and genetic factors that affect height in *Spartina alterniflora* Loisel. (salt marsh cord grass),” *Estuaries* 3(3), 168-176.

Aurand, D., and Daiber, F. C. (1973). “Nitrate and nitrite in the surface waters of two Delaware salt marshes,” *Chesapeake Science* 14, 105-111.

Baltz, D. M., Rakocinski, C., and Fleeger, J. W. (1993). “Microhabitat use by marsh-edge fishes in a Louisiana estuary,” *Environmental Biology of Fishes* 36, 109-126.

Bent, A. C. (1948). “Life histories of North American nuthatches, wrens, thrashers, and their allies,” *U.S. Nat. Mus. Bull.* 195, Washington, DC, 475 pp. [Reprinted by Dover Publ., Inc., New York, 1964].

Bolen, E. G., and Robinson, W. L. (2003). *Wildlife ecology and management*. 5th ed., Prentice Hall, Pearson Education, Inc., Upper Saddle River, NJ, 634 pp.

Brinson, M. M. (1993). “A hydrogeomorphic classification for wetlands,” Technical Report WRP-DE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brinson, M. M. (1995). “The HGM approach explained,” *National Wetlands Newsletter* 17, 7-13.

Brinson, M. M. (1996). “Assessing wetland functions using HGM,” *National Wetlands Newsletter* 18, 10-15.

Broome, S. W., Woodhouse, W. W., and Seneca, E. D. (1975). "The relationship of mineral nutrients to growth of *Spartina alterniflora* in North Carolina, I. Nutrient status of plants and soils in natural stands," *Proceedings, Soil Science Society of America* 39, 295-301.

Chapman, V. J. (1960). *Salt marshes and salt deserts of the world.* Interscience, New York, 392 pp.

Childers, D. L., Cofer-Shabica, S., and Nakashima, L. (1993). "Spatial and temporal variability in marsh-water column interactions in a southeastern USA salt marsh estuary," *Marine Ecology Progress Series* 95, 25-38.

Christmas, Y. J. (1973). "Cooperative Gulf of Mexico estuarine inventory and study, Mississippi. Phase I: Area description," Y. J. Christmas, ed., Gulf Coast Research Laboratory, Ocean Springs, MS.

Clewell, A. F. (1997). "Vegetation." *Ecology and management of tidal marshes: A model from the Gulf of Mexico.* C. L. Coultas and Y-P. Hsieh, ed., St. Lucie Press, Delray Beach, FL, 77-109.

Coastal Wetlands Planning, Protection, and Restoration Act Environmental Work Group. (1998). *Wetland value assessment methodology and community models* (draft). U.S. Fish and Wildlife Service, Lafayette, LA.

Cole, W. A., and Dent, J. H., Jr. (1964). "Soil survey of Jackson County, Mississippi." U.S. Department of Agriculture Soil Conservation Service, Washington, DC.

Conway, C. J. (2004). "Standardized North American marsh bird monitoring protocols," Wildlife Research Report 2004-07, U.S. Geological Survey, Arizona Cooperative Fish and Wildlife Research Unit, Tucson, AZ.

Conway, C. J., Eddleman, W. R., Anderson, S. H., and Hanebury, L. R. (1993). "Seasonal changes in Yuma clapper rail vocalization rate and habitat use," *Journal of Wildlife Management* 56, 282-290.

Cowardin, L. M., Carter, V., Golet, F., and LaRoe, E. (1979). "Classification of wetlands and deepwater habitats of the United States," Office of Biological Services Report FWS/OBS-79/31, U.S. Fish and Wildlife Service, Washington, DC.

Davis, L. V., and Gray, I. E. (1966). "Zonal and seasonal distributions of insects in North Carolina salt marshes," *Ecological Monographs* 36, 275-295.

Deegan, L. A. (2002). "Lessons learned: The effects of nutrient enrichment on the support of nekton by seagrass and slat marsh ecosystems," *Estuaries* 25, 727-742.

DeLaune, R. D., and Pezeshki, S. R. (1988). "Relationships of mineral nutrients to growth of *Spartina alterniflora* in Louisiana salt marshes," *Northeast Gulf Science* 10, 55-60.

Eddleman, W. R. (1989). “Biology of the Yuma clapper rail in the southwestern United States and northwestern Mexico,” Final Report, Intra-agency Agreement 4-AA-30-02060, U.S. Bureau of Reclamation, Yuma Project Office, Yuma, AZ, 127 pp.

Eddleman, W. R., and Conway, C. J. (1995). “Clapper rail.” *Migratory shore and upland game bird management in North America.* T. C. Tacha and C. E. Braun, ed., The International Association of Fish and Wildlife Agencies in cooperation with the Fish and Wildlife Service, Allen Press, Lawrence, Kansas, 167-179.

Eleuterius, L. N. (1972). “The marshes of Mississippi,” *Castanea* 37, 153-168.

Eleuterius, L. N. (1973). “The marshes of Mississippi,” *Cooperative Gulf of Mexico inventory and study, Mississippi.* J. Y. Christmas, ed., Gulf Coast Research Laboratory, Ocean Springs, MS, 147-190.

Eleuterius, L. N., and Caldwell, J. D. (1981). “Growth kinetics and longevity of the salt marsh rush *Juncus roemerianus*,” *Gulf Research Reports* 7(1), 27-34.

Emlen, J. T. (1971). “Population densities of birds derived from transect counts,” *Auk* 88, 323-342.

Fearn, M. L., Haywick, D. W., and Sanders, J. M. (2005). “Changes in water conditions and sedimentation rates associated with construction of the Mobile Bay Causeway.” *http://www.southalabama.edu/geography/fearn/Causeway.htm*

Fonseca, M. S., and Bell, S. S. (1998). “Influence of physical setting on seagrass landscapes near Beaufort, North Carolina, USA,” *Marine Ecology Progress Series* 171, 109-121.

Fulling, G. L., Peterson, M. S., and Crego, G. J. (1999). “Comparison of Breder traps and seines used to sample marsh nekton,” *Estuaries* 22(2A), 224-230.

Golet, F. C., and Larson, J. S. (1974). “Classification of freshwater wetlands in the glaciated Northeast,” U.S. Fish and Wildlife Service Resources Publication 116, Washington, DC.

Graul, W. D., Torres, J., and Denney, R. (1976). “A species-ecosystem approach for nongame programs,” *Wildlife Society Bulletin* 4, 79-80.

Greeley, M. S., Jr. (1984). “Spawning by *Fundulus pulverus* and *Adinia xenica* (Cyprinodontidae) along the Alabama Gulf coast is associated with the semilunar tidal cycle,” *Copeia* 1984, 797-800.

Greeley, M. S., Jr., and MacGregor, R., III. (1983). “Annual and semilunar reproductive cycles of the Gulf killifish, *Fundulus grandis*, on the Alabama Gulf coast,” *Copeia*, 711-718.

Greeley, M. S., Jr., Marion, K. R., and MacGregor, R. III. (1986). "Semilunar spawning cycles of *Fundulus similis* (Cyprinodontidae)," *Environmental Biology of Fishes* 17(2), 125-131.

Greeley, M. S., Jr., MacGregor, R., and Marion, K. R. (1988). "Changes in the ovary of the Gulf killifish, *Fundulus grandis* (Baird and Girard), during seasonal and semilunar spawning," *Journal of Fish Biology* 33, 97-107.

Gutzwiller, K. J., and Anderson, S. H. (1987). "Habitat suitability index models: Marsh wren," U.S. Fish Wildl. Serv. Biol. Rep. 82(10.139), 13 pp.

Hackney, C. T., and De la Cruz, A. A. (1979). "Patterns of suspended particle transport in a Mississippi tidal marsh system," *Gulf Research Reports* 6, 217-224.

Harper, H. H. (1998). "Stormwater chemistry and water quality," *http://www.stormwaterauthority.org/assets/47chemistry.pdf*

Hendon, J. R., Peterson, M. S., and Comyns, B. H. (2000). "Spatio-temporal distribution of larval *Gobiosoma bosc* in waters adjacent to natural and altered marsh-edge habitats of Mississippi coastal waters," *Bulletin of Marine Science* 66(1), 143-156.

Hickman, G. L., and Owens, C. (1980). "Soil survey of Mobile County, Alabama," U.S. Department of Agriculture, Soil Conservation Service, Washington, DC.

Hon, T., Odum, R. R., and Belcher, D. P. (1977). "Results of Georgia's clapper rail banding program," *Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies* 31, 72-76.

Howe, J. C., and Wallace, R. K. (2000). "Relative abundance of postlarval and juvenile peneaid shrimps in submerged aquatic vegetation and emergent marsh habitats," *Gulf of Mexico Science* 2000(2), 130-137.

Howe, J. C., Wallace, R. K., and Rikard, F. S. (1999). "Habitat utilization by postlarval and juvenile penaeid shrimps in Mobile Bay, Alabama," *Estuaries* 22(4), 871-979.

Hubbard, M. D., and Gidden, C. S. (1997). "Terrestrial vertebrates of Florida's Gulf Coast tidal marshes." *Ecology and management of tidal marshes: A model from the Gulf of Mexico.* C. L. Coultas and Y-P Hsieh, ed., St. Lucie Press, Delray Beach, FL, 331-338.

Isphording, W. C., Perry, H. M., Trigg, C. B., and Larsen, K. (2000). "Environmental assessment of the Mississippi-Alabama coastal zone," *Geological Society of America* 32(7), 56.

Kale, H. W., II. (1965). "Ecology and bioenergetics of the long-billed marsh wren *Telmatodytes palustris griseus* (Brewster) in Georgia salt marshes," *Publications of the Nuttall Ornithological Club* No. 5, 142 pp.

Kale, H. W., II. (1983). “Distribution, habitat, and status of breeding seaside sparrows in Florida.” *The seaside sparrow: Its biology and management; Occasional Papers of the North Carolina Biological Survey*. T. L. Quay, J. B. Funderburg, Jr., D. S. Lee, E. F. Potter, and C. S. Robbins, ed., Raleigh, NC, 41-48.

Keddy, P. A. (1982). “Quantifying within-lake gradients of wave energy: Interrelationships of wave energy, substrate particle size, and shoreline plants in Axe Lake, Ontario,” *Aquatic Botany* 14, 41-58.

King, D. M., and Adler, K. J. (1992). “Scientifically defensible compensation ratios for wetland mitigation.” *Effective mitigation: Mitigation banks and joint projects in the context of wetland management plans*. Association of State Wetland Managers, 64-73.

Kneib, R. T. (1997). “The role of tidal marshes in the ecology of estuarine nekton,” *Oceanography and Marine Biology Annual Review* 35, 163-220.

Kneib, R. T., and Wagner, S. L. (1994). “Nekton use of vegetated marsh habitats at different stages of tidal inundation,” *Marine Ecology Progress Series* 106, 227-238.

Knutson, P. L., and Inskeep, M. R. (1982). “Shore erosion control with salt marsh vegetation,” Coastal Engineering Technical Aid No. 82-3, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Knutson, P. L., and Woodhouse, W. W., Jr. (1983). “Shore stabilization with salt marsh vegetation,” Special Report No. 9, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Knutson, P. L., Allen, H. H., and Webb, J. W. (1990). “Guidelines for vegetative erosion control on wave-impacted coastal dredged material sites,” Technical Report D-90-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Knutson, P. L., Ford, J. C., and Inskeep, M. R. (1981). “National survey of planted salt marshes,” *Wetland Restoration* 1, 129-157.

Knutson, P. L., Brochu, R. A., Seelig, W. N., and Inskeep, M. (1982). “Wave damping in *Spartina alterniflora* marshes,” *Wetlands* 2, 87-104.

Kozicky, E. L., and Schmidt, F. V. (1949). “Nesting habits of the clapper rail in New Jersey,” *Auk* 66, 355-364.

Kroodsma, D. E., and Verner, J. (1997). “Marsh Wren (*Cistothorus palustris*).” *The Birds of North America*, No. 308, A. Poole and F. Gill, ed., The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists’ Union, Washington, DC.

Kruczynski, W. L., Subrahmanyam, C. B., and Drake, S. H. (1978). “Studies on the plant community of a North Florida salt marsh. Part I. Primary production,” *Bulletin of Marine Science* 28(2), 316-334.

Leonard, M. L., and Picman, J. (1987). “Nesting mortality and habitat selection by marsh wrens,” *Auk* 104, 491-495.

Lewis, J. C., and Garrison, R. L. (1983). “Habitat suitability index models: Clapper rail,” FWS/OBS-82/10.51, U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC, 15 pp.

Lin, J. P. (2004). “Review of published export coefficient and event mean concentration (EMC) data,” ERDC TN-WRAP-04-3, U.S. Army Engineer Research and Development Center, Vicksburg, MS, 15 pp.

Marks, M., Lapin, B., and Randall, J. (1994). “*Phragmites australis* (*P. communis*): Threats, management, and monitoring.” *Natural Areas Journal* 14, 285-294.

McBride, E. H., and Burgess, L. H. (1964). “Soil survey of Baldwin County, Alabama,” Series 1960, No. 12, U.S. Department of Agriculture Soil Conservation Service, U.S. Government Printing Office, Washington, DC. *http://soils.usda.gov/survey/online_surveys/alabama/baldwin/Baldwin.pdf*

McPherson, A. K., Moreland, R. S., and Atkins, J. B. (2003). “Occurrence and distribution of nutrients, suspended sediment, and pesticides in the Mobile River Basin, Alabama, Georgia, Mississippi, and Tennessee, 1999-2001,” Water Resources Investigations Report 03-4203, U.S. Geological Survey, Montgomery, Alabama. *http://pubs.usgs.gov/wri/wri034203/pdf/report.pdf*

Meanley, B. (1985). *The marsh hen: A natural history of the clapper rail of the Atlantic coast salt marsh*. Tidewater Publishers, Centreville, MD, 123 pp.

Miller, C. D. (1988). “Predicting the impact of vegetation on storm surges.” *Proceedings National Wetland Symposium - Wetland Hydrology*, Chicago, IL, September 16-18, 1987, Association of State Wetland Managers, Inc., Berne, NY, 113-121.

Mississippi Department of Wildlife, Fisheries, and Parks. (2005). Mississippi’s Comprehensive Wildlife Conservation Strategy. Jackson, MS.

Mitsch, W. J., and Gosselink, J. G. (1993). *Wetlands*. 2nd ed., Van Nostrand Reinhold, New York.

Mitsch, W. J., and Gosselink, J. G. (2000). *Wetlands.* John Wiley, New York, 920 pp.

Mueller-Dombois, D., and Ellenberg, H. (1974). *Aims and methods of vegetation ecology*. John Wiley, New York, 547 pp.

National Implementation Team. (1996). “National action plan to develop the hydrogeomorphic approach for assessing wetland functions,” *Federal Register* Vol. 61, No. 160, August 16, 1996.

Odum, E. P. (1974). “Halophytes, energetics, and ecosystems.” *Ecology of Halophytes*. R. J. Reimold and W. H. Green, ed., Academic Press, New York, 599-602.

Odum, W. E., and Heywood, M. A. (1978). “Decomposition of intertidal freshwater marsh plants.” *Freshwater wetlands: Ecological processes and management potential*, R. E. Good, D. F. Whigham, and R. L. Simpson, ed., Academic Press, New York, 89-97.

Oney, J. (1954). *Final report, clapper rail survey and investigations study*. Georgia Game Fish Commission, Atlanta, 50 pp.

Osgood, D. T., and Zieman, J. C. (1993). “Spatial and temporal patterns of substrate physico-chemical parameters in different-aged barrier island marshes,” *Estuarine, Coastal and Shelf Science* 37, 421-436.

Otvos, E. G. (1976). “Mississippi offshore inventory and geological mapping project (1975/76),” Report prepared for Mississippi Marine Resource Council, Coastal Zone Management Program, Gulf Coast Research Laboratory, Ocean Springs, 27 pp.

Otvos, E. G. (1985). *Guidebook, Coastal evolution - Louisiana to northwest Florida.* American Association of Petroleum Geologists Annual Meeting, New Orleans, The New Orleans Geological Society.

Pennings, S. C., Stanton, L. E., and Brewer, J. S. (2002). “Nutrient effects on the composition of salt marsh plant communities along the Southern Atlantic and Gulf coasts of the United States,” *Estuaries* 25, 1164-1173.

Peterson, G. W., and Turner, R. E. (1994). “The value of salt marsh edge vs. interior as a habitat for fish and decapod crustaceans in a Louisiana salt marsh,” *Estuaries* 17, 235-262.

Peterson, M. S., Fulling, G. L., and Woodley, C. M. (2003). “Status and habitat characteristics of the saltmarsh topminnow, *Fundulus jenkinsi* (Everman) in eastern Mississippi and western Alabama coastal bayous,” *Gulf and Caribbean Research* 15, 51-59.

Pihl, L. (1986). “Exposure, vegetation and sediment as primary factors for mobile epibenthic faunal community structure and production in shallow marine soft bottom areas,” *Netherlands Journal of Sea Research* 20(1), 75-83.

Post, W. (1974). “Functional analysis of space-related behavior in the seaside sparrow,” *Ecology* 55, 564-575.

Post, W., and Greenlaw, J. S. (1994). “Seaside sparrow (*Ammodramus maritimus*).” *The Birds of North America*, No. 127, A. Poole and F. Gill, ed., The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists’ Union, Washington, DC.

Post, W., Greenlaw, J. S., Merriam, T. L., and Wood, L. A. (1983). “Comparative ecology of northern and southern populations of the seaside sparrow.” *The seaside sparrow: Its biology and management; Occasional Papers of the North Carolina Biological Survey*, T. L. Quay, J. B. Funderburg, Jr., D. S. Lee, E. F. Potter, and C. S. Robbins, ed., Raleigh, NC, 123-136.

Provost, M. W. (1973). “Mean high water mark and use of tidelands in Florida,” *Florida Scientist* 36, 50-66.

Ralph, C. J., Droege, S., and Sauer, J. R. (1995). “Managing and monitoring birds using point counts: Standards and applications.” *Monitoring bird populations by point counts.* General Technical Report PSW-GTR-149, C. J. Ralph, J. R. Sauer, S. Droege, ed., U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station; Albany, CA, 161-175.

Rheinhardt, R. D., Brinson, M. M., and Farley, P. M. (1997). “A preliminary reference data set for wet forested flats in North Carolina and its application to wetland functional assessment, mitigation, and restoration,” *Wetlands* 17, 195-215.

Roberts, T. H. (1991). “Habitat value of man-made coastal marshes in Florida,” Technical Report WRP-RE-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Roman, C. T., Niering, W. A., and Warren, R. S. (1984). “Salt marsh vegetation change in response to tidal restriction,” *Environmental Management* 8, 141-150.

Rotenberry, J. T. (1985). “The role of habitat in avian community composition: Physiognomy or floristics?” *Oecologia* 67, 213-17.

Rozas, L. P. (1995). “Hydroperiod and its influence on nekton use of the salt marsh: A pulsing ecosystem,” *Estuaries* 18, 579-590.

Rozas, L. P., and LaSalle, M. W. (1990). “A comparison of the diets of Gulf killifish, *Fundulus grandis* Baird and Girard, entering and leaving a Mississippi brackish marsh,” *Estuaries* 13, 332-336.

Rozas, L. P., and Reed, D. J. (1993). “Nekton use of marsh-surface habitats in Louisiana (USA) deltaic salt marshes undergoing submergence,” *Marine Ecology Progress Series* 96, 147-157.

Rozas, L. P., McIvor, C. C., and Odum, W. E. (1988). “Intertidal rivulets and creekbanks: Corridors between tidal creeks and marshes,” *Marine Ecology Progress Series* 47, 303-307.

Saltonstall, K. (2002). “Cryptic invasion by a non-native genotype of common reed, *Phragmites australis*, into North America.” *Population Biology* 99, 2445-2449.

Sather, J. H., and Smith, R. D. (1984). “An overview of major wetland functions and values,” FWS/OBS-84/18, U.S. Fish and Wildlife Service, Washington, DC.

Schneider, D. C. (1994). *Quantitative ecology: Spatial and temporal scaling.* Academic Press, New York.

Schroeder, W. W., Dinnel, S. P., and Wiseman, W. J., Jr. (1990). “Salinity stratification in a river-dominated estuary,” *Estuaries* 13(2), 145-154.

Shafer, D. J., and Yozzo, D. J. (1998). “National guidebook for application of hydrogeomorphic assessment to tidal fringe wetlands,” Technical Report WRP-DE-16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Shafer, D. J., Herczeg, B., Moulton, D. W., Sipocz, A., Jaynes, K., Rozas, L. P., Onuf, C. P., and Miller, W. (2002). “Regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of Northwest Gulf of Mexico to tidal fringe wetlands,” Technical Report ERDC/EL TR-02-5, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Sinicrope, T. L., Hine, P. G., Warren, R. S., and Neiring, W. A. (1990). “Restoration of an impounded salt marsh in New England,” *Estuaries* 13, 25-30.

Smith, R. D., Amman, A., Bartoldus, C., and Brinson, M. (1995). “An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices,” Technical Report WRP-DE-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. *http://el.erdc.usace.army.mil/wetlands/pdfs/wrpde9.pdf*

Smith, W. I. (1975). “Soil survey of Harrison County, Mississippi,” U.S. Department of Agriculture Soil Conservation Service, Washington, DC.

Smith, W. I., Nichols, P., Jr., Walton, L. B., and Hale, L. B. (1981). “Soil survey of Hancock County, Mississippi,” U.S. Department of Agriculture, Soil Conservation Service, Washington, DC.

Sorenson, R. M. (1973). “Water waves produced by ships,” *Journal of the Waterways and Harbors Division* 99(WW2), 245-256.

Southern Regional Climate Center. (2005). “Climate synopsis for Mississippi.” *http://www.srcc.lsu.edu/southernClimate/atlas/msdescription*

Spencer, N. R., and Coulson, J. R. (1976). “The biological control of alligatorweed, *Alternanthera philoxeroides,* in the United States of America,” *Aquatic Botany* 2, 177-190.

Stevenson, J. C., Heinle, D. R., Flemer, D. A., Small, R. J., Rowland, R. A., and Ustach, J. F. (1977). "Nutrient exchanges between brackish water marshes and the estuary," *Estuarine Processes.* Vol. 2, M. Wiley, ed., Academic Press, New York.

Stewart, R. E. (1951). "Clapper rail populations of the Middle Atlantic States," *Transactions of the North American Wildlife Conference* 16, 421-430.

Stewart, R. E., and Kantrud, H. A. (1971). "Classification of natural ponds and lakes in the glaciated prairie region," Resource Publication 92, U.S. Fish and Wildlife Service, Washington, DC.

Stout, J. P. (1984). "The ecology of irregularly flooded salt marshes of the north-eastern Gulf of Mexico: A community profile," Biological Report 85(7.1), U.S. Fish and Wildlife Service, 98 pp.

Stout, J. P., and de la Cruz, A. A. (1981). "Marshes of Mississippi Sound: State of the knowledge." *Mississippi Sound Symposium*, June 25-26, 1981, Biloxi, MS, J. R. Kelly, ed., 8-20.

Teal, J. M. (1986). "The ecology of regularly flooded salt marshes of New England: A community profile," Biological Report 85(7.4), U.S. Fish and Wildlife Service, 61 pp.

Thomas, J. W., Miller, R. J., Maser, C., Anderson, R. G., and Carter, B. E. (1979). "Plant communities and successional stages." *Wildlife habitats in managed forests-The Blue Mountains of Oregon and Washington.* Agricultural Handbook No. 553, J. W. Thomas, ed., U.S. Department of Agriculture Forest Service, U.S. Government Printing Office, Washington, DC. 23-29.

Tomlinson, R. E., and Todd, R. L. (1973). "Distribution of two western clapper rail races as determined by responses to taped calls," *Condor* 75, 177-183.

U.S. Army Corps of Engineers. (1954). Bulletin of the U.S. Beach Erosion Board, Washington, DC, 8, 21.

U.S. Department of Agriculture, Natural Resources Conservation Service. (2005). *The PLANTS Database*, Version 3.5 (*http://plants.usda.gov*). Data compiled from various sources by Mark W. Skinner. National Plant Data Center, Baton Rouge, LA.

U.S. Fish and Wildlife Service. (1980). "Habitat evaluation procedures," Ecological Services Manual 102, Washington, DC.

Valiela, I., and Teal, J. M. (1974). "Nutrient limitation in salt marsh vegetation," *Ecology of Halophytes*. R. J. Reimold and W. H. Queen, ed., Academic Press, New York, 547-565.

van der Valk, A. (2002). "Methods for evaluating wetland condition: Land-use characterization for nutrient and sediment risk assessment," EPA-822-R-02-025, U.S. Environmental Protection Agency, Washington, DC, 10 pp.

Verner, J. (1965). "Breeding biology of the long-billed marsh wren," *Evolution* 18(2), 252-261.

Verner, J., and Engelsen, G. H. (1970). "Territories, multiple nest building, and polygyny in the long-billed marsh wren," *Auk* 87, 557-567.

Visser, J. M., Sasser, C. E., Chabreck, R. G., and Linscombe, R. G. (1998). "Marsh vegetation types of the Mississippi River deltaic plain," *Estuaries* 21, 818-828.

Wakeley, J. S. (1987). "Avian plot methods: Section 6.3.3, U.S. Army Corps of Engineers Wildlife Resources Management Manual," Technical Report EL-87-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Wayne, C. J. (1976). "The effects of sea and marsh grass on wave energy," *Coastal Research Notes* 4(7), 6-8.

Webb, J. W. (1982). "Salt marshes of the Western Gulf of Mexico." *Creation and restoration of coastal plant communities.* R. R. Lewis, ed., CRC Press, Inc., Boca Raton, FL, 89-109.

Wiegert, R. G., and Freeman, B. J. (1990). "Tidal salt marshes of the southeast Atlantic coast: A community profile," Biological Report 85(7-29), U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC, 70 pp.

Wieland, R. G. (1994). "Marine and estuarine habitat types and associated ecological communities of the Mississippi coast," Museum Technical Report No. 25, Mississippi Department of Wildlife, Fisheries, and Parks, Jackson, MS.

Wilson, M. F. (1974). "Avian community organization and habitat structure," *Ecology* 55, 1017-29.

Wolaver, T. G., Zieman, J. C., Wetzel, R. L., and Webb, K. L. (1983). "Tidal exchange of nitrogen and phosphorus between a mesohaline vegetated marsh and the surrounding estuary in the lower Chesapeake Bay," *Estuarine, Coastal and Shelf Science* 16, 321-332.

Zapfe, G. A. (2002). "Effects of marsh access on the feeding success and growth of juvenile spot, *Leiostomus xanthurus,*" M.S. Thesis, University of Southern Mississippi, Hattiesburg.

Appendix A
Assessment Development Team

Leah Bray
Mississippi Department of Marine Resources
1141 Bayview Avenue, Suite 101
Biloxi, MS 39530
Phone: 228-374-5000
E-mail: *Leah.bray@DMR.state.ms.us*

Ben Bloodworth
Utah Department of Natural Resources
Division of Forestry, Fire, and State Lands
1594 West North Temple, Suite 3520
Box 145703
Salt Lake City, Utah 84114-5703
Phone: 801-537-3371
E-mail: *benbloodworth@utah.gov*

Shawn Clark
Mississippi Department of Environmental Quality, Office of Pollution Control
Post Office Box 10385
Jackson, Mississippi 39289-0385
Phone: 601-961-5629
E-mail: *Shawn_Clark@deq.state.ms.us*

Patric Harper
U.S. Fish and Wildlife Service
Post Office Drawer 1190
Daphne, Alabama 36526
Phone: 251-441-5857
E-mail: *Patric_Harper@fws.gov*

Darren LeBlanc
U.S. Fish and Wildlife Service
Post Office Drawer 1190
Daphne, Alabama 36526
Phone: 251-441-5859
E-mail: *Darren_LeBlanc@fws.gov*

Michael B. Moxey
U.S. Army Corps of Engineers
Mobile District Office, Regulatory
Post Office Box 2288
Mobile, Alabama 36628-0001
Phone: 251-694-3771
E-mail: *Michael.B.Moxey@sam.usace.army.mil*

Mark S. Peterson
The University of Southern Mississippi
Department of Coastal Sciences
703 East Beach Drive
Ocean Springs, MS 39564
Phone: 228-872-4203
E-mail: *Mark_Peterson@usm.edu*

Keil Schmid
Mississippi Dept. of Environmental Quality, Office of Pollution Control
Post Office Box 10385
Jackson, Mississippi 39289-0385
Phone: 601-961-5651
E-mail: *Keil_Schmid@deq.state.ms.us*

Randy Shaneyfelt
Alabama Department of Environmental Management
Coastal Programs Office, 2204 Perimeter Road
Mobile, Alabama 36615-1131
Phone: 251-432-6533
E-mail: *RCS@adem.state.al.us*

Leslie Turney
Alabama Department of Environmental Management Coastal Programs Office
2204 Perimeter Road
Mobile, Alabama 36615-1131
Telephone: 251-432-6533
E-mail: *LET@adem.state.al.us*

Appendix B
Field Data Forms

Assessment Team:
Project: ____
Date: ____________
Size of the Wetland Assessment Area (WAA): _________ **(ha)**

Sample variables 1-5 using aerial photos, digital ortho-photo quadrangle imagery, etc., at a scale of (1:4800) (1 inch = 400 feet) (color infrared or true color preferred), using GIS or other means.

1. **V_{SIZE}** **Wetland Patch Size (ha)** _________
   Calculate the area (in hectares) of the contiguous tidal fringe wetland within which the WAA is located. In some situations, the WAA may encompass the entire wetland patch and the WAA size and wetland patch size will be equal.

2. **$V_{LANDUSE}$** **Adjacent land use**
   Determine the proportion of the WAA perimeter (expressed as a percentage, rounded to the nearest 5 percent) that is bounded by each of the following land use types.

Land Use Category	**Description**	**Proportion of WAA Perimeter**
Undeveloped naturally vegetated areas or open water	a) Open water: Shoreline is at least 100 m from navigation channel, if present. b) Terrestrial: > 75% of total area is naturally vegetated forested or grassy uplands or wetlands.	
Mostly agricultural	More than 50% of the total area is occupied by cropland.	
Mostly developed	a) Open water: Harbors, ports, and marinas b) Terrestrial: More than 40% of the total area is developed (i.e., residential, commercial, or industrial areas; also includes point sources such as golf courses, wastewater treatment plant outfalls, feedlots, etc.)	
Mixed	a) Open water: areas where the shoreline is within 100 m of a navigation channel. b) Terrestrial: Does not fit any of the above categories, may include low-density rural residential, unpaved roads, etc.	

3. **V_{WIDTH}** **Mean Marsh Width** _________ **(m)**
   Establish the appropriate number of transects according to the baseline length and record the length of each transect (in meters) in the boxes below, then calculate the average.

T1	T2	T3	T4	T5
T6	T7	T8	T9	T10

Assessment Team:
Project: ____
Date: ____________

4. **V_{EXPOSE}** **Wave Energy Exposure**
Circle the exposure condition that most closely corresponds to the site condition described in the table below.
Note: Sites with no exposed shorelines are not assessed for this function.

Site Description	Exposure
Geomorphic Setting: Low-Energy Interior Marsh These sites have one or more shorelines located along the edges of protected coves or embayments (concave shoreline) OR along the edge of a small tidal creek not used by commercial boat traffic.	Low
Geomorphic Setting: Moderate-Energy Interior Marsh These sites have one or more shorelines located along the edges of large tidal creeks or rivers that are used by recreational and/or commercial boat traffic.	Moderate
Geomorphic Setting: Open Bay or Estuary These sites have one or more shorelines located directly along the edges of an estuary or bay (e.g., Mississippi Sound, Mobile Bay). Shoreline is generally linear, exposed to relatively high wind and wave energy, with long fetch distances, or adjacent to navigation channel that is frequently used by recreational or commercial boat traffic.	High
Geomorphic Setting: Zero-Energy Interior Marsh These sites have no shorelines exposed to wind or wave energy present .	None

5. **V_{EDGE}** **Aquatic Edge**
Circle the qualitative or quantitative measure that most closely corresponds to the site condition described in the table below. See pictorial key in Appendix E (Figures E1-E11) for specific examples. *Note: Unvegetated shorelines (i.e. sandy beaches) are not included as edge.*

Site Description	Qualitative Measure	Quantitative Measure
1) Well-developed tidal drainage network present (Figures E-1 and E-2). OR 2) Very narrow fringe marsh that lacks tidal creeks. One lengthwise shoreline that represents at least 40% of the total perimeter is exposed to tidal waters (e.g., Daphne Bayfront Park). 3) Other geomorphic configuration with a large amount of shoreline relative to total area (i.e., small island or narrow peninsula) (Figures E-3 and E-4).	High	$\geq$ 225 m/ha
Simple tidal drainage network (may consist of one or more small channels) that are well-distributed across the total WAA area (Figures E-5 and E-6).	Moderate-High	175-224 m/ha
Tidal creeks may be lacking, or if present, drain only a small proportion of the total WAA area (Figures E-7, E-8, and E-9).	Moderate-Low	100-175 m/ha
Shoreline is generally linear or smooth curvilinear without embayments or convolutions. Tidal creeks typically absent. The area of marsh is large relative to shoreline length (Figure E-10).	Low	1-100 m/ha
No vegetated marsh-water interface present in WAA (Figure E-11).	Absent	0 m/ha

Assessment Team:
Project: ____
Date: _____________

Sample variables 6-8 based on a walking reconnaissance of the WAA.

6. **V_{HYDRO}** **Hydrologic regime**

Place a check in the box that most closely fits site conditions.

Site Description	**V_{HYDRO}**
Site is open to free exchange of tidal waters. Lower edges of vegetated marsh surface are flooded on a regular basis as evidenced by wrack lines, watermarks, etc. No obvious hydrologic alteration, fill, or restrictions present.	
Minor hydrologic alteration or restriction present (i.e., presence of low-elevation berm, which is frequently overtopped by high-tide events or has multiple breaches or large culverts; presence of some fill that raises a small portion (<20 percent of marsh area) of marsh surface above normal tidal flooding zone).	
Moderate hydrologic alteration present (i.e., presence of high-elevation berm, which is infrequently overtopped by high-tide events or has a single opening, breach, or small culvert; greater extent of fill (>20 percent) that raises portions of marsh surface elevation above normal tidal flooding zone).	
Severe hydrologic alteration; site receives tidal floodwaters only during extreme tide events (i.e., surface elevation of marsh is above normal tidal flooding zone; blocked culvert, etc.).	
Site is isolated from tidal exchange. The principal source of flooding is water sources other than tidal action (i.e., precipitation or groundwater). *Note: If this condition exists, use of another wetland assessment model should be strongly considered unless the site was a tidal wetland prior to hydrologic modification.*	

7. **V_{NHD}** **Nekton Habitat Diversity**

Check the habitats present within the WAA	
Low marsh (daily tidal flooding)	
High marsh (irregular tidal flooding)	
Subtidal channels	
Intertidal channels (exposed at low tide)	
Shallow (< 1 m) sand or mud flats	
Ponds or depressions (temporary or permanent)	
Check the habitats present within 30 m of WAA perimeter	
Submerged aquatic vegetation	
Oyster reef	
Total number of nekton habitat types present	

Assessment Team:
Project: ____
Date: _____________

8. **V_{WHD}** **Wildlife Habitat Diversity**
Check the habitats present within the WAA or adjacent to the WAA perimeter.

Wildlife Habitat Type	**Check if present**
Large patches of tall, robust herbaceous vegetation within the WAA that is at least irregularly flooded (*S. alterniflora, J. roemerianus, Typha* spp., *Schoenoplectus* spp.) Does tall robust herbaceous vegetation occupy at least 50 percent of the total WAA area? ____ YES _____ NO If tall robust herbaceous vegetation occurs in a narrow fringe, is this fringe greater than 10 m wide? ____ YES _____ NO	
Short herbaceous vegetation within the WAA that is infrequently flooded (*S. patens, Distichlis spicata, Borrichia frutescens, Batis maritima*)	
Intertidal creeks and mudflats within the WAA that are exposed at low tide	
Naturally vegetated upland buffer adjacent to WAA with a minimum width of 30 m (forested, shrub-scrub, or dense herbaceous)	

Assessment Team: ____
Project: ____
Date: ___________

Plant Community Field Data Sheet Page 1
Record the BB cover class midpoint () for each species.
Braun-Blanquet Cover Indices: 1 = 1-5% (2.5%); 2 = 6-25% (15.5%); 3 = 26-50% (37.5); 4 = 51-75% (67.5%); 5 = >75% (87.5%)

Herbaceous Wetland Species	**Plot 1**	**Plot 2**	**Plot 3**	**Plot 4**	**Plot 5**	**Plot 6**	**Plot 7**	**Plot 8**	**Plot 9**	**Plot 10**
I. Tall, Robust Species[1]										
Spartina alterniflora										
Spartina cynosuroides										
Juncus roemerianus										
Schoenoplectus americanus										
Schoenoplectus robustus										
Cladium jamaicense										
Typha angustifolia										
Zizaniopsis miliacea										
Phragmites australis										
[1]*Height (cm) for each plot*										
II. Low-Growing Species										
Batis maritima										
Crinum americanum										
Distichlis spicata										
Eleocharis spp										
Ipomoea sagittata										
Pontederia cordata										
Sagittaria spp.										
Spartina patens										
Salicornia spp.										
Symphyotrichum tenuifolium										
Total Cover by Plot										
[2]*Height (cm) for each plot*										

[1]Height is only measured for Group I species, if present.
[2]Height is measured for species in Group II only if none of the species in Group I is present onsite.

Assessment Team: ____
Project: ____
Date: _____________

Plant Community Field Data Sheet Page 2 Record the BB cover class midpoint () for each species. Braun-Blanquet Cover Indices: 1 = 1-5% (2.5%); 2 = 6-25% (15.5%); 3 = 26-50% (37.5); 4 = 51-75% (67.5%); 5 = >75% (87.5%)										
Woody Species	**Plot 1**	**Plot 2**	**Plot 3**	**Plot 4**	**Plot 5**	**Plot 6**	**Plot 7**	**Plot 8**	**Plot 9**	**Plot 10**
Acer rubrum										
Baccharis halimifolia										
Ilex vomitoria										
Ilex decidua										
Morella cerifera										
Iva frutescens										
Nyssa spp.										
Taxodium distichum										
Estimate Proportion of Entire Site Occupied by Woody Vegetation										
FAC/FACU Species										
Baccharis halimifolia										
Ilex vomitoria										
Morella cerifera										
Panicum virgatum										
Total FAC Cover by Plot OR										
Estimate Proportion of Entire Site Occupied by FAC/FACU Species (Use whichever method results in the highest value for percent cover)										
Exotic or Invasive Species										
Alternanthera philoxeroides										
Phragmites australis										
Cuscuta spp.										
Imperata cylindrica										
Panicum repens										
Triadica sebifera										
Typha latifolia										
Total Exotic Cover by Plot OR										
Estimate Proportion of Entire Site Occupied by Exotics (Use whichever method results in the highest value for percent cover)										

Appendix C
Summaries of Functions and Variables

Definitions, Functions, and Variables for North-Central Gulf of Mexico Tidal Fringe Marshes

Function 1: Wave Energy Attenuation

a. *Definition*. This function assesses the ability of a wetland to attenuate wind- and vessel-generated wave energy. A quantitative unit of measure of this function would be reduction in mean wave height per meter of marsh surface.

b. *Model variables-symbols-measures-units.*

(1) Mean Marsh Width - V_{WIDTH} - the distance that wind- and vessel-generated waves must travel across intervening tidal fringe wetland surface (distance from the shoreline) - meters.

(2) Wave Energy Exposure - V_{EXPOSE} - a qualitative classification of the opportunity to perform this function based on the geomorphic setting and fetch distance - unitless.

(3) Mean Percentage Cover Emergent Marsh Vegetation - V_{COVER} - the mean total percentage cover of native nonwoody marsh species - ratio. For the purposes of variable measurement, marsh species are those with a wetland indicator status of OBL or FACW.

c. *Assessment model*: $FCI = \left[\left(\frac{3 \times V_{WIDTH} + V_{COVER}}{4}\right) \times V_{EXPOSE}\right]^{1/2}$

Function 2: Biogeochemical Cycling

a. *Definition*. This function describes the ability of a tidal wetland to receive, transform, and export various elements and compounds through natural biogeochemical processes. A quantitative measure of this function is mass of elements or compounds, both dissolved and particulate, transformed per unit area per unit time ($g/m^2/year$).

b. *Model variables-symbols-measures-units*.

(1) Hydrologic Regime - V_{HYDRO} - evaluation of this variable is based on the degree of hydrologic alteration present - unitless. This variable is assigned a default value of 1.0 if no hydrologic alteration exists and the site is open to free exchange of tidal waters.

(2) Mean Percent Cover Emergent Marsh Vegetation - V_{COVER} - the mean total percentage cover of native non-woody marsh species - ratio. For the purposes of variable measurement, marsh species are those that have a wetland indicator status of OBL or FACW.

(3) Surrounding land use - $V_{LANDUSE}$ - estimates the potential for biogeochemical cycling functions to be impaired due to inputs of nutrients, metals, petroleum products, and other pollutants via stormwater runoff from adjacent land uses, based on the proportion of the wetland perimeter occupied by various land use types - unitless.

c. *Assessment model*: $FCI = \left(V_{HYDRO} \times V_{COVER} \times V_{LANDUSE}\right)^{1/3}$

Function 3: Nekton Utilization

a. *Definition*. This function describes the potential utilization of a marsh by resident and seasonally occurring nonresident adult or juvenile fish and macrocrustacean species. A quantitative measure of this function would be abundance (or biomass) of resident nekton per square meter.

b. *Model variables-symbols-measures-units*.

(1) Aquatic Edge - V_{EDGE} - the length of vegetated tidally connected marsh/water interface or edge expressed as a proportion of total WAA area – m/ha.

(2) Hydrologic Regime - V_{HYDRO} - evaluation of this variable is based on the degree of hydrologic alteration present - unitless. This variable is assigned a default value of 1.0 if no hydrologic alteration exists and the site is open to free exchange of tidal waters.

(3) Nekton Habitat Diversity - V_{NHD} – a measure of the heterogeneity of a site, based on comparison of the number of habitats actually

present at a site relative to the number of possible habitats known to occur in the appropriate regional subclass - ratio.

c. *Assessment model*: $FCI = \left(\frac{V_{EDGE} + V_{HYDRO} + V_{NHD}}{3} \right)$

Function 4: Provide Habitat for Tidal Marsh-Dependent Wildlife

a. *Definition*. This function is defined as the capacity of a coastal fringe marsh to provide critical life requisites to selected components of the vertebrate wildlife community.

b. *Model variables-symbols-measures-units*.

(1) Wetland Patch Size -V_{SIZE} - size of the contiguous tidal fringe wetland patch within which the WAA occurs – ha.

(2) Vegetation Height -V_{HEIGHT} – the most frequently occurring height of the plants within the tallest zone of the emergent marsh plant community - cm.

(3) Total percentage vegetative cover of emergent wetland species - V_{COVER} - the mean total percentage cover of native non-woody emergent marsh species - percent.

(4) Aquatic Edge - V_{EDGE} - the length of vegetated tidally connected marsh/water interface or edge expressed as a proportion of total WAA area – m/ha.

(5) Wildlife Habitat Diversity – V_{WHD} – a measure of the heterogeneity of a site, based on the known habitat requirements of the selected marsh dependent wildlife species - unitless.

c. *Assessment model*:

$$FCI = \left\{ V_{SIZE} \times \left[\frac{\left(V_{HEIGHT} + V_{COVER} \right)}{2} \right] \times \left[\frac{\left(V_{EDGE} + V_{WHD} \right)}{2} \right] \right\}^{1/3}$$

Function 5: Maintain Characteristic Plant Community Structure and Composition

a. *Definition*. The ability of a wetland to support a native plant community of characteristic species composition and structure.

b. *Model variables-symbols-measures-units*.

(1) Mean Percentage Cover Emergent Marsh Vegetation - V_{COVER} - the mean total percentage cover of native nonwoody marsh species -

ratio. For the purposes of variable measurement, marsh species are those with a wetland indicator status of OBL or FACW.

(2) Percentage cover by invasive or exotic species - V_{EXOTIC} - the proportion of the site that is occupied by non-native or invasive species - ratio.

(3) Wetland plant indicator status -V_{WIS} - the proportion of the site that is occupied by nonwetland (FAC and FACU) plant species.

(4) Percentage cover by woody plant species -V_{WOODY} - the proportion of the site that is occupied by shrub-scrub and other woody species- ratio.

c. Assessment model:

$$FCI = \left[\text{Minimum} \left(V_{COVER} \text{ or } V_{EXOTIC} \text{ or } V_{WIS} \text{ or } V_{WOODY} \right) \right]$$

Summary of Model Variables: Measure/Units, Methods, and Scaling

Landscape Scale Variables

1. **Wetland Patch Size (V_{SIZE})**

Measure/units: Size of the contiguous wetland patch within which the WAA occurs - ha.

Method:
(a) Using aerial photography, GIS tools, or other means, delineate the boundaries of the contiguous tidal fringe wetland within which the WAA is located.
(b) Using GIS or other means, calculate the area (in hectares) within these boundaries. In some situations, the WAA may encompass the entire wetland patch and the WAA size and wetland patch size will be equal.
(c) Assign a variable subindex value for V_{SIZE} according to Table C-1.

Table C-1
Relationship Between Wetland Patch Size and Functional Capacity

Wetland Patch Size, ha	Variable Subindex
< 0.04	0.1
0.04-0.2	0.25
0.21-0.5	0.50
0.51 - 2	0.75
> 2	1.0

2. **Adjacent Land Use (*$V_{LANDUSE}$*)**

Measure/units: The proportion of the wetland perimeter occupied by various land use types

Method:
(a) Determine the percentage of the total wetland perimeter that is bounded by each of the land use types listed in Table C-2. Percentages may be rounded to the nearest 5 percent.
(b) Assign a subindex value for $V_{LANDUSE}$ based on the descriptions in Table C-3.

Table C-2
Description of Land-Use Types

Land Use Category	Description
Undeveloped naturally vegetated areas or open water	a) Open water: Shoreline is at least 100 m from navigation channel, if present. b) Terrestrial: > 75% of total area is naturally vegetated forested or grassy uplands or wetlands.
Mostly agricultural	More than 50% of the total area is occupied by cropland.
Mostly developed	a) Open water: Harbors, ports, and marinas b) Terrestrial: More than 40% of the total area is developed (i.e. residential, commercial, or industrial areas; also includes point sources such as golf courses, wastewater treatment plant outfalls, feedlots, etc.)
Mixed use	a) Open water: areas where the shoreline is within 100m of a navigation channel. b) Terrestrial: Does not fit any of the above categories, may include low-density rural residential, un-paved roads, etc.

Table C-3
Relationship Between Adjacent Land Use and Functional Capacity

Proportion of Wetland Perimeter	Variable Subindex
>95% of wetland perimeter is bounded by undeveloped naturally vegetated areas or open water	1.0
70-95% of wetland perimeter is bounded by undeveloped natural areas, remainder is mixed use	0.8
< 70% of wetland perimeter is bounded by undeveloped naturally vegetated areas or open water, but >50% is bounded by agricultural or developed areas	0.6
50-75% of wetland perimeter is bounded by agricultural or developed areas	0.4
>75% of wetland perimeter is bounded by agricultural or developed areas	0.2

3. **Mean Marsh Width (V_{WIDTH})**

Measure/units: distance that wind- and vessel-generated waves must travel across intervening tidal fringe wetland (distance from the shoreline) - m.

Method:
(a) Using a recent aerial photo or direct field survey, establish a baseline within the WAA that runs roughly parallel to the shoreline and/or perpendicular to the topographic gradient (see Figure 5 in main text).

(b) Draw a series of regularly spaced transects perpendicular to this baseline, running from the edge of the shoreline, across the WAA boundaries to the nearest upland edge. The number of transects is determined by the length of the baseline (Table C-4). Measure the length of each transect, sum the lengths, and divide by the total number of transects to calculate the average width of the marsh in meters. Transects should be placed to capture the full range of variability in marsh width.
(c) Assign a variable subindex value for V_{WIDTH} according to Table C-5.

Table C-4
Number of Transects for Estimating Mean Marsh Width

Baseline Length, m	Number of Transects
< 300	3
300-1,500	5
1,500-3,000	7
>3,000	9

Table C-5
Relationship Between Mean Marsh Width and Functional Capacity

Mean Marsh Width, m	Variable Subindex
≥ 100	1.0
50-99	0.8
30-49	0.6
11-29	0.4
≤ 10	0.2

4. **Wave Energy Exposure (V_{EXPOSE})**

Measure/units: A qualitative classification of the potential for erosion by wind- and vessel-generated wave energy based on the geomorphic setting, and fetch distance - unitless.

Method:
(a) Using a recent aerial photo or direct field survey, identify the contiguous tidal fringe wetland occupied by the WAA. Qualitatively assess the degree of wave exposure of all shorelines bordering bodies of tidally connected open water by matching site conditions with the descriptions provided in Table C-6.
(b) Assign a variable subindex based on the geomorphic setting and conditions as described in Table C-6 for the contiguous tidal fringe wetland within which the WAA is located. If the wetland is bordered by shorelines in more than one geomorphic setting, assign a subindex based on the highest level of exposure present.

Table C-6 Relationship Between Wave Energy Exposure and Functional Capacity		
Site Description	**Exposure**	**Variable Subindex**
Geomorphic Setting: Low-Energy Interior Marsh These wetlands have one or more shorelines located along the edges of protected coves or embayments (concave shoreline) or along the edge of a small tidal creek not used by commercial boat traffic.	Low	0.3
Geomorphic Setting: Moderate-Energy Interior Marsh These wetlands have one or more shorelines located along the edges of rivers or large tidal creeks that are used by recreational and/or commercial boat traffic.	Moderate	0.6
Geomorphic Setting: Open Bay or Estuary These wetlands have one or more shorelines located directly along the edges of an estuary or bay (e.g., Mississippi Sound, Mobile Bay). Shoreline is generally linear, exposed to relatively high wind and wave energy, with long fetch distances, or adjacent to navigation channel that is frequently used by recreational or commercial boat traffic.	High	1.0
Geomorphic Setting: Zero Energy Interior Marsh These wetlands have no shorelines exposed to wind or wave energy present within the site boundaries.	None	0.0

5. **Aquatic Edge (V_{EDGE})**

Measure/units: The length in meters of vegetated tidally connected marsh/water interface or edge expressed as a proportion of total WAA area - ha.

Method:
(a) Qualitative Measure: Using aerial photography at a scale of 1 cm = 48 m (1 in. = 400 ft) , assign a subindex value for the site using the qualitative descriptions provided in Table C-7. See the pictorial key in Appendix E for specific examples.
(b) Quantitative Measure: Using GIS and aerial photography at the same scale, measure all visible marsh/water interfaces, including edges of tidal creeks (both banks), creeks, and open bay shoreline. Determine the total marsh area in hectares, and express the total amount of edge in meters as a function of total marsh area. Assign a subindex value using the data in Table C-7.
(c) Assign a variable subindex based on Table C-7.

Table C-7
Estimating V_{EDGE} Based on the Amount of Marsh/Water Interface Present

Site Description	Qualitative Estimate	Quantitatve Measure (m/ha)	Subindex
1) Well-developed tidal drainage network present (Figures E-1 and E-2) 2) Very narrow fringe marsh that lacks tidal creeks. One lengthwise shoreline that represents at least 40 percent of the total perimeter is exposed to tidal waters. (e.g., Daphne Bayfront Park) 3) Other geomorphic configuration with a large amount of shoreline relative to total area (i.e. small island or narrow peninsula) (Figures E-3 and E-4)	High	$\geq$ 225	1.0
Simple tidal drainage network (may consist of one or more small channels) that are well-distributed across the total WAA area (Figures E-5 and E-6)	Moderate-High	175-224	0.75
Tidal creeks may be lacking, or if present, drain only a small proportion of the total WAA area. (Figure E-7, E-8, and E-9)	Moderate-Low	100-175	0.5
Shoreline is generally linear or smooth curvilinear without embayments or convolutions. Tidal creeks typically absent. The area of marsh is large relative to shoreline length (Figure E-10)	Low	<100	0.25
No tidally connected vegetated marsh-water interface present in WAA (Figure E-11)	Absent	0	0.0

Site Scale Variables

6. **Hydrologic Regime (V_{HYDRO})**

   Measure/units: The degree of alteration to the normal tidal hydrology typical of the subclass - unitless.

   Method:
   (a) Visually inspect the site and determine if there is any evidence of hydrological alteration, berms, culverts, fill, or other alterations that affect normal tidal hydrology. The value of the variable subindex V_{HYDRO} is assumed to be 1.0 unless any of these altered conditions are present.
   (b) Match site condition with variable subindex value from Table C-8.

Table C-8 **Relationship Between Hydrologic Regime (V_{HYDRO}) and Functional Capacity**	
Site Description	**Variable Subindex**
Site is open to free exchange of tidal waters. Lower edges of vegetated marsh surface are flooded on a regular basis as evidenced by wrack lines, watermarks, etc. No obvious hydrologic alteration, fill, or restrictions present.	1.0
Minor hydrologic alteration or restriction present (i.e. presence of low-elevation berm, that is frequently overtopped by high-tide events or has multiple breaches or large culverts; presence of some fill that raises a small portion (<20 percent of marsh area) of marsh surface above normal tidal flooding zone).	0.75
Moderate hydrologic alteration present (i.e. presence of high-elevation berm, which is infrequently overtopped by high-tide events or has a single opening, breach, or small culvert; greater extent of fill (>20 percent) that raises portions of marsh surface elevation above normal tidal flooding zone).	0.50
Severe hydrologic alteration; site receives tidal floodwaters only during extreme tide events (i.e. surface elevation of marsh is above normal tidal flooding zone; blocked culvert, etc).	0.25
Site is isolated from tidal exchange. The principal source of flooding is water sources other than tidal action (i.e. precipitation or groundwater). *Note: If this condition exists, use of another wetland assessment model should be strongly considered unless the site was a tidal wetland prior to hydrologic modification.*	0.00

7. **Nekton Habitat Diversity (V_{NHD})**

Measure/units: Nekton habitat diversity is a measure of the heterogeneity of a site, based on comparison of the number of habitats actually present at a site relative to the number of possible habitats known to occur in the appropriate regional subclass.

Method:
(a) Visually inspect the WAA and areas immediately adjacent to the WAA perimeter, noting the presence of any of the habitat types identified in Table C-9 either within or within 30 m of the WAA perimeter.
(b) Assign a variable subindex based on Figure C-1.

Table C-9 **Possible Nekton Habitat Types**
Low marsh (i.e., daily tidal flooding)
High marsh (i.e., irregular tidal flooding)
Intertidal creeks/channels
Subtidal creeks/channels
Ponds or depressions (temporary or permanent)
Shallow (< 1 m) sand or mudflats
Submerged aquatic vegetation
Oyster reef

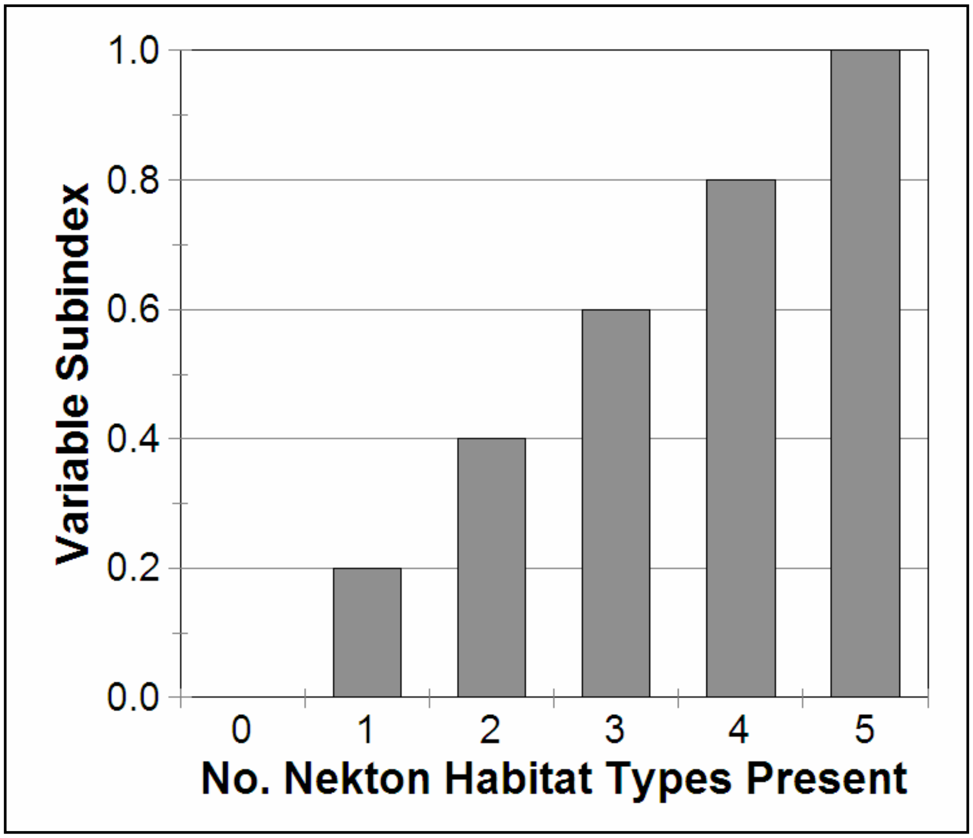

Figure C-1. Relationship between nekton habitat complexity and functional capacity

8. **Wildlife Habitat Diversity (V_{WHD})**

Measure/units: A measure of the occurrence of habitat types known to support selected marsh-dependent wildlife species within the WAA.

Method:
(a) Visually inspect the WAA and areas immediately adjacent to the WAA perimeter, noting the presence of any of the habitat types identified in Table C-10 either within the WAA or along the edges of the WAA perimeter.
(b) Assign a variable subindex based on Table C-11.

Table C-10 **Wildlife Habitat Types**
Tall, robust herbaceous vegetation that is at least irregularly flooded (i.e., *S. alterniflora, S. cynosuroides, J. roemerianus, Typha spp., Scirpus spp.*) **Required**.
Short herbaceous vegetation that is infrequently flooded (i.e., *S. patens, S. spartinae, Distichlis spicata, Borrichia frutescens, Batis maritima*)
Intertidal creek banks and mudflats that are exposed at low tide
Naturally vegetated upland buffer with a minimum width of 30 m (forested, shrub-scrub, or dense herbaceous) adjacent the to the WAA perimeter

Table C-11 **Relationship Between Number of Wildlife Habitat Types and Functional Capacity**	
Wildlife Habitat Types	**Variable Subindex**
1) WAA does not contain large patches of tall, robust, herbaceous vegetation as described in Table C-10 2) Tall, robust vegetation community occurs only in a narrow (<10 m) fringe that represents a small proportion of the total plant community within the WAA	0.0
WAA contains large patches of tall, robust, herbaceous vegetation, plus any one of the other habitat types listed above	0.35
WAA contains large patches of tall, robust, herbaceous vegetation, plus any two of the other habitat types listed above	0.70
At least 50 percent of the WAA is dominated by tall, robust, herbaceous vegetation; and all three of the other habitat types identified in Table C-10 are also present	1.0

Plant Community Variables

9. **Mean Percentage Cover Emergent Marsh Vegetation-** V_{COVER}

Measure/units: the mean total percentage cover of native nonwoody marsh species - ratio. For the purposes of variable measurement, marsh species are those with a wetland indicator status of OBL or FACW.

Method:
This variable should be measured during the growing season using the following procedure.
(a) Select one or more representative areas within the site for sampling. Beginning at the edge of a shoreline or tidal creek, establish one or more transects perpendicular to the shoreline or along the hydrologic gradient (e.g. increasing elevation). If there are multiple vegetation community types within the wetland assessment area (WAA), the transect should intersect each vegetation community to ensure a representative sample.
(b) Using a standard 1-m^2 frame, estimate total percentage cover of native nonwoody marsh (OBL or FACW) species using the Braun-Blanquet cover class categories (Table C-12) (Mueller-Dombois and Ellenberg 1974).[1] Both live and standing dead emergent plant material should be included. Tidal creeks and other areas where water depths are too deep to support the growth of emergent vegetation should be excluded. The number of transects and plots will depend on the size and heterogeneity of the site; a minimum of 10 plots per transect are recommended for all except the smallest sites.
(c) Calculate the total percentage cover of each plot by summing the cover class midpoints (Table C-12) for each species, then divide by the number of plots sampled to obtain the mean percentage cover of the study.
(d) Using Table C-13, determine the variable subindex that corresponds to the mean vegetation cover.

[1] References cited in this appendix are listed in the References section at the end of the main text.

Table C-12 **Braun-Blanquet Cover Class Categories**		
% Cover	**Cover Class**	**Cover Class MidPoint**
> 75	5	87.5
50-75	4	62.5
25-50	3	37.5
5-25	2	15.0
<5	1	2.5

Table C-13 **Relationship Between Mean Percentage Emergent Marsh Vegetation Cover and Functional Capacity**	
Mean **% Cover**	**Variable Subindex**
> 70	1.0
61-70	0.8
51- 60	0.6
41-50	0.4
31- 40	0.2
11-30	0.1
<11	0.0

10. **Vegetation Height (V_{HEIGHT})**

Measure/units: The most frequently occurring height of the plants within the tallest zone of the emergent marsh plant community **-** cm.

Method: It is important that this variable be measured during the growing season since use of senescent plants to estimate height will typically result in lower subindex values for this variable. This variable is measured using the following procedure:
(a) This variable measure employs a stratified sampling design based on plant community zonation. First, identify the tallest species assemblages present within the WAA. In brackish and saline marshes within the subclass, this zone will typically be dominated by *Juncus roemerianus*, *Spartina alterniflora*, *S. cynosuroides*, or *Schoenoplectus* spp. If *Phragmites* is present, it should be included in the height measurements, but only in proportion to its distribution within the WAA.
(b) Within 1-m^2 plots, measure the height in centimeters (rounded to the nearest 5 cm) at which the bulk of the biomass occurs (i.e., the mean or most frequently occurring height). Record this value.

In plots composed of mixed species assemblages of tall, robust plants, record only one value for height, corresponding to the most frequently occurring height of the entire species assemblage. Do not include the height of low-growing species that occur within the same plot, such as *Distichlis spicata*.

Although standing dead stems may be used to estimate the maximum height obtained during peak biomass periods, measurement of this variable during winter and early spring is not recommended.

(c) Repeat this procedure for each plot and average the results from all plots. At least 10 plots per transect are recommended for most sites, but this number can change depending on the degree of variability within the WAA.
(d) Using Figure C-2, determine the variable subindex that corresponds to the mean vegetation height.

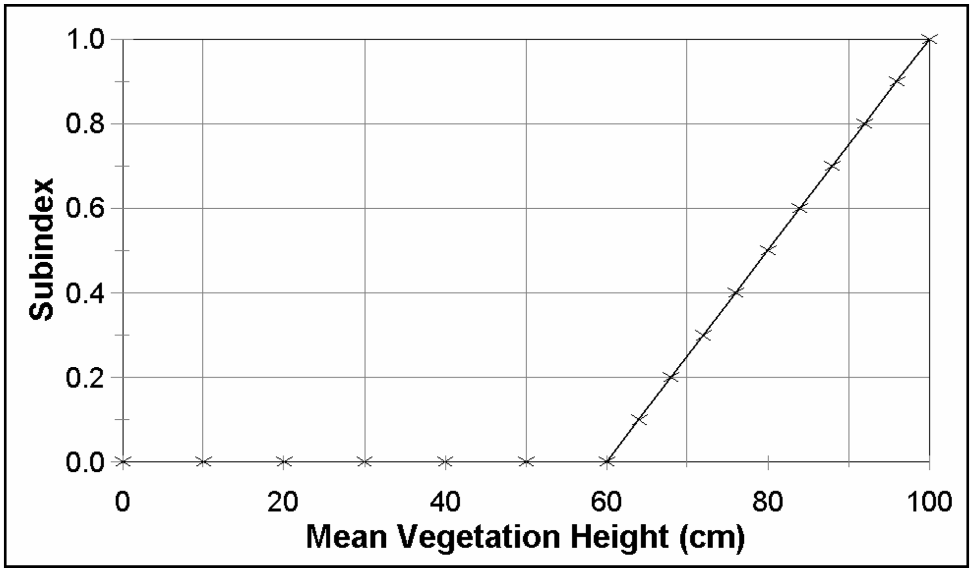

Figure C-2. Relationship between mean vegetation height and functional capacity

11. **Percentage cover by invasive or exotic species (V_{EXOTIC})**

Measure/units: The proportion of the site that is covered by non-native or invasive plant species - ratio.

Method:
(a) Using the Braun-Blanquet cover class categories (Table C-12), visually estimate the percentage of the entire site that is covered by non-native or invasive plant species (Table C-14). For some species, such as *Alternanthera philoxeroides*, this may be accomplished using the same 1-m^2 plots used in the assessment of native emergent species. However, for larger species, such as *Phragmites australis*, that are often not well-represented in small 1-m^2 plots, it is best to visually estimate the percentage cover of the entire site. If there is uncertainty regarding the most appropriate technique for measurement of this variable, use the method that results in the highest value for percentage cover of invasive or exotic plants.
(b) Assign a variable subindex based on Table C-15.

Table C-14
Non-native or Invasive Species That May Occur Within the Regional Subclass[1]

Scientific Name	Common name	Designation
Alternanthera philoxeroides	Alligator weed	Alabama Class C noxious weed
Cuscuta spp.	Dodder	Alabama Class A noxious weed
Imperata cylindrica	Cogongrass	Alabama Class A noxious weed; MS noxious weed
Ipomoea purpurea	Tall morning glory	Introduced
Panicum repens	Torpedograss	Alabama Class C noxious weed
Phragmites australis	Common reed	Alabama Class C noxious weed
Triadica sebifera	Chinese tallow	MS noxious weed
Typha latifolia	Broadleaf cattail	Invasive

Source: Wieland (1994), USDA PLANTS Database (2005).
[1] Additional species may be added to this list.

Table C-15
Relationship Between Percentage Cover by Non-Native or Invasive Plant Species (V_{EXOTIC}) and Functional Capacity

% Exotic Cover	Variable Subindex
0-5	1.0
6-10	0.8
11-20	0.6
21-30	0.4
31-50	0.2
> 50	0.1

12. **Percentage cover by woody plant species (V_{WOODY})**

Measure/units: The proportion of the site that is covered by shrub-scrub or other woody plant species - ratio.

Method:
(a) Using the Braun-Blanquet cover class categories (Table C-12), visually estimate the percentage of the entire site that is covered by woody plants (shrub-scrub and tree species) (see Table 8 for specific examples). Since these species are usually not well-represented in small 1-m^2 plots, it is best to visually estimate the percent cover of the entire site using aerial photography.
(b) Assign a variable subindex based on Table C-16.

Table C-16 Relationship Between Percentage Cover by Woody Plant Species (V_{WOODY}) and Functional Capacity	
% Woody Cover	**Variable Subindex**
0-5	1.0
6-10	0.8
11-20	0.6
21-30	0.4
>30	0.2

13. **Wetland indicator Status (V_{WIS})**

Measure/units: The ratio of the percentage cover of FAC/FACU plant species to the percentage cover of emergent herbaceous wetland (OBL or FACW) plants.

Method:
(a) Using the Braun-Blanquet cover class categories, visually estimate the percentage of each plot that is occupied by plants with a wetland indicator status of FAC or FACU. Table 12, main text, provides a few examples; for more detailed information please see the USDA PLANTS online database. For some species, this may be accomplished using the same 1-m^2 plots used in the assessment of other plant community parameters. However, for some larger species, such as *Baccharis halimifolia*, that may not be well-represented in small 1-m^2 plots, it is best to visually estimate the percentage cover of the entire site. If there is uncertainty regarding the most appropriate technique for measurement of this variable, use the method that results in the highest value for percentage cover of FAC or FACU plant species.
(b) Sum the cover class midpoints of FAC/FACU species for all plots.
(c) Sum the cover class midpoints of emergent herbaceous wetland plants (OBL or FACW) for all plots.
(d) Divide the sum cover class midpoints of FAC/FACU species by the sum of the cover class midpoints of emergent herbaceous wetland plants and multiply by one hundred.
(e) Assign a variable subindex based on Table C-17.

Table C-17 Relationship Between Percentage Cover of Nonwetland Plants (Wetland Indicator Status = FAC or FACU) (V_{WIS}) and Functional Capacity	
% Cover Nonwetland species	**Variable Subindex**
0-1	1.00
2-4	0.75
5-10	0.50
>10	0.25

Appendix D
Reference Data

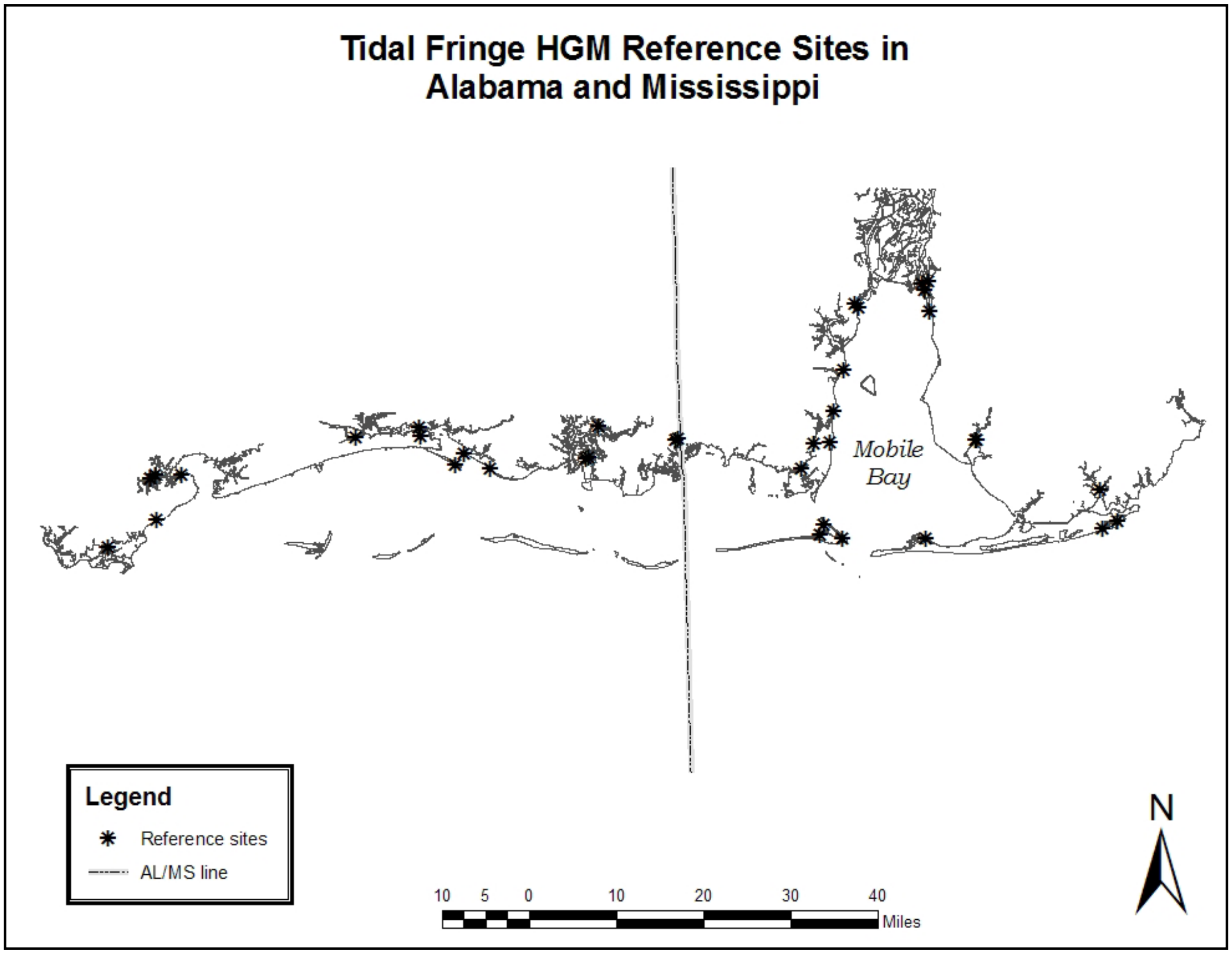

Figure D-1. Locations of sampling sites within the reference domain.

Table D-1
Landscape Scale Variable Measures and Subindices

State	Site	V_{SIZE} (ha)	*V_{SIZE} Subindex*	V_{WIDTH} (m)	*V_{WIDTH} Subindex*	V_{EXPOSE}	*V_{EXPOSE} Subindex*	*$V_{LANDUSE}$ Subindex*
Mississippi	Deer Island*	7.3	*1.0*	237	*1.0*	High	*1.0*	*1.0*
	Bayou Heron*	3.2	*1.0*	161	*1.0*	High	*1.0*	*1.0*
	Pascagoula River	298.0	*1.0*	1257	*1.0*	Moderate	*0.6*	*0.8*
	Belle Fontaine	11.6	*1.0*	162	*1.0*	High	*1.0*	*1.0*
	Marsh Point	8.3	*1.0*	327	*1.0*	High	*1.0*	*1.0*
	Ingalls Restoration Site	74.0	*1.0*			Moderate	*0.6*	*0.4*
	Oyster Bar	1.3	*0.75*	85	*0.8*	Low	*0.3*	*0.8*
	Bayou Bernard	4.8	*1.0*	111	*1.0*	Moderate	*0.6*	*1.0*
	Buccaneer State Park	2.6	*1.0*	229	*1.0*	Low	*0.3*	*0.8*
	Shoreline Park	1.2	*0.75*	86	*0.8*	Moderate	*0.6*	*0.6*
	Escatawpa River	19.6	*1.0*	83	*0.8*	Low	*0.3*	*1.0*
	Keegan Bayou	6.4	*1.0*	69	*0.8*	Low	*0.3*	*0.2*
	Jourdan River	5.1	*1.0*	142	*1.0*	Moderate	*0.6*	*0.6*
	Ansley Restoration Site	26.1	*1.0*	NA	*NA*	None	*NA*	*0.8*
	Texas St. A	0.1	*0.25*	18	*0.4*	Low	*0.3*	*0.6*
	Texas St. B	0.1	*0.25*	28	*0.4*	Low	*0.3*	*0.6*
	D'Iberville Casino	4.1	*1.0*			Low	*0.3*	*0.2*
Alabama	Little Dauphin Island*	36.6	*1.0*	309	*1.0*	High	*1.0*	*1.0*
	Little Point Clear*	141.0	*1.0*	> 2,000	*1.0*	High	*1.0*	*1.0*
	Wolf Bay*	41.0	*1.0*	452	*1.0*	High	*1.0*	*1.0*
	Fowl River TNC*	36.6	*1.0*	947	*1.0*	Moderate	*0.6*	*1.0*
	Weeks Bay	14.3	*1.0*	512	*1.0*	High	*1.0*	*0.6*
	East Fowl River Narrows	8.6	*1.0*	80	*0.8*	Moderate	*0.6*	*1.0*
	ADCNR	21.1	*1.0*	315	*1.0*	Moderate	*0.6*	*0.8*
	Blakeley River	3.2	*1.0*	70	*0.8*	Moderate	*0.6*	*1.0*
	Old East Fowl River	7.8	*1.0*	319	*1.0*	High	*1.0*	*1.0*
	Meaher Boat Launch	1.1	*0.75*	35	*0.6*	Low	*0.3*	*1.0*
	Dauphin Island Airport	2.9	*1.0*	176	*1.0*	Moderate	*0.6*	*0.6*
	Alonzo Landing	9.7	*1.0*	135	*1.0*	Moderate	*0.6*	*0.6*
	Fish River	0.2	*0.25*	75	*0.8*	Low	*0.3*	*0.6*
	Cotton Bayou	0.2	*0.25*	89	*0.8*	Low	*0.3*	*0.8*
	Brookley	11.0	*1.0*	81	*0.8*	High	*1.0*	*0.8*
	Boggy Point	0.35	*0.50*	NA	*NA*	None	*NA*	*0.6*
	Brookley Golf Course	0.33	*0.50*	24	*0.4*	High	*1.0*	*0.6*
	Daphne Bayfront Park	0.14	*0.25*	35	*0.6*	High	*1.0*	*0.6*
	Mon Luis Island	5.8	*1.0*			None	*NA*	*0.8*
	Middle Bay Port	9.2	*1.0*	276	*1.0*	High	*1.0*	*0.6*

* Reference standard sites

Table D-2
Habitat Variable Measures and Subindices

State	Site	V_{NHD}	*V_{NHD} Subindex*	V_{WHD}	*V_{WHD} Subindex*	V_{HEIGHT} (cm)	*V_{HEIGHT} Subindex*
Mississippi	Deer Island	6	*1.0*	4	*1.0*	90	0.8
	Bayou Heron	5	*1.0*	4	*1.0*	112	1.0
	Pascagoula River	4	*1.0*	4	*1.0*	--	--
	Belle Fontaine	2	*0.4*	4	*1.0*	100	1.0
	Marsh Point	5	*1.0*	4	*1.0*	82	0.6
	Ingalls Restoration Site	3	*0.6*	3	*0.7*	--	--
	Oyster Bar	4	*1.0*	4	*1.0*	64	0.2
	Bayou Bernard	5	*1.0*	3	*0.7*	127	1.0
	Buccaneer State Park	4	*1.0*	4	*1.0*	86	0.7
	Shoreline Park	5	*1.0*	3	*0.7*	137	1.0
	Escatawpa River	3	*0.6*	2	*.35*	158	1.0
	Keegan Bayou	5	*1.0*	4	*1.0*	104	1.0
	Jourdan River	5	*1.0*	4	*1.0*	144	1.0
	Ansley Restoration Site	3	*0.6*	4	*1.0*	108	1.0
	Texas St. A	5	*1.0*	4	*1.0*	--	--
	Texas St. B	4	*1.0*	3	*0.7*	--	--
	D'Iberville Casino	5	*1.0*	4	*1.0*	--	--
Alabama	Little Dauphin Island	8	*1.0*	4	*1.0*	97	0.9
	Little Point Clear	6	*1.0*	4	*1.0*	98	0.9
	Wolf Bay	6	*1.0*	4	*1.0*	100	1.0
	Fowl River TNC	5	*1.0*	4	*1.0*	101	1.0
	Weeks Bay	5	*1.0*	3	*0.7*	112	1.0
	East Fowl River Narrows	5	*1.0*	3	*0.7*	110	1.0
	ADCNR	6	*1.0*	4	*1.0*	114	1.0
	Blakeley River	5	*1.0*	2	*0.35*	199	1.0
	Old East Fowl River	5	*1.0*	4	*1.0*	105	1.0
	Meaher Boat Launch	7	*1.0*	4	*1.0*	119	1.0
	Dauphin Island Airport	7	*1.0*	4	*1.0*	65	0.2
	Alonzo Landing	6	*1.0*	4	*1.0*	81	0.5
	Fish River	5	*1.0*	3	*0.7*	--	--
	Cotton Bayou	6	*1.0*	3	*0.7*	120	1.0
	Brookley	4	*1.0*	3	*0.7*	144	1.0
	Boggy Point	1	*0.2*	2	*.35*	125	1.0
	Brookley Golf Course	3	*0.6*	2	*0*	> 100	1.0
	Daphne Bayfront Park	4	*1.0*	1	*0*	--	--
	Mon Louis Island	3	*0.6*	3	*0.7*	--	--
	Middle Bay Port	6	*1.0*	4	*1.0*	--	--

Table D-3
Measures and Subindex Values for Aquatic Edge and Hydrologic Regime Variables

Qualitative Estimate	Site	Quantitative Measure Edge:Area, m/ha	V_{EDGE} Subindex	V_{HYDRO} Subindex
High edge:area	Daphne Bayfront Park	936	*1.0*	*1.0*
	Dauphin Island Airport	573	*1.0*	*1.0*
	Bayou Barnard	474	*1.0*	*1.0*
	Texas St. A	430	*1.0*	*1.0*
	Wolf Bay	416	*1.0*	*1.0*
	Old East Fowl River	403	*1.0*	*1.0*
	Royal D'Iberville Casino	332	*1.0*	*0.75*
	Fish River	330	*1.0*	*1.0*
	Pascagoula River Ref	319	*1.0*	*1.0*
	Little Point Clear	315	*1.0*	*1.0*
	Blakely River	310	*1.0*	*1.0*
	Texas St. B	310	*1.0*	*0.75*
	Meaher Boat Ramp	291	*1.0*	*1.0*
	Narrows East Fowl River	276	*1.0*	*1.0*
	Shoreline Park	273	*1.0*	*0.25*
	Oyster Bar	258	*1.0*	*0.75*
	Alonzo Landing	244	*1.0*	*1.0*
	ADCNR	244	*1.0*	*1.0*
	Keegan Bayou	237	*1.0*	*1.0*
	Fowl River TNC	235	*1.0*	*1.0*
	Little Dauphin Island	235	*1.0*	*1.0*
Moderate-high edge:area	Jordan River	224	*0.75*	*0.50*
	Deer Island	211	*0.75*	*1.0*
	Middle Bay Port	202	*0.75*	*0.75*
	Brookley	183	*0.75*	*1.0*
	Ansley Restoration Site	172	*0.75*	*0.25*
	Buccaneer State Park	167	*0.75*	*0.50*
Moderate-low edge:area	Belle Fontaine	147	*0.50*	*0.50*
	Week's Bay (Lulu's)	144	*0.50*	*1.0*
	Brookley Golf Course	130	*0.50*	*0.25*
	Marsh Point	110	*0.50*	*0.75*
	Ingalls Restoration	109	*0.50*	*0.75*
	Heron Bayou	106	*0.50*	*1.0*
Low edge:area	Escatawpa River	81	*0.25*	*1.0*
	Cotton Bayou	52	*0.25*	*1.0*
	Mon Luis Island	29	*0.25*	*0.25*
No edge present	Boggy Point Restricted	0	*0*	*0*
	Oyster Bar Restricted	0	0	*0*

Table D-4
Plant Community Variables

State	Site	V_{COVER}	V_{COVER} Subindex	V_{EXOTIC}	V_{EXOTIC} Subindex	V_{WIS}	V_{WIS} Subindex	V_{WOODY}	V_{WOODY} Subindex
Mississippi	Deer Island	72.95	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Bayou Heron	60.55	*1.0*	0.00	*1.0*	0.41	*1.0*	0.25	*1.0*
	Pascagoula River	30.35	*0.1*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Marsh Point	93.85	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Belle Fontaine	100.00	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Ingalls Restoration Site	37.25	*0.2*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Oyster Bar	27.80	*0.1*	0.00	*1.0*	5.58	*0.5*	1.55	*1.0*
	Buccaneer State Park	60.80	*0.8*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Bayou Bernard	66.70	*0.8*	5.15	*1.0*	0.00	*1.0*	0.00	*1.0*
	Shoreline Park	87.65	*1.0*	0.00	*1.0*	20.65	*0.25*	19.65	*0.6*
	Escatawpa River	28.95	*0.1*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Keegan Bayou	55.55	*0.6*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Jourdan River	58.50	*0.6*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Ansley Restoration Site	52.35	*0.6*	0.00	*1.0*	0.00	*1.0*	5.30	*0.8*
	Texas St. A	53.50	*0.6*	0.00	*1.0*	0.00	*1.0*	10.60	*0.6*
	Texas St. B	57.90	*0.6*	0.00	*1.0*	7.08	*0.5*	22.70	*0.4*
	D'Iberville Casino	39.80	*0.2*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
Alabama	Little Dauphin Island	80.90	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Little Point Clear	72.55	*1.0*	0.00	*1.0*	0.00	*1.0*	1.55	*1.0*
	Wolf Bay	81.45	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Fowl River TNC	81.55	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Weeks Bay	95.30	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	East Fowl River Narrows	61.80	*0.8*	0.00	*1.0*	0.40	*1.0*	0.25	*1.0*
	ADCNR	100.00	*1.0*	49.05	*0.2*	0.00	*1.0*	0.00	*1.0*
	Blakeley River	100.00	*1.0*	86.33	*0.1*	0.00	*1.0*	0.00	*1.0*
	Old East Fowl River	71.10	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Meaher Boat Launch	96.10	*1.0*	8.65	*0.8*	0.00	*1.0*	0.00	*1.0*
	Dauphin Island Airport	78.25	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Alonzo Landing	82.30	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Fish River	86.60	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Cotton Bayou	70.50	*1.0*	0.00	*1.0*	0.00	*1.0*	0.00	*1.0*
	Boggy Point	82.60	*1.0*	7.50	*0.8*	0.00	*1.0*	0.00	*1.0*
	Brookley	80.50	*1.0*	8.75	*0.8*	0.00	*1.0*	0.00	*1.0*
	Brookley Golf Course	25.50	*0.1*	12.50	*0.6*	0.00	*1.0*	3.10	*1.0*
	Daphne Bayfront Park	84.50	*1.0*	35.00	*0.2*	0.00	*1.0*	0.00	*1.0*
	Mon Luis Island	85.55	*1.0*	0.0	*1.0*	6.2	*0.5*	35.6	*0.2*
	Middle Bay Port	74.40	*1.0*	14.55	*0.6*	0.00	*1.0*	0.00	*1.0*

Appendix E
Pictorial Key for Estimating Aquatic Edge

Examples of High Aquatic Edge

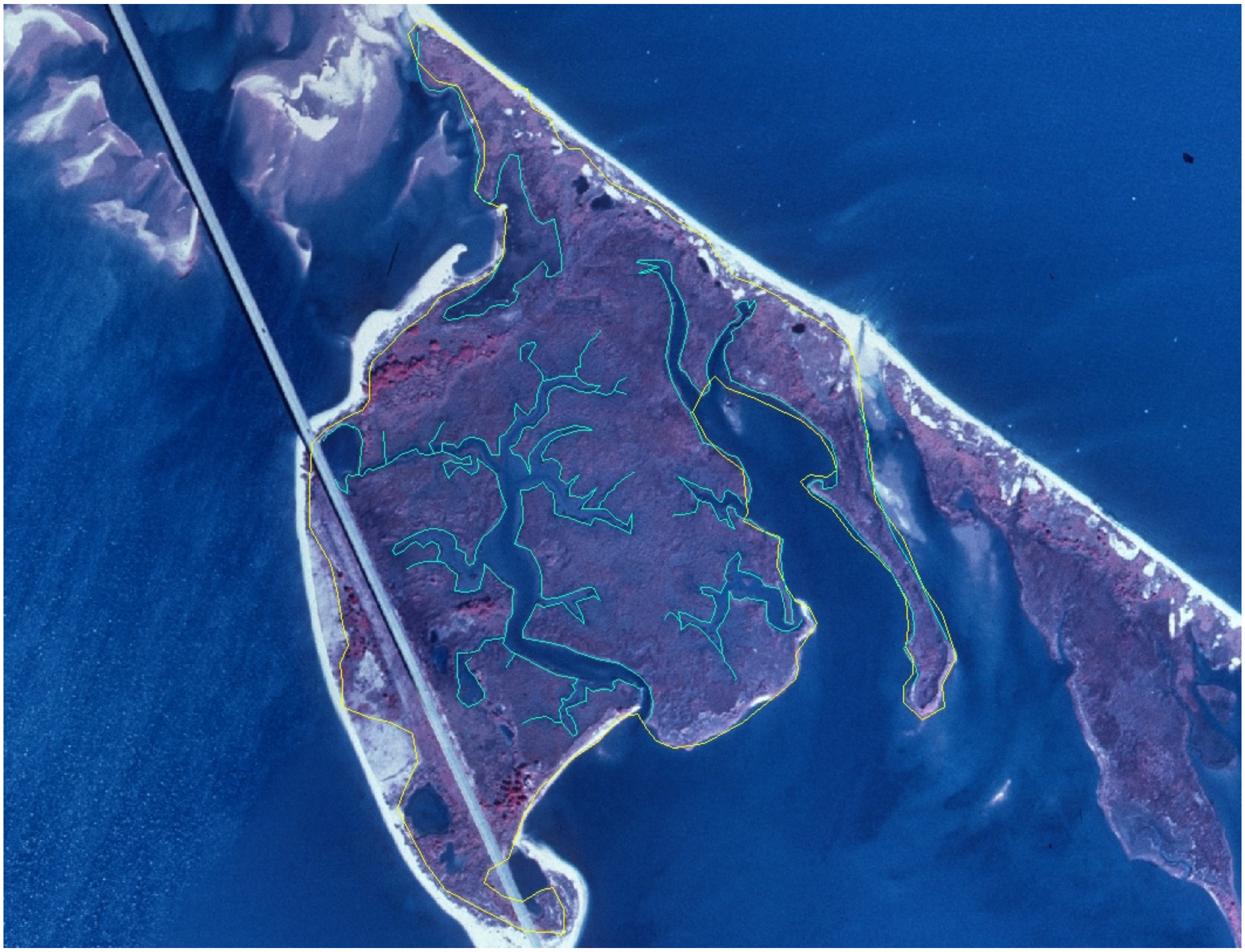

Figure E-1. Little Dauphin Island, AL. Example of marsh with high edge:area ratio. Note extensive tidal channel development with 1st-, 2nd-, and 3rd-order channels draining a large proportion of the total area of the WAA. WAA outlined in yellow. Tidally connected edge outlined in light blue.

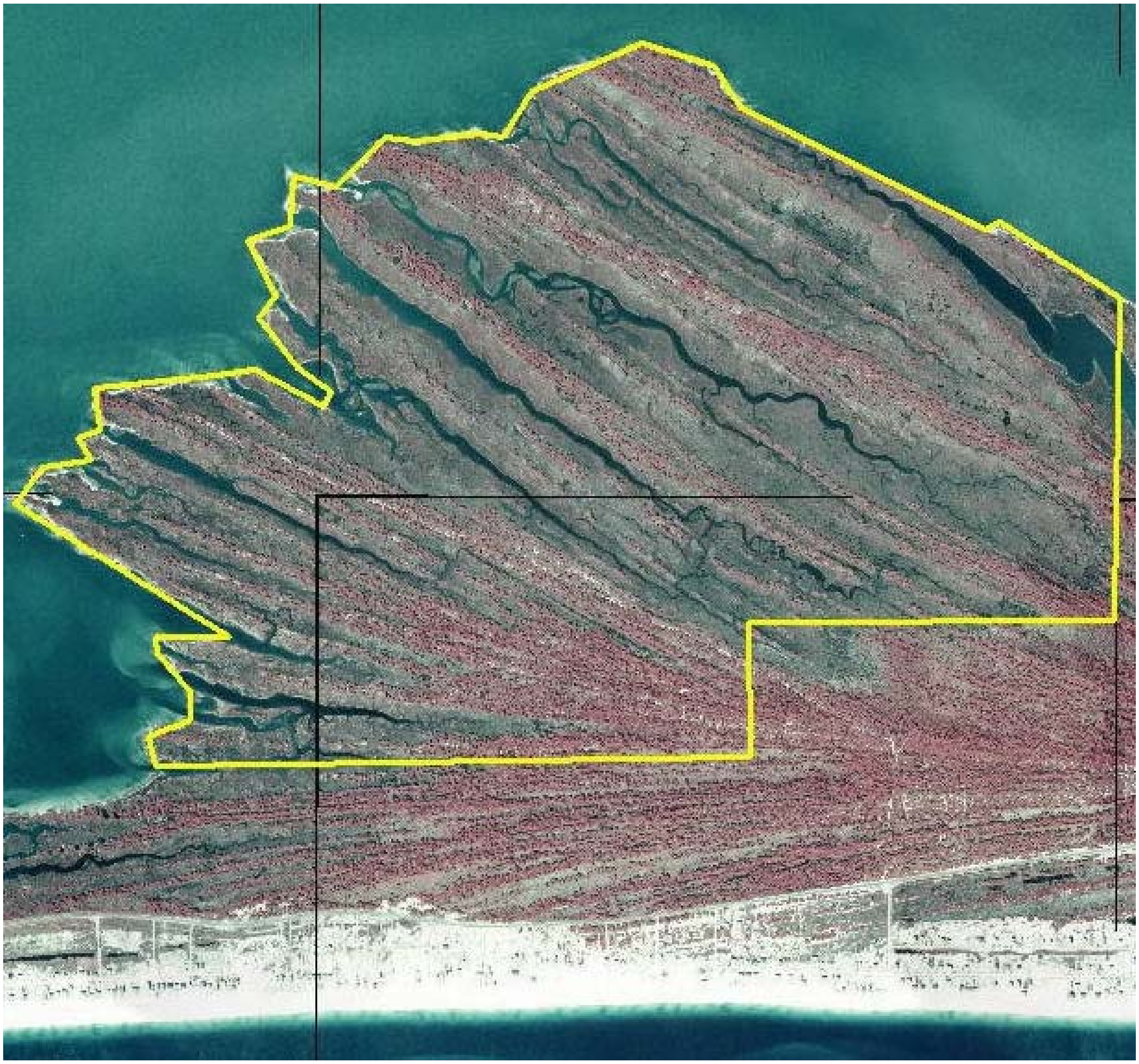

Figure E-2. Little Point Clear, AL. Example of marsh with high edge:area ratio. Note extensive tidal channel development with 1st-, 2nd-, and 3rd-order channels draining a large proportion of the total area of the WAA (WAA outlined in yellow).

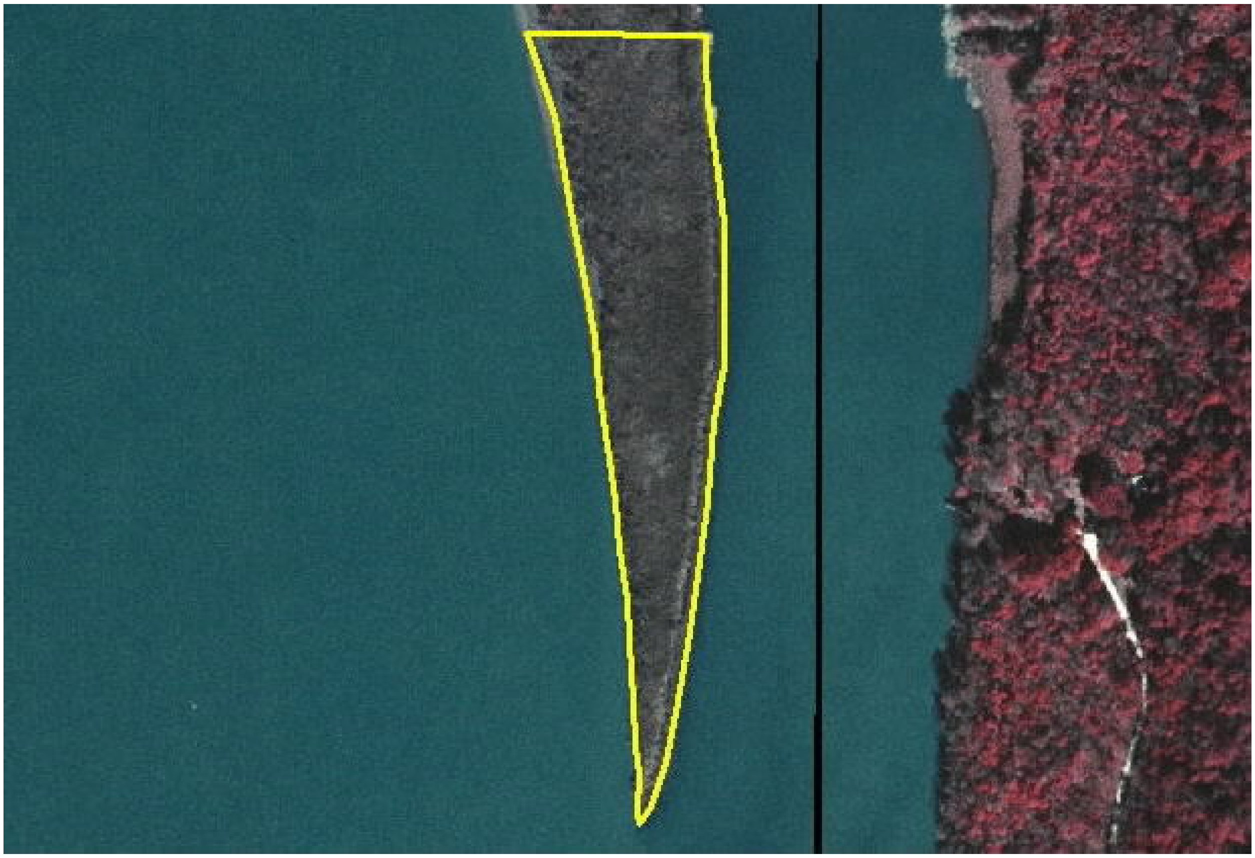

Figure E-3. Blakeley River, AL. Example of marsh with high edge:area ratio. Island or narrow peninsula configuration.

Figure E-4. Shoreline Park, MS. Example of marsh with high edge:area ratio. Island or narrow peninsula configuration.

Examples of Moderate-High Aquatic Edge

Figure E-5. Buccaneer State Park, MS. Example of marsh with moderate-high edge:area ratio. Note simple tidal drainage system that traverses the entire WAA.

Figure E-6. Brookley, AL. Example of marsh with moderate-high edge:area ratio. Narrow linear fringe marsh, curved shoreline, large shoreline length relative to total marsh area.

Examples of Moderate-Low Aquatic Edge

Figure E-7. Belle Fontaine, MS. Example of marsh with moderate-low edge:area ratio. Only the northern edge of linear shoreline is a vegetated shoreline open to tidal flooding; length of shoreline is small relative to total area of WAA.

Figure E-8. Ingalls Restoration Site, MS. Example of marsh with moderate-low edge:area ratio. Only one edge of linear shoreline open to tidal flooding; length of shoreline is small relative to total area

Figure E-9. Weeks Bay (LuLu's), MS. Example of marsh with moderate-low edge:area ratio. Two narrow tidal creeks that drain the upper portion of the WAA are present. Note that sandy shorelines, which constitute much of the visible shoreline in this image, do not count as aquatic edge because they are not vegetated.

Examples of Low Aquatic Edge

Figure E10. Cotton Bayou, AL. Example of marsh with low edge:area. Site lacks tidal creeks. Length of shoreline is small relative to marsh size.

Figure E-11. Boggy Point, AL. No tidally connected marsh-water edge present within WAA.

Appendix F
Supplemental Information

Table F-1
Plant Species Characteristic of North-Central Gulf of Mexico Tidal Fringe Wetlands

Scientific Name	Common Name	Saline	Brackish	Intermediate	Wetland Indicator Status
Alismataceae					
Sagittaria latifolia	Broad-leaf arrowhead		X		OBL
Sagittaria lancifolia	Bulltongue arrowhead		X	X	OBL
Amaryllidaceae					
Crinum americanum	Seven sisters		X	X	OBL
Apiaceae					
Lilaeopsis chinensis	Eastern glasswort		X		OBL
Sium suave	Hemlock water parsnip		X	X	OBL
Asteraceae					
Symphyotrichum subulatus	Annual saltmarsh aster		X		OBL
Symphyotrichum tenuifolium	Perennial saltmarsh aster	X	X		OBL
Solidago sempervirens	Seaside goldenrod		X		FACW
Ambrosia artemisiifolia	Annual ragweed		X		FACU
Iva frutescens	Jesuit's bark		X		FACW+
Baccharis halimifolia	Eastern baccharis	X	X		FAC
Boltonia asteroides	White doll's daisy	X	X	X	FACW
Borrichia frutescens	Seaside tansy	X			OBL
Pluchea odorata	Sweetscent		X	X	FACW
Bidens frondosa	Devil's beggartick		X	X	FACW
Bataceae					
Batis maritima	Turtleweed	X			OBL
Campanulaceae					
Lobelia cardinalis	Cardinalflower		X		FACW+
Chenopodiaceae					
Salicornia virginica	Virginia glasswort	X			OBL
Salicornia bigelovii	Saltwort	X			OBL
Suaeda linearis	Annual seepweed	X			OBL
Convolvulaceae					
Ipomoea sagittata	Saltmarsh morning glory		X		FACW
Ipomoea purpurea	Tall morning glory		X		FACU

Sources: Eleuterius (1972), Stout (1984), Wieland (1994). Taxonomy according to USDA PLANTS database (2005). References cited in this appendix are listed in the References section at the end of the main text.

(Continued)

Table F-1 (Concluded)

Scientific Name	Common Name	Saline	Brackish	Intermediate	Wetland Indicator Status
Cyperaceae					
Schoenoplectus pungens	Common three-square		X	X	OBL
Schoenoplectus robustus	Sturdy bulrush	X	X		OBL
Schoenoplectus californicus	California bulrush		X		OBL
Schoenoplectus americanus	Chairmaker's bulrush	X	X		OBL
Schoenoplectus tabernaemontani	Soft-stem bullrush		X	X	OBL
Cladium mariscus ssp. jamaicense	Jamaica sawgrass		X	X	OBL
Fimbristylis castanea	Marsh fimbry		X	X	OBL
Fimbristylis caroliniana	Carolina fimbry		X		OBL
Carex hyalinolepis	Shoreline sedge		X		FACW+
Eleocharis cellulosa	Gulf coast spike rush		X		OBL
Eleocharis intermedia	Matted spike rush		X	X	FACW
Cyperus odoratus	Fragrant flat sedge		X		FACW
Gramineae					
Spartina alterniflora	Smooth cordgrass	X	X		OBL
Spartina cynosuroides	Big cordgrass	X	X		OBL
Spartina patens	Saltmeadow cordgrass	X	X		FACW
Spartina spartinae	Gulf cordgrass	X			OBL
Distichlis spicata	Seashore saltgrass	X	X		FACW+
Panicum virgatum	Switchgrass		X		FAC+
Panicum amarum	Bitter panic grass		X		FAC
Zizaniopsis miliaceae	Water millet		X	X	OBL
Phragmites australis	Common reed		X	X	FACW
Iridaceae					
Iris virginica	Virginia iris		X	X	OBL
Juncaceae					
Juncus roemerianus	Needlegrass rush	X	X	X	OBL
Juncus effusus	Common rush			X	FACW+
Lilliaceae					
Hymenocallis spp.	Spider lilly		X	X	FACW
Lythraceae					
Lythrum lineare	Wand lythrum		X	X	OBL
Onagraceae					
Ludwigia sphaerocarpa	Globefruit primrose-willow		X	X	OBL
Osmundaceae					
Osmunda regalis var. *spectabilis*	Royal fern		X	X	OBL
Polygonaceae					
Polygonum setaceum	Bog smartweed		X	X	FACW
Pontederiaceae					
Pontederia cordata	Pickerelweed			X	OBL
Plumbaginaceae					
Limonium carolinianum	Carolina sea lavender	X	X		OBL
Typhaceae			X		
Typha domingensis	Southern cattail				OBL
Vitaceae					
Ampelopsis arborea	Peppervine		X		FAC+
Ampelopsis cordata	Heart-leaf peppervine		X		FAC+

Table F-2
Animal Species of Concern Found in Association with Tidal Marshes and Intertidal Mud/Sandy Beaches Within the Reference Domain[1]

Scientific Name	Common Name
Insects	
Euphyes bayensis	Bay St. Louis Skipper
Land Snails	
Gastrocopta pellucida	Slim Snaggletooth
Polygyra septemvola	Florida Flatcoil
Succinea luteola	Spanish Ambersnail
Amphibians	
Bufo nebulifer	Gulf Coast Toad
Reptiles	
Alligator mississippiensis	American Alligator
Caretta caretta	Loggerhead Sea Turtle
Chelonia mydas	Green Sea Turtle
Deirochelys reticularia	Chicken Turtle
Malaclemys terrapin pileata	Mississippi Diamondback Terrapin
Nerodia clarki	Gulf Salt Marsh Snake
Pseudemys alabamensis	Alabama Red-bellied Turtle
Thamnophis proximus orarius	Gulf Coast Ribbon Snake
Fishes	
Fundulus jenkinsi	Saltmarsh Topminnow
Heterandria formosa	Least Killifish
Leptolucania ommata	Pygmy Killifish
Birds	
Ammodramus maritimus	Seaside Sparrow
Ammodramus nelsoni	Nelson’s Sharp-tailed Sparrow
Anas fulvigula	Mottled Duck
Anas acuta	Northern Pintail
Anas rubripes	American Black Duck
Aythya affinis	Lesser Scaup
Calidris alpina	Dunlin
Calidris canutus	Red Knot
Calidris mauri	Western Sandpiper
Charadrius melodus	Piping Plover
Charadrius alexandrinus tenuirostris	Southeastern Snowy Plover
Charadrius wilsoni	Wilson’s Plover
Circus cyaneus	Northern Harrier
Coturnicops noveboracensis	Yellow Rail
Egretta rufescens	Reddish Egret
Egretta thula	Snowy Egret
Egretta tricolor	Tricolored Heron
Egretta cerulean	Little Blue Heron
Elanoides forficatus	Swallow-Tailed Kite
Eudocimus albus	White Ibis
Falco columbarius	Merlin
Falco peregrinus	Peregrine Falcon

Sources: Wieland (1994), MS Dept. of Wildlife and Fisheries (2005). [1] Additional species may be added to this list.

(Continued)

Table F-2 (Concluded)	
Scientific Name	**Common Name**
Haematopus palliates	American Oystercatcher
Haliaeetus leucocephalus	Bald Eagle
Laterallus jamaicensis	Black Rail
Limosa fedoa	Marbled Godwit
Mycteria americana	Wood Stork
Nycticorax nycticorax	Black-Crowned Night-Heron
Nycticorax violaceus	Yellow-Crowned Night-Heron
Pandion haliaetus	Osprey
Plegadis chihi	White-Faced Ibis
Pelecanus occidentalis	Brown Pelican
Pelecanus erythrorhynchos	American White Pelican
Rallus elegans	King Rail
Sterna antillarum	Least Tern
Sterna maxima	Royal Tern
Sterna nilotica	Gull-billed Tern
Sterna sandvicensis	Sandwich Tern
Tyrannus dominicensis	Gray Kingbird
Tyrannus forficatus	Scissor-Tailed Flycatcher

Table F-3
Bird Species Found in Tidal Marshes of the Northern Gulf of Mexico

Family/Scientific Name	Common Name
Anseriformes	
Dendrocygna bicolor	Fulvous Whistling-Duck
Anas platyrhynchos	Mallard
A. rubripes	American Black Duck
A. fulvigula	Mottled Duck
A. strepera	Gadwall
A. acuta	Northern Pintail
A. crecca	Green-winged Teal
A. discors	Blue-winged Teal
A. americana	American Wigeon
A. clypeata	Northern Shoveler
Aythya americana	Redhead
A. affinis	Lesser Scaup
Melanitta perspicillata	Surf Scoter
Mergus serrator	Red-breasted Merganser
Ciconiiformes	
Ardea herodias	Great Blue Heron
A. herodias occidentalis	Great White Heron
A. alba	Great Egret
Butorides virescens	Green Heron
Egretta caerulea	Little Blue Heron
E. thula	Snowy Egret
E. tricolor	Tricolored Heron
Nycticorax nycticorax	Black-crowned Night Heron
Ixobrychus exilis	Least Bittern
Botaurus lentiginosus	American Bittern
Plegadis falcinellus	Glossy Ibis
Plegadis chihi	White-Faced Ibis
Eudocimus albus	White Ibis
Cathartes aura	Turkey vulture
Falconiformes	
Circus cyaneus	Northern harrier
Gruiformes	
Rallus elegans	King rail
R. longirostris	Clapper rail
R. limicola	Virginia rail
Porzana carolina	Sora rail
Coturnicops noveboracensis	Yellow rail
Porphyrula martinica	Purple gallinule
Gallinula chloropus	Common moorhen

Source: Stout (1984) and Hubbard and Gidden (1997)

(Continued)

Table F-3 (Concluded)

Family/Scientific Name	Common Name
Charadriiformes	
Larus atricilla	Laughing Gull
Sterna nilotica	Gull-billed Tern
S. forsteri	Forster's Tern
S. caspia	Caspian Tern
Haematopus palliates	American Oystercatcher
Charadrius semipalmatus	Semi-palmated Plover
C. melodus	Piping Plover
C. alexandrinus	Snowy Plover
C. wilsonia	Wilson's Plover
C. vociferous	Killdeer
Pluvialis squatarola	Black-bellied Plover
Arenaria interpres	Rudy Turnstone
Numenius americanus	Long-Billed Curlew
N. phaeopus	Whimbrel
Catoptrophorus semipalmatus	Willet
Tringa melanoleuca	Greater Yellowlegs
Calidris canutus	Redknot
C. bairdii	Baird's Sandpiper
C. minutilla	Least Sandpiper
C. alpina	Dunlin
C. himantopus	Stilt Sandpiper
C. purilla	Semi-palmated Sandpiper
C. mauri	Western Sandpiper
Limnodromus griseus	Short-billed Dowitcher
Recurvirostra americana	American Avocet
Passeriformes	
Tachycineta bicolor	Tree Swallow
Corvus ossifragus	Fish Crow
Cistothorus palustris	Marsh Wren
C. platensis	Sedge Wren
Sturnella magna	Eastern Meadowlark
Agelaius phoeniceus	Red-winged Blackbird
Quiscalua major	Boat-tailed Grackle
Ammodramus nelsoni	Nelson's Sharp-tailed Sparrow
A. maritimus	Seaside Sparrow

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
April 2007

2. REPORT TYPE
Final report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Tidal Fringe Wetlands Along the Mississippi and Alabama Gulf Coast

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Deborah J. Shafer, Thomas H. Roberts, Mark S. Peterson, and Keil Schmid

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Environmental Laboratory, U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; Tennessee Technological University, Dept. of Biology, P.O. Box 5063, Cookeville, TN 38505; University of Southern Mississippi, Dept. of Coastal Sciences, 703 East Beach Dr., Ocean Springs, MS 39564; Mississippi Dept. of Environmental Quality, P.O. Box 10385, Jackson, MS 39289-0385

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/EL TR-07-2

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Mississippi Department of Marine Resources
1141 Bayview Avenue
Biloxi, MS 39530

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence. During the Development Phase of the HGM Approach, four critical components are integrated in a Regional Guidebook for assessing the functions of a regional wetland subclass. Subsequently, during the Application Phase, end users, following the protocols outlined in the Guidebook, assess the functional capacity of selected wetlands. This Regional Guidebook (a) characterizes the tidal fringe wetlands of the Mississippi and Alabama gulf coast (north-central Gulf of Mexico) reference domain, (b) provides a rationale to select functions for the regional tidal fringe subclass, (c) provides a rationale to select model variables and metrics, (d) provides a rationale to develop assessment models, (e) provides data from reference wetlands and documents their use in calibrating model variables and assessment models, and (f) outlines protocols for applying the functional indices to the assessment of tidal fringe wetland functions in the north-central Gulf of Mexico.

15. SUBJECT TERMS
Functional assessment
Hydrogeomorphic approach
Tidal fringe wetlands

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		140	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18