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National Guidebook for Application of Hydrogeomorphic Assessment to Tidal Fringe Wetlands

by

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Technical Editors

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December 1998 – Final Report

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Final report

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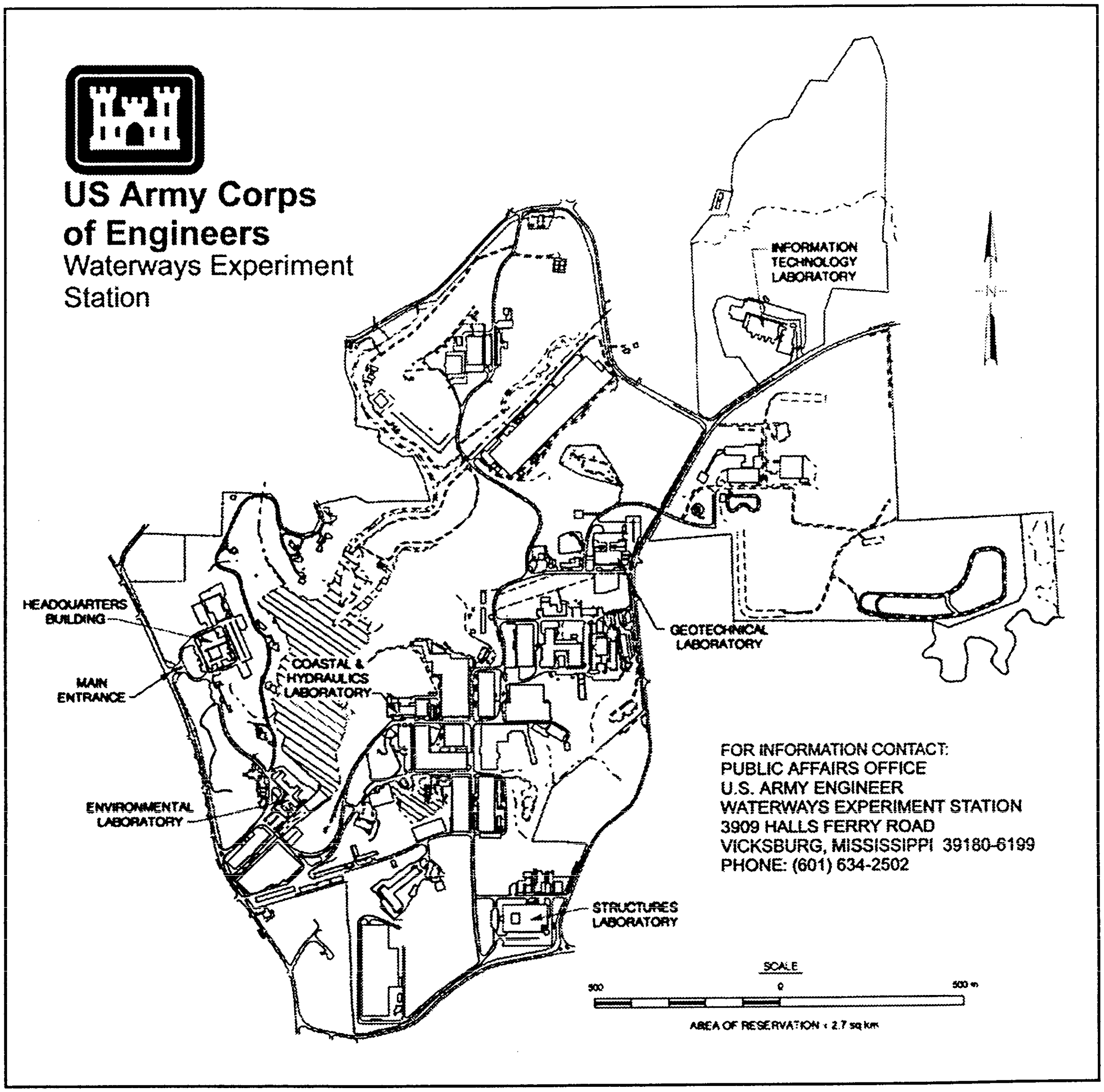

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Assessing Wetland Functions

National Guidebook for Application of Hydrogeomorphic Assessments to Tidal Fringe Wetlands (WRP-DE-16)

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 dredge or fill material in "waters of the United States." As part of the permit review process, the impact of the discharge of dredged or fill material on wetland functions must be assessed. Existing procedures for assessing wetland functions fail to meet the technical and programmatic requirements of the 404 Regulatory Program.

RESEARCH: The objective of this research is to develop an approach for assessing the functions of wetlands in the context of the 404 Regulatory Program.

SUMMARY: This document is for use by a team of individuals who adapt information in this guidebook to tidal fringe wetlands in speific physiographic regions. By adapting from the generalities of the class to specific regional tidal fringe subclasses such as low-elevation salt marshes of the northwestern Gulf of Mexico, the procedure can be made responsive to the specific conditions found there.

AVAILABILITY OF REPORT: This report is available on Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, telephone (601) 634-2355.

To purchase a copy, call the National Technical Information Service (NTIS) at (703) 487-4650. For help on identifying a title for sale, call (703) 487-4780. NTIS report numbers may also be requested from the WES librarians.

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Contents

Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Characterization and Restoration of Wetlands Research Program (CRWRP). Mr. Dave Mathis (CERD-C) was the CRWRP Coordinator at the Directorate of Research and Development, HQUSACE; Ms. Colleen Charles (CECW-OR) served as the WRP Technical Monitor's Representative; Dr. Russell F. Theriot, Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), was Manager, CRWRP; and Mr. Ellis J. Clairain, Wetlands Branch, Ecological Research Division (ERD), EL, was the Task Area Manager. The work was performed under the direct supervision of Mr. Clairain and under the general supervision of Dr. Morris Mauney, Chief, Wetlands Branch; Dr. Conrad J. Kirby, Chief, ERD; and Dr. John Harrison, Director, EL.

This report was prepared by Ms. Deborah J. Shafer, Coastal Ecology Branch, ERD, and Dr. David J. Yozzo, Vittor & Associates, based on a draft manuscript funded by WES under CRWRP and written by Dr. Mark LaSalle, Mississippi State University Coastal Research and Extension Center, Biloxi, MS; Dr. Courtney Hackney, University of North Carolina, Wilmington; Dr. Michael Josselyn, Tiburon Center for Environmental Studies, Tiburon, CA; Dr. Ron Knieb, University of Georgia Marine Institute, Sapelo Island, GA; Dr. Irving Mendelssohn, Louisiana State University Wetland Biogeochemistry Institute, Baton Rouge; Dr. Lawrence Rozas, National Marine Fisheries Service, Galveston, TX; Mr. Charles Simenstad, University of Washington Fisheries Research Center, Seattle; and Dr. Scott Warren, Connecticut College, New London. The contributions of those who attended the National Tidal Fringe HGM Workshop held in Charleston, SC, in September 1996 (Appendix A) are gratefully acknowledged. Mr. Dan Smith, Wetlands Branch, EL, provided comments on the final draft version of this document.

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1 Introduction

Background

The Hydrogeomorphic (HGM) Approach is a suite of concepts and methods used to develop functional indices and apply them to the assessment of wetland functions. The indices were initially intended to be used in the U.S. Army Corps of Engineers regulatory program required under Section 404 of the Clean Water Act to assess the impact of dredge and fill projects on wetlands. Other potential uses such as wetland restoration planning and determining minimal effects under the Flood Security Act have been subsequently identified.

A National Action Plan (NAP) to implement the HGM Approach has been cooperatively developed by the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highways Administration (FHWA), and U. S. Fish and Wildlife Service (USFWS) (U.S. Army Corps of Engineers 1996). The plan outlines a strategy for developing regional guidebooks for assessing wetland functions and for facilitating cooperation and participation by Federal, State, and local agencies, academia, and the private sector in these efforts.

The HGM Approach is implemented in two phases: a Development Phase and an Application Phase. Under the Development Phase, an interdisciplinary team of regional experts is responsible for developing a regional guidebook by classifying wetlands, characterizing a regional subclass, developing assessment models for that subclass, and calibrating the models with data from reference wetlands. The Application Phase involves utilization of the regional guidebook developed under Phase One to assess a particular site or project, and includes characterization, assessment and analysis, and application components. Potential applications of the HGM Approach include, but are not limited to, the following:

a. Comparing functions between sites of similar wetland types.

b. Establishing an objective and technically sound "currency" for use in calculating mitigation ratios and credits.

c. Evaluating the status of habitat restoration/creation efforts.

d. Planning habitat restoration/creation efforts.

e. Providing a reference database on the functional status of wetland ecosystems.

f. Guiding research efforts aimed at testing basic assumptions about ecosystem form and function.

The utility of this approach toward wetland functional assessment 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 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 would allow for the emphasis to be placed on the entire suite of functions or selected functions.

There is no presumption that this assessment procedure is better or worse than any other approach just because it may have been adopted for use by a particular agency or firm. Because this functional assessment procedure is completely open to review and examination and the documentation is explicit, the method can be scrutinized and improved by addition or change as new information becomes available on wetlands and their functions. Details may be challenged or defended based on evidence and facts as they currently exist. The intent of the HGM Approach is to improve consistency and predictability of decision making in wetland regulatory programs by applying the best science possible.

Purpose and Organization of the National Guidebook

The first publication outlining the application of the HGM Approach to wetland assessments was *A Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands* (Brinson et al. 1995). That National Guidebook was the first in a series of seven planned National Guidebooks, one for each of the seven hydrogeomorphic classes of wetlands (Table 1).

A Guidebook for Application of Hydrogeomorphic Assessments to Tidal Fringe Wetlands is the second in the series, and provides a template for developing regional guidebooks for wetlands belonging to the tidal fringe class. Many of the functions and variables included in this National Guidebook were originally included as part of a separate rapid assessment procedure developed by a nine-member interdisciplinary team of estuarine ecologists under contract to the U.S. Army Engineer Waterways Experiment Station (WES). This document also reflects input received from the regional specialists who attended the National Tidal Fringe HGM Workshop held in Charleston, SC, in 1996 (Appendix A).

Table 1
Definitions of Hydrogeomorphic Wetland Classes

Hydrogeomorphic Class	Definition
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 riverflow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and riverine is where bidirectional flows from tides dominate over unidirectional ones 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, by saturated overland flow to tidal creek channels, and by 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.
Depression	Depressional wetlands occur in topographic depressions. Dominant water sources are precipitation, groundwater discharge, and interflow from adjacent uplands. The direction of flow is normally from the surrounding uplands toward the center of the depression. Elevation contours are closed, thus allowing the accumulation of surface water. Depressional wetlands may have any combination of inlets and outlets or lack them completely. Dominant hydrodynamics are vertical fluctuations, primarily seasonal. Depressional wetlands may lose water through intermittent or perennial drainage from an outlet and by evapotranspiration and, if they are not receiving groundwater discharge, may slowly contribute to groundwater. Peat deposits may develop in depressional wetlands. Prairie potholes are a common example of depressional wetlands.
Slope	Slope wetlands normally are found where there is a discharge of groundwater to the land surface. They normally occur on sloping land; elevation gradients may range from steep hillsides to slight slopes. Slope wetlands are usually incapable of depressional storage because they lack the necessary closed contours. Principal water sources are usually groundwater return flow and interflow from surrounding uplands as well as precipitation. 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 saturation subsurface and surface flows and by evapotranspiration. Slope wetlands may develop channels, but the channels serve only to convey water away from the slope wetland. 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, saturation overland flow, and seepage to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage, often due to spodic horizons and hardpans, and low lateral drainage, usually due to low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become organic soil flats. Pine flatwoods with hydric soils are a common 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 saturation overland flow and seepage to underlying groundwater. 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 common examples of organic soil flat wetlands.

(Continued)

Table 1 (Concluded)	
Hydrogeomorphic 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 hydrologic connections between the stream channel and adjacent wetlands. Additional water sources may be interflow and return flow from adjacent uplands, occasional overland flow from adjacent uplands, tributary inflow, and precipitation. At the headwaters, riverine wetlands may intergrade with slope or depressional wetlands as the channel (bed) and bank disappear, or they may intergrade with poorly drained flats or uplands. Perennial flow is not required. Riverine wetlands may lose surface water via the return of floodwater to the channel after flooding, and through saturation surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deep groundwater, 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 hardwood floodplains are a common example of riverine 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 such as seiches in the adjoining lake. Lacustrine fringe wetlands are indistinguishable from depressional wetlands where the size of the lake becomes so small relative to fringe wetlands that the lake is incapable of stabilizing water tables. Lacustrine wetlands lose water by flow returning to the lake after flooding, by saturation surface flow, and by evapotranspiration. Organic matter normally accumulates in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are a common example of lacustrine fringe wetlands.

The National Guidebook is not an assessment manual because "manual" connotes a procedure that can be taken to the field and immediately applied. Brinson et al. (1995) pointed out that National Guidebooks describing the HGM Approach are *not for direct application* by environmental consultants, agency personnel, and others who assess wetland functions under the 404 regulatory program. Instead, the guidebooks serve as templates for the development of regional HGM guidebooks. For a guidebook to be applicable by field personnel, the assessment models that are at the heart of the Approach must first be tested to determine their effectiveness under local and regional conditions. The assessment models must also be calibrated using data obtained from reference wetlands.

A sequence of steps must be followed for developing a regional guidebook for a wetland subclass as outlined in Appendix B. This process normally requires an interdisciplinary assessment team (A-team) effort. Ideally, the A-Team should consist of individuals knowledgeable in hydrology, geomorphology, plant ecology, ecosystem ecology, population ecology, soil science, wildlife biology, and other related disciplines. In order to ensure consistency, each A-Team should be coordinated through the regional Corps of Engineers office and include members from key Federal and State regulatory agencies. In this way, quality assurance in data collection, analysis, and compilation can be ensured and a centralized regional depository of information can be established and maintained for future use.

This document is organized around the major components of the development phase of the HGM Approach. Chapter 1 provides background information on the HGM Approach, outlines basic principles, and sets the scope and objectives of the National Tidal Fringe Guidebook. Each of the seven wetland classes defined under the HGM classification system is briefly described. Chapter 2 presents a detailed characterization of the tidal fringe wetland class and a rationale for defining regional tidal fringe wetland subclasses. The concept and role of reference wetlands is also presented. Chapter 3 contains the definitions of the functions and variables which make up the conceptual assessment models. Chapter 4 outlines a generic assessment protocol for assessing the functions of tidal fringe wetlands.

Hydrogeomorphic Classification

Wetlands occur in a wide range of geological, climatic, and physiographic conditions. This variability presents a challenge to developing accurate and practical techniques for wetland assessments that can be performed within the short time frames typically required. More "generic" methods, designed to assess multiple wetland types, often lack the resolution necessary to detect significant changes in function. The HGM classification (Brinson 1993) was developed to address this problem by identifying groups of wetlands that function similarly, thereby reducing the level of variability.

Under the HGM classification system, wetlands are grouped using three fundamental criteria that influence wetland function, developed by Brinson (1993): geomorphic setting, water source, and hydrodynamics. Geomorphic setting refers to the landscape position and geologic evolution of a wetland. Water source refers to the origin of the water just prior to entering the wetland; primary water sources include precipitation, surface flow, and groundwater. Hydrodynamics refers to the energy and direction of water flow within a wetland. Seven broad classes of wetlands are recognized: riverine (floodplain, riparian, and channel environments), tidal fringe (occupying coastal margins), lacustrine fringe (lake edge), depressional (prairie potholes, playa lakes), slope (seepage areas), mineral flats (wet pine savannas), and organic flats (peatbogs) (Table 1). Each wetland class has been identified based on significant differences in variables that affect functional attributes of these wetlands, in addition to any regional differences. Tidal wetlands, for example, constitute an important wetland category and by definition belong to the Class Tidal Fringe in that they occur along the shoreline of coastal ecosystems and are subject to the ebb and flow of tides. Intertidal marshes, forested swamps along tidally influenced river reaches, and mangrove swamps are all included in this class.

National guidebooks are prepared to characterize wetland classes, including general functions and variables. Wetland classes are further subdivided into regional subclasses, based on additional wetland attributes such as soils, vegetation, slope, and other features. Regional guidebooks are prepared for these regional subclasses, and include a detailed characterization of the regional wetland subclass. The regional guidebooks provide information about specific functions and variables and assessment models calibrated with data derived from a suite of reference sites.

To facilitate development of regional guidebooks, WES is developing a National Guidebook for each of the seven wetland classes described in Table 1. These seven classes are the result of applying Brinson's (1993) hydrogeomorphic criteria of landscape setting, water source, and hydrodynamics to wetlands at a national scale. The purpose of these National Guidebooks is to provide a conceptual template for developing regional guidebooks by characterizing the wetland class, identifying and defining important functions performed by the wetland class, identifying model variables to represent characteristics of the wetland and surrounding landscape that influence the function, and developing conceptual assessment models for deriving functional indices. In effect, these models also describe hypotheses about the relationships between form and function within wetlands. Each model is defined based on the physical and biotic factors that are believed to influence the performance of that function and which may serve as indicators of the level of function (i.e., variables in assessment models). Variable measures are scaled from 0 to 1 based on the natural range of these variables within each wetland type (i.e., values derived from reference sites). Model calibration and verification occur at the regional level, and depend on the collection of regional reference data sets.

2 Characterization of Tidal Fringe Wetlands

Definition of Tidal Fringe Wetlands

This National Guidebook provides a template for developing regional guidebooks that can be used to apply the HGM Approach for wetland functional assessment to tidal fringe wetlands. 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, fjords, and other coastal waterways; receive their water primarily from marine or estuarine sources; and are affected by astronomical tidal action. Included in this group are wetlands commonly known as intertidal marshes, salt marshes, forested riverine swamps, and mangrove swamps and correspond 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, and precipitation. Tidal fringe wetlands lose water by tidal exchange, by saturated overland flow to tidal creek channels, and by 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.

Limits in Geographic Scope and Approach

The geographic scope of this National Guidebook is limited to the continental United States. This decision was based on the conclusion that wetlands in the arctic and tropical regions of the United States (i.e., Hawaii) are functionally different enough from those in the more temperate regions of the country to warrant separate consideration. For similar reasons, tidal riverine swamp forest and mangrove forest, while considered as tidal fringe wetlands under the HGM classification scheme, are not included within the scope of this National

Guidebook for the functional assessment of tidal fringe wetlands. To a large degree, these exclusions reflect the dearth of information about these systems compared with that for the grass- and sedge-dominated tidal marshes. This guidebook, therefore, is restricted to nonforested tidal systems. This approach also considers regional differences in the biotic structure of tidal wetlands and also recognizes the possibility for regional differences in function. Submerged aquatic beds are also excluded from assessment because they are not defined as wetlands under the Corps regulatory program.

Regional Boundaries

For the purposes of initially subsetting tidal fringe wetlands into regional wetland subclasses, the continental United States is subdivided into nine regions. The borders of these regions reflect a combination of major break points in overall tidal range and biota. With some exceptions (particularly the Gulf coast and subunits of the mid-Atlantic), the regional boundaries parallel the estuarine and marine provinces defined by Cowardin et al. (1979). The regional boundaries and characteristics are as follows:

a. *North Atlantic* (Eastport, Maine, to Cape May, New Jersey). Large tidal range (> 3 m), characterized by boreal biota to the break point of Cape May, New Jersey. Includes the Acadian and part of the Virginian Provinces of Cowardin et al. (1979). The Cape May break point was chosen based on the change in tidal range.

b. *Mid-Atlantic* (Cape May, New Jersey, to Virginia Beach, Virginia). Moderate tidal range (1-2 m), the biota being a mixture of boreal and temperate species. This region includes the Delaware and Chesapeake Bay estuaries and, except for the exclusion of the microtidal Albemarle and Pamlico Sounds, parallels the Virginian Province of Cowardin et al. (1979).

c. *South Atlantic* (Virginia Beach, Virginia, to Indian River, Florida). Primarily temperate in nature (largely the Carolinian Province of Cowardin et al. (1979)), subdivided into three subregions (north to south) based on gross differences in tidal regimes:

(1) <u>Microtidal</u> (tidal range < 0.5 m, meteorologically dominated tides, e.g., Pamlico and Albemarle Sounds)
(2) <u>Macrotidal</u> (tidal range 1-3 m, e.g., the Georgia Bight)
(3) <u>Tidally restricted lagoons</u> (e.g., Indian River Lagoon)

d. *South Florida* (Indian River, Florida, to Cedar Key, Florida). Moderate to small tidal range (< 1 m), with subtropic to tropic biota. Includes marsh and mangrove habitats. Part of the West Indian Province of Cowardin et al. (1979).

e. *Northeast Gulf* (Cedar Key, Florida, to Pearl River, Mississippi). Small tidal range (< 1 m), meteorologically dominated diurnal or semidiurnal tides. Freshwater input primarily from small to moderate size coastal plain river systems. This region and the following two regions form the Louisiana Province of Cowardin et al. (1979).

f. *North Central Gulf* (Pearl River, Mississippi, to Galveston Bay, Texas). Small tidal range (< 1 m), meteorologically dominated diurnal tides. Freshwater input primarily from moderate to large river basins (Mississippi, Atchafalaya, and Sabine Rivers). Includes the Mississippi River Deltaic and Chenier plain regions.

g. *Northwest Gulf* (Galveston Bay, Texas, to Texas-Mexico border). Small (< 1 m) to microtidal (< 0.5 m in south Texas), meteorologically dominated diurnal tides. Some subtropical biota in south Texas.

h. *South Pacific* (Baja Peninsula, California, to Cape Mendocino, California). Moderate tidal range (1-2 m), temperate biota, low levels of freshwater runoff (the Californian Province of Cowardin et al. (1979)).

i. *North Pacific* (Cape Mendocino, California, to southeastern Alaska). Moderate (1-2 m) to large (> 3 m) tidal range, temperate and boreal biota, large inputs of freshwater (the Columbian Province of Cowardin et al. (1979).

Classification of Tidal Fringe Wetlands

In defining regional wetland subclasses, several factors, including surface hydrology, salinity, and vegetation type, should be considered (Table 2). The order in which these factors are presented reflects their assumed relative importance in determining the types and levels of wetland functions across these gradients.

Table 2
Basis for Development of Regional Tidal Fringe Wetland Subclasses

CLASS: Tidal Fringe
REGIONAL SUBCLASSES based on:
a. **Surface Hydrology (regularly flooded, irregularly flooded)**
b. **Salinity (saline, brackish, fresh)**
c. **Vegetation Type (marshes, forested swamps)**

Surface hydrology

The influence of astronomical tides is the major factor affecting tidal wetlands and can be defined along both vertical (i.e., intertidal) and horizontal axes (e.g., along coastal rivers). The hydroperiod of these wetlands is affected by both short-term lunar (14- and 28-day) and long-term seasonal cycles in the height of the tides. In some areas, meteorological influences may also be important, but these effects are more difficult to predict due to their random nature. By definition (Cowardin et al. 1979), the intertidal zone refers to that portion of the tidal zone (area under the influence of fluctuating tides) that is alternately exposed to air and flooded by water during the tidal cycle and includes the vertical range between the extreme high and low water levels of spring tides. Most vegetated intertidal wetlands occupy the upper region of the intertidal zone, between the seaward extent of growth of emergent vegetation and the extreme high water level. Within riverine systems, tidal wetlands extend horizontally to the upstream limit of tidal influence and may or may not be exposed to fluctuating salinities (e.g., tidal swamps, tidal freshwater marshes).

The source, frequency, and duration of water exchange affect the rates and sometimes the direction of various physical, chemical, and biotic processes (i.e., functions), the most recognizable consequence of which is the zonation patterns of vegetation in coastal marsh habitats. These patterns have been attributed largely to a combination of hydroperiod, the effect of hydroperiod on physical and chemical properties of wetland soils (e.g., soil texture, chemistry, and oxygen levels), and interspecific competition (Redfield 1972; Ball 1980; Niering and Warren 1980; Nixon 1982; Odum et al. 1984; Vince and Snow 1984; Bertness and Ellison 1987; Latham, Pearlstine, and Kitchens 1994). Other wetland functions, such as nutrient exchange and use of the habitat by aquatic or terrestrial organisms, are also directly affected by hydroperiod. Tidal creeks and rivulets are important conduits for the exchange of water and associated nutrients, particulates, and organisms (Rozas, McIvor, and Odum 1988) and contribute to increasing the "edge" between the vegetated and unvegetated portions of the intertidal zone. Edge is considered a major variable in the current method: the greater the edge, the greater the "potential" for exchange of waterborne materials and/or organisms. In general, low-elevation marshes are dissected by a greater number of tidal creeks and rivulets compared to higher zones. In their description of marsh development patterns, Frey and Basan (1985) associated this phenomenon with the relative age and vertical position of a given marsh and the associated level of tidal exchange (i.e., younger low-elevation marshes have greater numbers of creeks). Redfield (1972) observed that New England high marshes were characterized by fewer creeks and pond holes or pannes. Basan (1979) further noted that, in addition to having fewer creeks, high marshes were more strongly influenced by extreme tidal conditions (i.e., spring high tides) and freshwater runoff from adjacent uplands. From a functional perspective, therefore, regularly flooded and irregularly flooded portions of intertidal wetlands (i.e., low and high marshes, respectively) represent fundamentally different zones based on hydrology and geomorphology.

The current state of knowledge concerning form and function does not support more than a gross division of tidal wetlands relative to this modifier. For this reason, two major divisions of the intertidal zone are recognized based on flooding regime: regularly flooded where tidal waters alternately flood and expose the marsh surface at least daily, and irregularly flooded, where the marsh surface is flooded less than daily (Cowardin et al. (1979)). These categories largely correspond to the low and high marsh habitats defined by Nixon (1982) and Bertness and Ellison (1987). This division implies a general separation of the hydroperiod based solely on flooding frequency and eliminates consideration of the highly variable flooding duration component of the hydroperiod. Regional conditions (e.g., small-tide range and/or wind-dominated areas) may lead to variation in the definition of flooding frequency and may be reflected in the values used to separate categories. In some regions, further subdivision of the intertidal zone based on flooding regime may be necessary. For example, tidal marshes along the northeastern Gulf of Mexico may be classified into three categories (i.e., frequently flooded, low elevation; infrequently flooded, midelevation; and rarely flooded, high elevation).

Salinity

A horizontal salinity gradient ranging from polyhaline or euhaline (occasionally hyperhaline) conditions in some estuaries to fresh conditions in associated riverine systems is characteristic of many estuaries. Salinity affects wetland function primarily through its effect on chemical processes and organism distributions. Tidal freshwater marshes and tidal swamps are located on the freshwater end of the scale with a gradation of tidal marsh "types" extending to the euhaline part of the range. The salinity categories used by Cowardin et al. (1979) (Table 3) are proposed for use in the Guidebooks.

Table 3
Classification Levels for Salinity

Level	Salinity, ppt
Fresh	<0.5
Mixohaline	0.5 - 30.0
Euhaline	30.0 - 40.0
Hyperhaline	>40.0

Vegetation type

Wetlands are often classified by the dominant vegetation type (Golet and Larson 1974; Shaw and Fredine 1956). Marshes, for example, are dominated by grasses and sedges; swamps by trees. In the case of tidal wetlands, most fall within the category of marshes, but some important exceptions include tidally influenced swamp forests, mangrove swamps, and shrub/scrub wetlands. From a functional perspective, these designations are important because vegetation is a key factor determining the types and magnitudes of some wetland functions. From the standpoint of habitat, for example, the vegetative structure of a tidal swamp (large trees) contrasts greatly with that of an adjacent grass-dominated marsh in terms of the kinds of organisms that it can support. Additional biotic, chemical, and physical functions are similarly influenced by these differences.

The effect of salinity on form and function varies along a horizontal gradient within a given tidal region (i.e., estuarine or marine system) and, in combination with site hydrology and climate, affects the vegetative form and species composition of tidal wetlands. The type and form of the vegetation characteristics of these wetlands, therefore, may be used as indicators. The boundary between the two major hydrological zones (i.e., regularly versus irregularly flooded) roughly corresponds to the mean high-water mark and may be readily identified through association with region-specific low-elevation plant zones. The low elevation/frequently flooded zone of marshes generally corresponds to the "tall form" *Spartina alterniflora* zone of northeast Atlantic coast marshes (Nixon 1982; Bertness and Ellison 1987), the tall to medium height *Spartina alterniflora* zones of southeastern Atlantic and Gulf coast marshes (Stout 1984; Wiegert and Freeman 1990), the *Spartina foliosa* zone of California marshes (Josselyn 1983), and the low sandy/low silty, mixed species zones of northwest Pacific coast marshes (Seliskar and Gallagher 1983). As reported by McKee and Patrick (1988), however, the exact upper elevational extent of growth of *Spartina alterniflora* cannot be fixed to a consistent tidal datum (e.g., mean high water), but rather is influenced by the mean tidal range and maximum tidal range.

Exceptions include Alaskan marshes (Vince and Snow 1984), which by this definition are all infrequently flooded, and tidal freshwater marshes (Odum et al. 1984), which generally occur below the mean high-water level. Frequently flooded areas (i.e., low marsh) of tidal freshwater marshes consist of a mixture of broad-leafed emergent species (e.g., *Peltandra virginica, Nuphar luteum,* or *Pontederia cordata*), which changes with latitude (Odum et al. 1984). The high marsh typically supports a mixture of grasses and other herbaceous species.

Although vegetation patterns have been used to define or indicate vertical regions within tidal habitats, the number and relative position of identifiable zones vary on a regional basis and represent varying degrees of inundation associated with local tidal patterns and geomorphic setting (e.g., basin morphology, slope, etc.). Recognition or consideration of many of these microhabitats is beyond the scope and ability of the Tidal Fringe HGM Assessment method being developed.

Under this classification system, tidal fringe wetland types are characterized by specific combinations of hydrologic and salinity regimes (e.g., a regularly flooded, polyhaline marsh) within each of the defined geographic regions. Functional profiles for each wetland type identified in each region will provide reference information about the physical, chemical, and biotic characteristics that define those types. This information can be used to identify or verify the wetland type that is being assessed. Some of this information may also be used as input variables to assessment models. More importantly, these profiles will eventually include reference standard values for each assessment model, as these values are derived from application of the method to the reference wetlands in each regional reference domain.

Reference Wetlands

Reference wetlands are wetlands sites that represent the range of variability that occurs in a regional subclass as a result of natural processes and disturbance (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as anthropogenic alterations. The HGM procedural document (Smith et al. 1995) provides the rationale for the role of reference wetlands in functional assessment and also provides detailed instructions for identifying reference wetlands and determining reference standards. The HGM Approach uses reference wetlands for several purposes. First, they provide a concrete, physical representation of wetlands ecosystems that can be observed and measured. Second, they establish the range and variability of conditions exhibited by the Regional Wetlands Subclass in the reference domain (i.e., the geographic area represented by the reference wetland). Finally, they provide the data necessary for calibrating assessment model variables and functional indices (Smith, in preparation).

Variable measures are calibrated by comparison with reference wetlands that represent the natural range of these variables within each wetland subclass. Reference data must be collected from a suite of reference wetlands within a particular geographic region of the country (reference domain). Reference standard wetlands are the subset of reference wetlands that achieve the highest sustainable level of functioning across the suite of functions. Generally, they are the least altered wetland sites in the least altered landscapes. By definition, all model variable subindices and functional capacity indices (FCI) are scaled to 1.0 based on the range of conditions found in reference standard wetlands (Smith et al. 1995). Table 4 outlines the terms and conditions used in the context of reference wetlands.

Reference wetland data have not been provided in this document because it would be inappropriate to do so. The functional assessment models in a National Guidebook are of a conceptual nature only; by definition, the collection of reference data and model calibration and verification must occur at a regional level.

Table 4
Categories and Nomenclature for Reference

Term	Definition
Reference domain	The geographic area from which reference wetlands representing the regional subclass are selected (Smith et al. 1995, p. 29)
Reference wetlands	Wetlands that encompass the known range of variation in the regional subclass resulting from natural processes such as disturbance and anthropogenic alteration. They are used to establish the range of functioning within the subclass.
Reference standard wetlands	The sites within the reference wetland data set that achieve the highest sustainable level of functions. Generally, they are the least altered wetland sites in the least altered landscapes. By definition, the functional capacity index is 1.0 in reference standard wetlands.
Reference standard variable conditions	The range of conditions exhibited by a group of reference standard wetlands. By definition, reference standard conditions receive a variable subindex score of 1.0.
Site potential	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 subclass.
Project target	The level of function identified or negotiated for a restoration of creation project. The project target is based on the level of function in reference standard wetlands and/or site potential.

3 Assessment Models and Functional Indices

Modeling Approach and Assumptions

In the HGM Approach assessment models are simple representations of functions performed by wetland ecosystems that are constructed and calibrated by the assessment team during the development phase. Assessment models define the relationship between one or more characteristics or processes of a 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.

Assessment model variables represent the characteristics of the wetland ecosystem and the surrounding landscape that influence the functional capacity of the wetland ecosystem. 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 a procedural statement for measuring the variable directly or calculating it from other measurements, (d) a set of values that are generated by applying the procedural statement, and (e) units on an appropriate measurement scale. Table 5 provides several examples.

Table 5
Components of a Model Variable

Name (Symbol)	Measure/Procedural Statement	Resulting Values	Units (Scale)
Surface Roughness V_{ROUGH}	Manning's Roughness Coefficient (*n*). Visually observe wetland characteristics to determine adjustment values for roughness component.	0.01 0.16 0.20	Unitless (interval scale)
Vegetation Density V_{DEN}	Mean density of the dominant vegetation type. Measure stem density in sample plots, convert to area (m^2).	36 112 378	stems/m^2 (ratio scale)
Redoximorphic Features V_{REDOX}	Status of redoximorphic features. Visually inspect soil profile for redoximorphic features.	Present Absent	Unitless (nominal scale)

Model variables can occur in various conditions that correspond to the range of conditions exhibited by reference wetlands in a reference domain. For example, vegetation species composition can be more or less diverse, flooding may be more or less frequent, and soils can be more or less permeable. Model variables are assigned a subindex ranging from 0.0 to 1.0 based on the relationship between that variable condition and the functional capacity of the wetland. When the condition of a variable is similar to a reference standard defined for a reference domain, it is assigned an index of 1.0. As the condition of the variable deviates from the reference standard, it is assigned a progressively lower value that reflects the decrease in functional capacity.

In the assessment models, variables are combined in the form of an aggregation equation to produce a functional capacity index (FCI). The FCI is a measure of the functional capacity of a wetland relative to reference standards in the reference domain, and ranges from 0.0 to 1.0. Wetlands with a functional capacity index of 1.0 exhibit conditions similar to reference standards. A wetland ecosystem with an FCI of 0.1 performs the function at a minimal, essentially unmeasurable level, but retains the potential for recovery. A wetland with an FCI of 0.0 does not perform the function and does not have the potential for recovery, in a practical sense, because the change is essentially permanent.

Descriptions of Functions and Variables

The choice of functions[1] that were included in this National Guidebook was made based on a combination of previous reviews of wetland form and function (Sather and Smith 1984; Strickland 1986; Simenstad et al. 1991), as well as the ideas of the workshop participants (Appendix A) and others involved in the development of HGM assessment techniques (Brinson et al. 1995; Smith et al. 1995). Because the models in this National Guidebook are not intended to be taken to the field and directly applied, they are intentionally general and inclusive, rather than specific. By adapting from the generalities of the tidal fringe class to specific regional tidal fringe subclasses, the procedure can be made responsive to the specific conditions found in the region of interest.

The functional assessment models derived for the tidal wetland HGM Approach utilize a series of measured, recorded, and/or calculated variables that reflect the extent to which selected physical (e.g., amount of edge), hydrologic (e.g., flooding duration and frequency), geographic (e.g., connection with the greater ecosystem), and biotic (e.g., type of vegetation) characteristics of a given site affect the ability of that site to perform certain functions. Variable measures are compared with a region-specific reference data set, reflecting the range of variation exhibited in a regional reference wetland domain. For example, intertidal marshes vary in terms of their accessibility by fishes and crustaceans, which in many cases are highly dependent on marshes for foraging. A given

[1] Appendix C lists definitions and variables for tidal fringe wetlands.

marsh, therefore, will fall within a range of "fisheries potential" based on factors (e.g., flooding duration, amount of creek to marsh edge) that determine the relative time during which fishes have access to this resource (i.e., the marsh surface). Scales for each factor may vary among regions reflecting variation in marsh characteristics. This latter point is the prime reason for the regionalization of this method. Any wetland assessed using this method will be compared with similar wetlands in its respective region.

Four major considerations were used in identifying and selecting the variables that make up the functional assessment models described in this chapter:

a. *Presumed importance*: What is the documented or hypothesized relationship between a factor/variable and the function being described, and is its relative contribution (i.e., importance) toward describing that function enough to warrant its inclusion in the model?

b. *Basis of importance*: What supporting data are available about the relationship between a factor/variable and the function being described? (In many cases, data that would directly support these relationships are currently not available.)

c. *Feasibility of measurement*: Is the factor/variable easily measured, observed, or recorded?

d. *Integrative measurement*: Is the factor/variable subject to extremes of intra-annual and interannual variability that would make it of minimal use as an indicator?

To determine an index for the level of functioning (Index of Function or Functional Capacity) (Smith et al. 1995), pertinent variable indices are combined in equations or models. After the variables are measured in the field, the user will consult the appropriate functional profile to determine the index value for each variable measured. For each function, a variable index matrix is provided that describes the relationship between field indicators and the variable indices. Actual values for the variable indices will ultimately be obtained from functional profiles generated from field data collection at regional reference standard sites. The reference standards represent the highest level of sustainable functioning in the landscape. These are the conditions used to calibrate the models so that both variables and the Index of Function are set at 1.0. For example, the model for Tidal Surge Attenuation (TSA) is:

$$TSA = (V_{DIST} + V_{ROUGH}) / 2 \tag{1}$$

where

$$V_{DIST} = distance$$

$$V_{ROUGH} = surface\ roughness$$

Eight functions have been selected for inclusion in the National Tidal Fringe Guidebook. These functions are not specific for any physiographic region of the country, but rather are generic to provide a common point of departure for regional A-Teams. Each tidal fringe wetland function is described in the following order: definition, importance, discussion of function, functional capacity index, description of variables, and variable indices. For example, the definition of the function Tidal Surge Attenuation is "the capacity of a wetland to attenuate the amplitude of storm surges." Each function is described and a brief rationale is provided, including appropriate literature citations, if available.

Hydrogeomorphic functions

Tidal Surge Attenuation
The capacity of a wetland to reduce the amplitude of tidal storm surges.

Tidal Nutrient and Organic Carbon Exchange
The ability of a wetland to import and export nutrients and organic carbon (dissolved and particulate).

Sediment Deposition
Deposition and retention of inorganic and organic particulates from the water column, primarily through physical processes.

Habitat functions

Maintenance of Characteristic Plant Community Composition and Structure
The ability of a wetland to support a native plant community of characteristic species composition and structure.

Resident Nekton Utilization
Describes potential utilization of the wetland by resident fishes and macrocrustaceans.

Nonresident Nekton Utilization
Describes potential utilization of the wetland by nonresident (transient) fishes and macrocrustaceans.

Nekton Prey Pool
Describes the potential for the wetland to produce and maintain a characteristic benthic and epiphytic invertebrate prey pool.

Wildlife Habitat Utilization
Describes potential utilization of the wetland by resident and migratory avifauna, reptiles, amphibians, and mammals.

Variables

Aquatic Edge V_{AE}
The amount of edge between the intertidal vegetated, intertidal unvegetated, and subtidal areas is considered to be an important factor governing the exchange of organisms. The measured linear edge of recognizable tidal creeks, rivulets, and ponds expressed as a function of the total area of the site is scaled against the linear edge per unit area at reference standard sites.

Distance V_{DIST}
Average measured distance from landward or upland edge of site to nearest unobstructed marsh edge.

Flooding Duration V_{FD}
The proportion of time that the marsh surface is flooded due to tidal inundation, compared with reference standard sites in the region. An accurate determination of flooding duration requires the installation and monitoring of water level recorders. In the absence of such data, the value of this variable is assumed to be 1.0 unless tidal restrictions such as culverts, dams, and levees are present.

Mean Plant Density V_{DEN}
Mean density of the dominant macrophytic vegetation at a site relative to regional subclass reference standard sites. If more than one plant community type or zone occurs, estimate separate values for each zone, then combine and average.

Mean Plant Height V_{HGT}
Mean height of the dominant macrophytic vegetation at a site/mean height of the dominant macrophytic vegetation at reference standard sites. If more than one plant community type or zone occurs, estimate separate values for each zone, then combine and average.

Nekton Habitat Complexity V_{NHC}
A measure of the habitat heterogeneity of a site, based on the comparison of the number of subhabitat types present at a site relative to the number of possible subhabitats known to occur in the appropriate regional reference standard site.

Opportunity for Marsh Access V_{OMA}
V_{OMA} is calculated by adding the perimeters of all the tidally connected waterways (channels, ponds, and embayments), then dividing by the area of the site. The density of connected waterways across the Wetland Assessment Area (WAA) is an indirect measure of the surface of the marsh that is occupied by access routes for aquatic organisms. Unlike aquatic edge, which includes all possible interfaces (including areas that lack a tidal connection to the estuary, e.g., isolated ponds), this variable estimates the contribution that water bodies with connections to the estuary alone have on the potential access of transient organisms, thereby reflecting the assumed relative importance of this form of edge over others.

Percent Vegetative Cover by Exotic or Nuisance Species V_{EXOTIC}
The proportion of a site covered with exotic or other undesirable plant species.

Proximity to Source Channel V_{PSC}
Distance between the center of the site and the nearest large distributary channel, river, bay, or ocean.

Surface Roughness V_{ROUGH}
This variable describes the potential effects of emergent vegetation, obstructions, and microtopographic features on the hydrodynamics of tidal floodwaters.

Total Percent Vegetative Cover V_{COV}
The proportion of a site covered with macrophytic vegetation compared with reference standard sites in the region.

Upland Edge V_{UE}
This variable is calculated to assign a higher value to those sites at which the upland edge is in a natural, undisturbed condition (e.g., forested uplands), and lower scores for upland edge that have been developed or disturbed (e.g., agricultural fields). The amount of upland edge at a site is calculated using the following formula:

$$\frac{\dfrac{Natural\ Upland\ Edge}{Total\ Upland\ Edge} + \dfrac{1 - Total\ Upland\ Edge}{Project\ Perimeter}}{2} \tag{2}$$

and scaled to the amount of upland edge present at reference standard sites in the region.

Wildlife Habitat Complexity V_{WHC}
A measure of the habitat heterogeneity of a site, based on the comparison of the number of subhabitat types present at a site relative to the number of possible subhabitats known to occur in the appropriate regional reference standard site.

Each tidal fringe wetland function is described in the following order: definition, importance, discussion of function, functional capacity index, description of variables, and variable indices.

Tidal Surge Attenuation (TSA)

Definition

This function is defined as the capacity of a wetland to reduce the amplitude of tidal storm surges. A quantitative measure of this function would be the percent reduction in wave energy (or height) per unit distance across the marsh surface.

Importance of the function

Vegetated intertidal wetlands provide a measure of protection against the destructive effects of wave energy associated with storm surges. Vegetation characteristics and the distance across which a storm surge must travel are key factors in the ability of a tidal wetland to mediate the effects of tidal storm surges. Coastal engineers have long recognized the energy-buffering capacity of intertidal wetlands, and many tidal marshes have been established in the United States specifically for the purpose of wave energy reduction and shoreline preservation.

Discussion of function

The ability of a wetland to attenuate storm surges depends on several factors, including the degree of surface roughness attributed to vegetation, surface obstructions and/or microtopography, and the distance over which storm surges may travel across the wetland. Early efforts to establish salt marshes for the purpose of reducing shoreline erosion depended on recognition of the importance of marsh vegetation in dampening wave action (Woodhouse 1979; Broome, Seneca, and Woodhouse 1988). Detailed evaluation of wave climate and the potential for marsh vegetation to attenuate wave energy is a prerequisite for successful marsh establishment projects (Knutson and Inskeep 1982; Knutson et al. 1982; Knutson and Woodhouse 1983).

Roughness coefficients represent resistance to flow. The density, diameter, and height of emergent macrophyte stems are major contributors to site roughness. 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 further induce drag and decrease water velocity. Variation in surface microtopography may also contribute to determination of roughness characteristics. Manning's friction coefficient n has been effectively used to characterize frictional resistance attributed to intertidal marsh vegetation. For example, Miller (1988) calculated a Manning's n of 0.06 for short *Spartina alterniflora* in a South Carolina salt marsh. *Juncus roemerianus* was assigned a Manning's n of 0.125, and is therefore considered more effective in dissipating tidal surges. Emergent marsh vegetation tends to disperse floodwaters uniformly over the marsh surface. In contrast, forested wetlands tend to retain waters locally, often resulting in temporary increases in local flood elevations.

Although not considered in the present model, regional A-Teams may also wish to include other variables to incorporate some measure of the potential wave climate, as well as site slope. Any marsh of a given size and roughness may be highly effective at attenuating short-period, low-energy waves such as those resulting from wind chop or boat traffic, but less effective at attenuating long-period, high-energy storm surges.

Description of variables

Surface roughness V_{ROUGH}. This variable describes the potential effects of emergent vegetation, obstructions, and microtopographic features on the hydrodynamics of tidal floodwaters. Arcement and Schneider (1989) present a detailed protocol for determination of Manning's n on densely vegetated nontidal freshwater floodplains; this protocol could potentially be adapted for use in tidal marsh applications.

The protocol is as follows: One first determines a base roughness n_b and incrementally makes adjustments for various roughness factors in order to determine the total n value for the area in question. Seasonal variability in vegetation characteristics must be considered. For example, salt marshes retain most of their standing plant biomass throughout the year; thus Manning's n is not likely to vary seasonally. In contrast, tidal freshwater marsh communities senesce rapidly in autumn, leaving the marsh surface unvegetated throughout winter and early spring. In this case, a variable roughness coefficient would be necessary in order to discriminate between vegetated and unvegetated conditions and to compensate for changes in vegetation characteristics (height, density, species composition) throughout the growing season.

The following equation is modified from Gardiner and Dackombe (1983) (Tables 6 and 7) for the determination of n values on vegetated tidal marsh surfaces:

$$n = (n_b + n_1 + n_2) \tag{3}$$

where

n_b = a base value of n for the bare soil surface of the marsh

n_1 = a correction factor for the effect of surface irregularities (microtopographic features) on the marsh surface

n_2 = a value for vegetation on the marsh surface

Table 6
Representative Values of n_b and n_1 for Marsh Soil Surface and Marsh Surface Irregularities [1]

Soil Surface	n_b	Marsh Surface Irregularity	n_1
Earth	0.020	Smooth	0.000
Rock	0.025	Minor	0.005
Fine gravel	0.024	Moderate	0.010
Coarse gravel	0.028	Severe	0.020

[1] Gardiner and Dackombe (1983)

Table 7
Range of Values for n_2 for Marsh Vegetation

Marsh Surface Vegetation	n_2 Low	Average	High
Short grasses, no brush	0.025	0.030	0.035
Tall grasses, no brush	0.030	0.035	0.050
Scattered brush, heavy weeds	0.035	0.050	0.070
Light brush and weeds, winter	0.035	0.050	0.060
Light brush and weeds, summer	0.040	0.060	0.080
Medium to dense brush, winter	0.045	0.070	0.110
Medium to dense brush, summer	0.070	0.100	0.160

Distance - V_{DIST}. This variable describes the distance that water must travel across an intervening tidal fringe wetland (distance from the edge.) 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. The greater the width of the marsh, the greater the reduction in wave energy. Marsh width generally depends on regional geomorphologic characteristics, tidal range, and slope of the shoreline.

Measurement

The distance across the wetland that water must travel can be conveniently estimated indirectly from a recent aerial photo or directly in the field. First, establish a baseline by identifying the upland boundary or WAA perimeter, which runs roughly parallel to the shoreline and/or perpendicular to the topographic gradient. Draw a series of transects from this baseline perpendicular to the shoreline and measure the distance to estimate the mean width of the marsh (Figure 1). The number of transects is determined by the length of the baseline (Table 8). Two methods of scaling the variable are suggested, depending on whether the assessment is being conducted in relationship with a proposed project or in the absence of a project. This variable is scaled to a reference standard only if there is no project.

Table 8
Suggested Number of Transects for Estimating Mean Marsh Width

Baseline Length, ft (m)	Number of Transects
<1,000 (<304.8)	3
1,000-5,000 (304.8-1,524)	5
5,000-10,000 (1,524-3,048)	7
>10,000 (>3,048)	variable

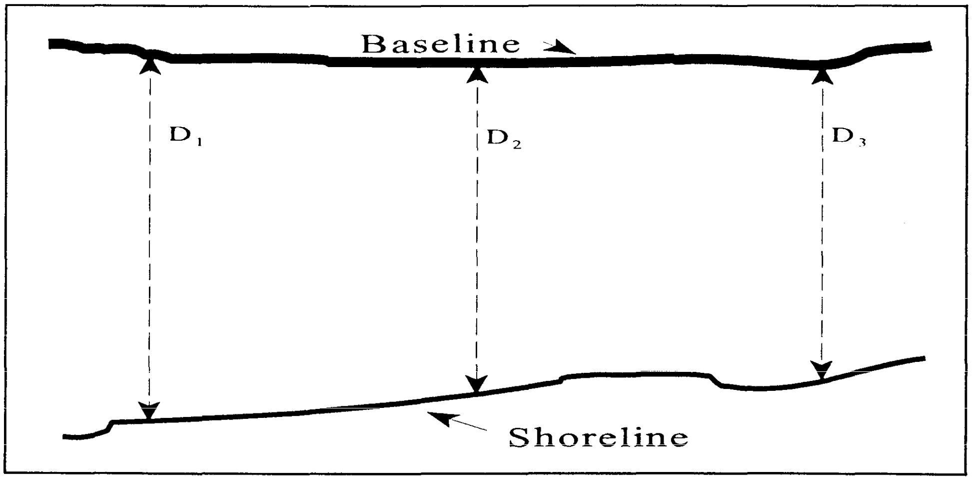

Figure 1. Measurement of the variable V_{DIST}

a. *Scaling Option 1: With Project.* This method estimates the proportion of the width of the WAA that would be lost as a direct result of project impacts. Determine the mean distance as described above. Determine V_{DIST} by dividing the postproject distance to nearest shoreline by the preproject distance to nearest shoreline (After/ Before). Note that in this case, unlike most other HGM variables, this variable is NOT scaled to reference standards.

b. *Scaling Option 2: Without Project.* In the absence of potential project impacts, the value of the variable index is determined by comparison with regional reference standards. Determine V_{DIST} by dividing the mean distance to nearest shoreline at site by the mean distance at reference standard sites.

Functional index

The functional index for tidal surge attenuation (TSA) is calculated using Equation 1:

$$TSA = (V_{DIST} + V_{ROUGH}) / 2$$

Sediment Deposition

Definition

This function refers to the deposition and retention of inorganic and organic particulates from the water column, primarily through physical processes. A quantitative measure of this function would be cm/hectare/year.

Importance of the function

Tidal marshes accrete vertically and expand horizontally across the coastal landscape by accumulating sediments. If sediment availability is reduced, or if accretion rates are insufficient to maintain pace with sea level rise or storm-induced erosion, marsh loss will result. The ability of a tidal marsh to maintain an adequate rate of sediment deposition is critical to maintaining its integrity in a highly dynamic coastal setting.

Discussion of function

Tidal marshes maintain their vertical and horizontal position in the coastal landscape by achieving a balance between two processes: (a) the accretion of mineral and organic sediments, and (b) coastal submergence due to the combined effects of eustatic sea level rise and subsidence. Along transgressive coastlines, the vertical position of the marsh surface relative to mean sea level is determined by sediment supply and the frequency of tidal flooding events. Deposition occurs when the marsh surface is inundated and suspended sediment settles onto the marsh surface. Most material settles out in the low marsh and along tidal creeks, forming levees; the least amount of material settles out in the high marsh, where peat accumulation is the dominant accreting process. If the accretion rate is sufficient, fringing marshes will accrete laterally, as well as vertically, to encroach upland mainland slopes, maintaining their areal extent as erosion occurs along the seaward edge (Kastler and Wiberg 1996).

Marsh sediments originate from a variety of potential sources, including terrestrial drainage, erosion of headlands or shore deposits, eolian transport, washover, and longshore drift. The mineral fraction of marsh sediments includes both sand and finer silt and clay components. Organic constituents include plant detrital material, benthic micro- and macroinvertebrates, organic films, and animal fecal pellets (Kastler and Wiberg 1996).

Several factors may potentially affect the process of sediment accumulation in tidal marshes including elevation, flooding duration, suspended solid concentration, flow baffling by vegetation, and proximity to source (DeLaune, Baumann, and Gosselink 1983; Cahoon and Reed 1995; Leonard and Luther 1995; Leonard 1997). No single factor dominates; instead, they act synergistically to control marsh sedimentation rates (Leonard 1997). High levels of function are associated with low elevation, high concentration of suspended sediment in floodwaters, and low organic content of the suspended sediments.

The behavior of sediment particles with respect to site-specific tidal hydraulics influences the potential for marsh accretion. Settling lag, the tendency for a particle to continue moving with a fluid beyond the point where the current is competent to suspend it, is an important factor. Scour lag, the related process by which a particle remains in place even after its critical velocity has been reached, must also be considered. Tide-velocity asymmetry, the difference in the length of ebb and flood phases of the lunar tidal cycle, also affects the potential for accretion of sediment due to its effect on flooding duration and current velocity (Kastler and Wiberg 1996). Many of these processes are certainly beyond the scope of the HGM method; however, they should be recognized and considered, particularly in the calibration phase of regional model development.

Coastal storm events may have significant influence on sedimentation rates, especially in microtidal or mesotidal systems, where storms result in extensive and prolonged inundation and canopy flow. In these systems, the effects of major storms may far surpass the amount of sedimentation attributed to daily tidal events (Wolaver et al. 1988; Leonard, Hine, and Luther 1995). In macrotidal systems, storms rarely produce more flooding than a typical spring tide event, and are therefore of little consequence in total sediment input (Stumpf 1983). Although the generic form of the Sediment Deposition Function presented here does not consider climatic forcing events, regional A-Teams may wish to incorporate a storm effects variable into the function, depending on the tidal regime of the region under consideration.

Not all tidal marshes function as sediment sinks. Many areas along the mid-Atlantic coast are losing tidal marsh rapidly due to wave- and wind-induced erosion. Eroding high marshes in Chesapeake Bay export sediments and maintain their relative vertical position in the coastal landscape by deposition of peat materials, rather than accumulation of inorganic sediment (Stevenson, Kearney, and Pendleton 1985). It has been suggested that a chronic reduction in sediment loading from riverine sources, brought about by changes in land use, may be more important than changes in eustatic sea level rise as a factor in marsh loss in certain areas of the U.S. east coast (Stevenson, Ward, and Kearney 1988). Along the central U.S. Gulf coast, vertical accretion of tidal marshes has not kept pace with rising sea level, resulting in considerable loss of marsh area and conversion of marsh to shallow open-water habitat (DeLaune, Baumann, and Gosselink 1983). In contrast, marshes along Florida's west-central coast appear to be accreting at rates exceeding local sea level rise (Leonard, Hine, and Luther 1995).

Description of variables

Flooding duration V_{FD}. The length of time during which the marsh surface is inundated has been demonstrated to affect sedimentation rates (Wolaver et al. 1988; Cahoon and Reed 1995). The opportunity for particles to settle out of suspension increases with increasing flooding duration. An accurate determination of flooding duration requires the installation and monitoring of water level recorders. In the absence of such data, the value of the variable index V_{FD} is assumed to be 1.0 unless tidal flow is restricted due to the presence of culverts, dikes, or impoundments.

Surface roughness V_{ROUGH}. The baffling effect of emergent marsh vegetation and microtopographic relief, which retards surface water flow, allows suspended particulates to settle out of suspension (Stumpf 1983; Leonard, Hine, and Luther 1995). Emergent macrophyte roots and rhizomes serve to stabilize sediments, reducing the potential for tidal resuspension and transport. See previous section for guidance on the calculation of Manning's n roughness values for tidal marshes. Algal mats on the surface of tidal wetlands also serve to bind sediments. Filter-feeding bivalves remove sediment from overlying water and deposit it on the marsh surface as feces or pseudofeces. Although not included in the generic national function, these factors could be represented on a region-specific basis.

Proximity to source channel V_{PSC}. The potential for sediment deposition decreases with increasing distance from the source of sediments. This relationship is likely to be a logarithmic one, since turbulent flow energy in tidal marsh canopies decays exponentially with increasing distance from the creek edge (Leonard and Luther 1995). A source channel is defined here as the nearest distributary channel, river, bay, or ocean.

Functional index

The functional index for sediment deposition (SD) is calculated using Equation 4:

$$SD = (V_{PSC} + V_{FD} + V_{ROUGH}) \ / \ 3 \tag{4}$$

Tidal Nutrient and Organic Carbon Exchange

Definition

This function is defined as the ability of the wetland to import and/or export nutrients and organic carbon. Quantitative measures of this function include mass of organic carbon, phosphorus, and ammonium nitrogen transported per unit area per unit time.

Importance of the function

Tidal nutrient flux via surface water or groundwater is important in maintaining the high levels of primary productivity characteristic of tidal wetlands. Characterization of the magnitude and direction of nutrient flux in tidal wetlands is important in the determination of the ability of the wetland to mediate water quality and to maintain characteristic plant communities. The latter is especially relevant to newly created or developing tidal wetlands, where nutrient limitation often dictates project success or failure.

Tidal wetlands are known to export organic carbon to nearshore coastal waters in both dissolved (DOC) and particulate (POC) forms. This process has been the focus of a dominant paradigm in coastal ecology, the "outwelling hypothesis" (Odum 1980). Although the importance and general applicability of this paradigm have been challenged in recent years, particularly with regard to the role of phytoplankton production in coastal waters, it has formed the basis of much subsequent research and numerous management strategies in coastal systems.

Future regional guidebook developers may wish to review the applicability of this function to tidal wetlands of interest in their particular geographic region. Regional A-teams may elect to modify this function to evaluate carbon/nutrient export and import functions separately. Other variables, not included in this generic national model, such as soil texture and marsh age, may also be considered.

Discussion of function

Odum (1974) proposed that nutrient inputs via tidal waters were important in maintaining the characteristic high productivity of *Spartina alterniflora* in creek-side salt marshes. Nutrient input 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 *Spartina alterniflora* growth form to gradients in chemical and physical characteristics of tidal marshes, including nutrient availability (Valiela and Teal 1974; Broome, Woodhouse, and Seneca 1975; DeLaune and Pezeshki 1988). This is particularly true for developing or man-made 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 both ammonium and nitrate at the root-pore-water interface, especially when multiple stressors are present.

Nutrient exchange capacity in tidal wetlands may be considered a function of 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, Woodhouse, and Seneca 1975; Osgood and Zieman 1993) in which *Spartina alterniflora* plants in newly developed marshes exhibited an enhanced growth response relative to plants in older marshes.

Previous efforts to characterize nutrient exchanges in tidal marshes have yielded varying results, and seasonal differences in nutrient exchange are often pronounced. Major fluxes of nitrogen in the Great Sippewisset marsh in Massachusetts were attributed to nitrate in groundwater and dissolved organic nitrogen (DON) in tidal surface waters. A net export of DON was documented; however, inputs and outputs of total nutrients were approximately equal (Valiela et al. 1978; Kaplan, Valiela, and Teal 1979). Woodwell et al. (1979) observed a net export of ammonium nitrogen during summer and fall from a Long Island, New York, salt marsh. During winter and spring, the marsh imported ammonium nitrogen and nitrate. Wolaver et al. (1983) observed strong seasonal trends in tidal exchanges of nitrogen and phosphorus in a Virginia salt marsh, with considerable export of DON 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.

Nutrient flux in tidal freshwater wetlands has not been studied as extensively as in salt marshes; however, based on geomorphologic similarities and other ecosystem attributes, it has been suggested that, like salt marshes, they can function either as sources, sinks, or transformers of nutrients (Mitsch and Gosselink 1993). Simpson et al. (1983) found that tidal freshwater marshes in New Jersey imported nitrogen and phosphorus during spring, primarily from upland runoff. During late spring and throughout the summer, most nutrients were tied up in plant biomass. During fall, there was a rapid and significant export of nutrients associated with the rapid senescence and decomposition of plant material. Thus, overall, a net export of nitrogen and phosphorus occurred across the entire year.

Tidal wetlands may potentially export organic carbon, in both the particulate and dissolved form, to adjacent coastal waters where it may be utilized by benthic and pelagic microconsumers. Because these processes are influenced by a variety of factors, including basin geomorphology, marsh age, vegetation dynamics, and season, it is quite difficult to generalize among tidal wetlands regarding their ability to perform this function. Many studies have attempted to estimate net flux of detrital material to coastal waters, although such estimates are often subject to considerable error, due primarily to tidal cycle asymmetry. The relative importance of DOC versus POC is still largely unknown, due to the difficulty in estimating leaching rates of DOC from decomposing macrophytes and other sources (phytoplankton, benthic algae).

Vegetation decomposition rates 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., in tidal freshwater marshes occurs more rapidly than breakdown of salt marsh species such as *Spartina patens* or *Juncus roemerianus*, which are characterized by high carbon:nitrogen ratios, and thus decompose gradually (Odum and Heywood 1978). Water and air temperatures 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, via either passage through the gut or mechanical fragmentation by chewing.

Wiegert, Christian, and Wetzel (1981) developed an ecosystem model for salt marshes on Sapelo Island, Georgia. In their model, the tidal export coefficient estimated a combined POC and DOC export value of approximately 1000 g C/m^2/year. 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.

A number of other potentially important factors are worthy of future consideration by regional A-teams. Nutrients can enter tidal wetlands by precipitation, upland runoff, groundwater flow, and tidal exchange. In the current index, tidal exchange is considered the dominant nutrient source, and the potential role of other sources is not specifically addressed. Only recently have ecologists investigated the role of subsurface nutrient flux in determining gradients in primary productivity. Nutrient-rich marsh pore waters are exchanged at interfaces such as marsh creeks; subsurface exchanges may account for as much as 50 percent of nutrient export from tidal marshes (Jordan and Correll 1985). Childers, Cofer-Shabica, and Nakashima (1993) postulated that marshes in coastal areas with tidal ranges in excess of one meter were dominated by subtidal horizontal exchanges of pore waters, whereas solute exchange in marshes characterized by tidal ranges of less than one meter occurred primarily within marsh surface waters. It has been demonstrated that, in areas of increased pore-water flux, *Spartina alterniflora* production is enhanced. Regularly flooded tidal marshes, especially those in an early stage of development, tend to exhibit increased rates of nutrient flux relative to older marshes, in which distinct, isolated zones of subsurface hydrology are recognized, and within which internal nutrient cycles may predominate. Storm events are also not considered, although they are certainly responsible for the transport of considerable amounts of suspended organic and inorganic materials in tidal marsh systems.

Description of variables

Nutrient cycling in tidal systems is mediated by physical, chemical, and biological factors. Many of the factors affecting these processes are either poorly understood or beyond the scope of a rapid assessment method such as this one. Although algae, phyptoplankton, and bacteria are known to be important contributors to nutrient cycling and primary production in coastal systems, the difficulties involved in accurate data collection and the highly variable nature of the data make consideration of these factors impractical. The variables chosen for this functional index represent those factors that are both practical to measure and are presumed to affect nutrient and organic carbon flux in tidal systems.

This index incorporates variables that are believed to represent biological and hydrologic site characteristics that would logically contribute to the production, suspension, and removal of detrital particles and any associated nutrients via tidal exchange of surface waters. Particulate organic carbon flux in tidal systems is largely a function of the quality and quantity of organic detritus produced (percent cover of emergent plant species, height, and density) and the mechanisms available for transport (tidal flooding). High levels of function are assumed to occur at those sites with flooding frequency, duration, percent vegetative cover, height, and density similar to reference standard sites.

Flooding duration and the aggregate of plant variables representing biomass were considered of equal weight. Therefore, the plant variables were aggregated first by computing the arithmetic mean. Flooding duration and the aggregate plant index were combined using a geometric mean, so that a zero value for either would result in an FCI of zero.

Flooding duration V_{FD}. Infiltration of nutrients to the root zone occurs during periods of inundation. Increases or decreases in the flooding duration at a particular site relative to reference standard sites in the region may change nutrient cycling patterns within the marsh. An accurate determination of flooding duration requires the installation and monitoring of water level recorders. In the absence of such data, the value of the variable index V_{FD} is assumed to be 1.0 unless tidal flow is restricted due to the presence of culverts, dikes, or impoundments.

Total percent vegetative cover V_{COV}. This variable is a measure of the relative proportion of a site that is covered with emergent vegetation. High levels of organic carbon production and nutrient cycling are assumed to occur at sites with a high proportion of vegetative cover.

Mean plant density V_{DEN} and mean plant height V_{HGT}. Dense, structurally complex emergent vegetation serves to retard the flow of tidal surface waters across the marsh surface, providing opportunity for nutrient transformation and materials exchange. Vegetation also provides surface area for bacterial populations, which play an important role in nutrient cycling. Plant height and density directly affect the potential for organic carbon exchange by influencing the quantity of organic detritus produced. A short, stunted growth habit may be an indication of nutrient limitation.

Functional index

The functional index for tidal nutrient and organic carbon exchange (TNOCE) is calculated using Equation 5:

$$TNOCE = \left[V_{FD} \times \frac{(V_{COV} + V_{DEN} + V_{HGT})}{3} \right]^{1/2} \tag{5}$$

Maintain Characteristic Plant Community Composition

Definition

This function is defined as the ability of a wetland to support a native plant community of characteristic species composition. Quantitative measures of this function would be species composition and the relative proportion of a site covered with exotic or nuisance vegetation.

Importance of the function

The vegetative community is one of the fundamental components of both terrestrial and wetland ecosystems. Changes in the plant species composition and vegetative structure may profoundly affect the entire suite of physical, chemical, and biological processes occurring within a site. The critical role of the vegetative community in the functions of wave attenuation, shoreline stabilization, nutrient and organic carbon cycling, and fisheries and wildlife support is recognized through the incorporation of variables measuring plant species composition, height, and/or density into each of these functions. This function seeks to address issues of regional biodiversity, as well as the ability of the plant community to serve as potential indicators of site degradation from sources such as nutrient enrichment and hydrological alteration.

Discussion of function

The number of plant species that are able to exist in salt marshes is limited due to environmental stress factors such as the duration, frequency, and depth of flooding and high pore-water salinity levels. Salt marsh vegetation is dominated by grasses (Poaceae), rushes (Juncaceae), sedges (Cyperaceae), and chenopods (Chenopodiaceae) 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 generally lack the complex multilayered structure characteristic of forested communities; although a shrub-scrub 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 scheme.

Changes in the extent of aereal coverage and species composition of tidal marshes may occur as a direct result of altered hydrology, such as dikes, channels, or impoundments. 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 augustifolia*, at the expense of more salt-tolerant species such as *Spartina alterniflora* (Sinicrope et al. 1990). Such conditions may also allow the introduction and spread of non-native or undesirable species, such as *Phragmites australis* (Roman, Niering, and Warren 1984).

The following paragraphs briefly describe typical species composition and zonation patterns for tidal marshes along the Atlantic, Gulf, and Pacific coasts. Regional A-Teams will develop regional profiles for each subclass describing the specific vegetation characteristics of reference standard sites within their region. Since plant communities in tidal marshes have been relatively well studied, most, if not all, of this information can be derived from previously published resources.

Smooth cordgrass *(Spartina alterniflora)* is the dominant plant in the intertidal zone along the Atlantic coast and the western Gulf of Mexico. This species generally occurs between mean high water and mean low water and exhibits considerable variation in growth form (i.e., tall, medium, and short), as determined primarily by tidal flooding frequency and duration. Above mean high water, floral composition of salt marshes increases in diversity and varies with latitude. Common species include saltmeadow cordgrass (*Spartina patens*), saltgrass *(Disticlis spicata)*, blackgrass (*Juncus gerardi*), and black needlerush (*Juncus roemerianus*). Unvegetated salt pannes are common intertidal landscape features in Atlantic and Gulf coast salt marshes, and these pannes may be fringed by halophytes such as glasswort (*Salicornia* sp.) and saltwort (*Batis maritima*).

Brackish marshes generally occur in association with freshwater input from coastal rivers and bayous. Depending on the amount of freshwater input and its effect on the local salinity regime, these marshes may be dominated by either smooth cordgrass or big cordgrass (*Spartina cynosuroides*). Bulrush (*Scirpus americana*) and pickerelweed (*Pontederia cordata*) may also be present in mixed stands associated with big cordgrass.

Along central and southern California, the intertidal zone is dominated by Pacific cordgrass (*Spartina foliosa*). Bulrush (*Scirpus robustus*) may occur in brackish areas (Knutson and Woodhouse 1983). The high marsh (above mean high water) is dominated by pickleweed (*Salicornia virginia*), and saltgrass is common. Species diversity is highest in Pacific northwest tidal marshes. The dominant species here include pickleweed, Lyngbye's sedge (*Carex lyngbyei*), three-square bulrush (*Scirpus californicus*), and spike rushes (*Eleocharis* spp.). In the upper elevations, saltgrass is common (Knutson and Woodhouse 1983).

Description of variables

Total percent vegetative cover V_{COV}. This variable is measured by comparison of the total percent vegetative cover of a site with the percent vegetative cover for reference standard sites in a given region. A mosaic of vegetation interspersed with bare patches and/or open water is characteristic of many coastal marshes. Abnormally high cover may be indicative of a pathological condition related to nutrient enrichment. Conversely, very low cover may indicate marsh fragmentation and deterioration due to subsidence or hydrological modification.

Percent vegative cover by exotic or nuisance species V_{EXOTIC}. 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 in proportion to the amount of the site that is covered by undesirable species.

Functional Capacity Index

The plant community composition (PCC) functional index is calculated using Equation 6:

$$PCC = \frac{V_{COV} + V_{EXOTIC}}{2} \tag{6}$$

Resident Nekton Utilization

Definition

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

Importance of the function

Tidal marshes provide forage habitat, spawning sites, and a predation refuge for resident fishes and macrocrustaceans. These organisms are typically year-round residents of intertidal marshes and adjacent subtidal shallows. The ubiquitous killifishes (*Fundulus* spp.) and grass shrimp (*Palaemonetes* spp.) are characteristic residents of Atlantic and Gulf coast intertidal wetlands. These organisms are consumed by nektonic and avian predators and are considered to represent an important link in marsh-estuarine trophic dynamics.

Discussion of 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 type (see also the section "Nonresident Nekton Utilization"). Most evidence suggests that resident organisms (e.g., killifishes, grass shrimp) utilize the entire marsh surface across the range from low to high elevations for foraging and reproduction and as a refuge from predators. Although a number of factors are believed to determine utilization of these areas by 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. The model includes the following factors: habitat complexity, access to and availability of "aquatic edge," and the duration of tidal flooding. It is assumed that the potential utilization of a site by resident nekton will change as a direct function of each of these variables.

Resident nekton are widely distributed throughout the lower intertidal marsh early and late in the tidal cycle (Kneib 1984a; Rozas and Reed 1993). Field experimentation has shown that the mummichog *Fundulus heteroclitus* requires access to the marsh surface for foraging to maintain normal growth rates (Weisberg and Lotrich 1982). Gulf killifish *Fundulus grandis* consume more prey when they have access to the marsh surface than when they are confined to subtidal areas by low tides (Rozas and LaSalle 1990). Resident nekton will make extensive use of high marsh when spring tide conditions facilitate access to the upper intertidal zone. Kneib (1993) found that when high and low *Spartina alterniflora* marshes were flooded for equal periods (5 to 6 hours), growth rates and survival of mummichog (*Fundulus heteroclitus*) larvae were greater in the high marsh, presumably due to greater availability of preferred invertebrate prey. The dense vegetation characteristic of high marsh habitats may also offer greater protection from natant predators than low marshes. Several resident killifish species, including *Fundulus heteroclitus,* rely on availability of high intertidal marsh, coincident with spring tidal events, for use as spawning sites (Taylor et al. 1979; Taylor and DiMichele 1983; Greeley and MacGregor 1983).

Tidal creeks and channels are used as "staging areas" for resident and nonresident nekton at low tide and represent corridors between the marsh surface and deeper, subtidal habitats (Rozas, McIvor, and Odum 1988). In tidal freshwater marshes, the presence of dense submerged aquatic vegetation (SAV) provides foraging opportunities and a predation refuge to resident nekton confined to subtidal areas at low tide (Rozas and Odum 1987a, 1987b). The shallow pools that remain in intertidal channels may also provide a low tide refuge for resident species (Kneib and Wagner 1994). Shallow, water-filled depressions and rivulets distributed across the marsh surface provide habitat for small resident organisms and allow them to remain there at low tide (Kneib 1978, 1984a, 1987).

Resident nekton are not confined to the marsh edge or marsh-open water interface due to their mobility, small size, and broad environmental tolerances. However, densities of most species tend to decrease substantially with distance from the marsh-open water interface. Therefore, resident nekton abundance across the intertidal marsh surface may be positively correlated with the amount of marsh edge available (Kneib and Wagner 1994; Minello, Zimmerman, and Medina 1994; Peterson and Turner 1994; Zimmerman and Minello 1984).

Description of variables

The weighting factors assigned to each variable in the functional index equation represent purely subjective estimates of the relative importance of each of the variables to the overall function. Regional A-teams may wish to reevaluate these factors based on existing data.

Aquatic edge V_{AE}. The amount of edge between the intertidal vegetated, intertidal unvegetated, and subtidal areas is considered to be an important factor governing the exchange of organisms. The measured linear edge of recognizable tidal creeks, rivulets, ponds, and pans per unit area of the site is compared with the linear edge per unit area at reference standard sites.

The measured aquatic edge includes the actual edge between the marsh and adjacent bodies of water within the WAA, including the edge along open water such as rivers or bays, edges of ponds located within the WAA, and edges along both banks of tidal creeks. The edges of the smallest detectable creeks should be included, even when open water is not apparent. It does not include upland (terrestrial) edge. Using a distance-measuring instrument and an appropriate aerial photo, measure these edges. For creek edge, either measure both sides of every creek or measure the length of each and multiply by 2. The edge should be expressed as a function of the total area of the site (i.e., meters of edge/hectare).

As an alternative to a linear measurement of edge, regional guidebook developers may consider developing a series of photographs illustrating increasing amounts of edge. The amount of edge at a given site could be estimated by matching edge patterns from aerial photos with known amounts of edge in the photos.

Flooding duration V_{FD}. Since resident 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. An accurate determination of flooding duration requires the installation and monitoring of water level recorders. In the absence of such data, the value of the variable index V_{FD} is assumed to be 1.0 unless tidal flow is restricted due to the presence of culverts, dikes, or impoundments.

Nekton habitat complexity V_{NHC}. Habitat complexity is a measure of the heterogeneity of a site, based on the 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, midmarsh, high marsh), water bodies (e.g., ponds, tidal creeks, and channels), physical structures (e.g., coarse woody debris, oyster reefs), and the presence of SAV in adjacent subtidal areas all contribute to the habitat complexity of a site and may affect utilization by resident nekton species. Habitat complexity is computed by dividing the number of habitats found in the WAA by the maximum number of habitats indicated for that subclass in the regional reference data set. 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. The user should refer to the reference standard data set for the particular regional subclass in question to determine the possible habitat types that may be present.

Functional index

The functional index for resident nekton utilization (RNU) is calculated using Equation 7.

$$RNU = \frac{(V_{AE} + 2V_{FD} + 0.5V_{NHC})}{3.5} \tag{7}$$

Nonresident Nekton Utilization

Definition

This function describes the potential utilization of a site by seasonally occurring adults or juveniles of marine or estuarine-dependent fisheries species. A quantitative measure of this function would be abundance (or biomass) of nonresident nekton per square meter.

Importance of the function

Tidal marshes provide foraging opportunities and a predation refuge for a variety of estuarine-dependent fisheries species. Most of these organisms are seasonal inhabitants, entering tidal marshes as juveniles in the spring and leaving in the fall. Several important commercial fisheries in the United States (i.e., southeast and Gulf coast penaeid shrimp) are critically dependent on the availability of suitable tidal marsh nursery habitat.

Discussion of function

Nonresident or transient fishes and macrocrustaceans utilize tidal wetlands as forage sites and protection from predators. This model is based on both the opportunity and the means by which transient nekton access a tidal wetland and the attributes of the wetland that provide prey resources and refuge from predation. The model incorporates variables that include measurement of the proximity of a site to subtidal source channels, access to the site via the tidal drainage channel network, the nature and extent of aquatic edge, the duration of tidal flooding, and a measure of habitat complexity. It is assumed that the potential utilization of a site by transient nekton will change as a direct function of each of these variables.

Nonresident nekton utilize tidal wetlands on a seasonal basis and typically do so only for part of their life cycle. In most cases, it is the juvenile forms that utilize these habitats as nurseries and refuges from large predators. Unlike resident nekton (e.g., killifishes, grass shrimp), which utilize intertidal wetlands for most of their life histories and utilize the entire elevational range of these habitats (i.e., low to high elevation zones), nonresident nekton are more restricted in their access to these areas. These organisms invade coastal marshes on rising tides, access the marsh almost exclusively through the tidal channel system, utilize the interior marsh surface only during longer, higher tides, and usually vacate all tidal channels during tidal exposure (Zimmerman and Minello 1984; Kneib 1991; Rakocinski, Baltz, and Fleeger 1992; Rozas and Reed 1993; Baltz, Rakocinski, and Fleeger 1993; Peterson and Turner 1994).

Most transient nekton species found in coastal marshes originate from subtidal habitats (mainstream and large distributary channels, deepwater bay, or ocean) that are linked to marshes by the tidal drainage system. Although resident nekton may occupy residual waters in tidal channels within or adjacent to the marsh (see the section "Resident Nekton Utilization"), nonresident nekton tend not to remain in shallow microhabitats and must retreat to deeper water on most ebb tides. Thus, the tidal channels linking the marsh drainage system and the subtidal refuge constitute corridors between the two habitats (Rozas, McIvor, and Odum 1988). Although information on recurring movement patterns is lacking, the current belief is that transient nekton have no strong fidelity toward a particular wetland site, but tend to move about an estuary or between estuaries.

A number of additional variables may also be considered as indicators of nonresident nekton utilization, but are probably not as easily measured or estimated as the variables presented here. Geomorphic characteristics including tidal channel diversity (i.e., the number and relative abundance of channels of varying order), the rate of bifurcation of channels, and channel sinuosity are believed to be important factors that may influence utilization patterns of transient and possibly resident nekton. These variables may be appropriate for consideration by regional A-Teams for inclusion in future models.

Description of variables

Aquatic edge V_{AE}. See description under the section "Resident Nekton Utilization."

Flooding duration V_{FD}. The opportunity for transient nekton to access the tidal channel system, as well as the marsh surface from the tidal channels, is determined primarily by the duration of tidal flooding. 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). See previous sections for a description of the measurement of V_{FD}.

Nekton habitat complexity V_{NHC}. Use of the marsh by nonresident nekton may also be influenced by the structural attributes of the intertidal and adjacent subtidal habitats. Many nekton species, such as penaeid shrimp, exhibit preferences for certain attributes of marsh vegetation, such as stem density or height, which may mediate susceptibility to predation (Minello and Zimmerman 1983; Zimmerman and Minello 1984). Other structures, such as coarse woody debris (Everett and Ruiz 1993), oyster reefs (Crabtree and Dean 1982), and the prop roots of red mangroves (Thayer, Colby, and Hettler 1987) also appear to attract transient nekton. Shallow ponds and ditches in the midmarsh to upper intertidal marsh may also attract transient nekton, but access will be limited to those organisms that can penetrate interior marshes on higher tides. See previous section for a description of the calculation of V_{NHC}.

Opportunity for marsh access V_{OMA}. V_{OMA} is calculated by adding the perimeters of all the tidally connected waterways (channels, embayments, and ponds), then dividing by the area of the WAA. The density of connected waterways across the WAA is an indirect measure of the surface of the marsh that is occupied by access routes for aquatic organisms. Unlike aquatic edge, which includes all possible interfaces (including areas that lack a tidal connection to the estuary, e.g., isolated ponds), this variable estimates the contribution that water bodies with connections to the estuary alone have on the potential access of transient organisms, thereby reflecting the assumed relative importance of this form of edge over others.

Functional index

The nonresident nekton utilization (NNU) functional index is calculated from Equation 8:

$$NNU = \left[\left(\frac{V_{AE} + V_{FD} + V_{NHC}}{3} \right) \times V_{OMA} \right]^{1/2} \tag{8}$$

Nekton Prey Pool

Definition

This function is defined as the potential for the wetland to produce and maintain a characteristic benthic and epiphytic invertebrate prey pool. A quantitative measure of this function would be abundance of nekton species per unit area.

Importance of the function

Benthic and epiphytic invertebrates represent a critical link in the trophic transfer of energy (in the form of secondary production) to near-coastal waters. Resident nektonic predators (e.g., killifish, caridean shrimp) access the intertidal marsh surface on rising tides to forage on macroinfauna and epifauna. These consumers, in turn, are preyed upon by larger predatory fishes in adjacent subtidal habitats.

Discussion of function

The spatial distribution of benthic and epiphytic invertebrates in tidal marshes is known to be nonrandom. Important factors that may determine invertebrate distribution and abundance include predation, competition, larval settlement patterns, and variation in environmental conditions. Physical variables, such as macrophyte stem height and density and microtopography, also influence aggregation patterns of intertidal benthic organisms (Bell 1979; Van Dolah 1978; Osenga and Coull 1983; Rader 1984). Macroinfauna are often more abundant in dense marsh vegetation (e.g., *Spartina*) than in bare or sparsely vegetated intertidal habitats. Small benthic organisms that are able to exploit the root or culm surface benefit from increased area for colonization. Nonrandom recruitment of larvae and postlarvae may result from the hydrodynamic effects of *Spartina* culms. The structural complexity of emergent macrophytes may inhibit predation by natant macrofauna (e.g., killifishes and caridean shrimp) on benthic and epiphytic invertebrates, resulting in differential postrecruitment mortality in vegetated versus unvegetated habitats (Rader 1984).

Small-scale patterns of invertebrate distribution have been attributed to the patchy distribution of food sources (Findlay 1981; Decho and Castenholz 1986) and the influence of biogenic structures (Bell, Watzin, and Coull 1978; Osenga and Coull 1983). Certain taxa (e.g., nematodes) may be locally abundant around structures such as fiddler crab burrows; others, such as copepods, may exhibit reduced densities in the vicinity of biogenic structures. Microtopographic features, such as intertidal pools and rivulets or elevated plant hummocks, influence distribution patterns, abundance, and composition of small benthic and epifaunal invertebrates in tidal freshwater wetlands (Yozzo and Smith 1995).

Heat and/or dessication stress has been suggested as a possible limiting factor in the distribution of intertidal invertebrate populations. However, the water-retaining properties and associated evaporative cooling of salt marsh substrate enhance survival of benthic invertebrates during extended low-tide/high-temperature conditions (Van Dolah 1978), and most tidal marsh taxa tolerate a broad range of environmental conditions. Similarly, while sediment composition and texture may exert considerable influence on the distribution of certain benthic organisms in deeper aquatic or marine habitats, the distribution patterns of most common salt marsh benthic invertebrates are apparently not determined by sediment composition (Kneib 1984b). However, Wenner and Beatty (1988) indicated that the most important variables affecting the distribution and abundance of benthic and epifaunal invertebrates in South Carolina salt marshes included sediment composition, along with type and density of vegetation, amount of flooding and hydroperiod, and water circulation. Low water circulation and prolonged conditions of oxygen depletion are detrimental to colonization by many intertidal invertebrates.

Predation may exert significant influence on the abundance and population size-structure of benthic and epibenthic fauna. Peak densities for salt marsh invertebrates seem to occur in spring or autumn with lowest densities occurring in midsummer (Bell 1979, 1980, 1982; Cammen 1979; Kneib and Stiven 1982) when the abundance of the most common natant marsh predators (primarily killifish, *Fundulus* spp., and caridean shrimp) is highest. Predation effects are complex, difficult to quantify, and may be confounded by environmental factors (Wenner and Beatty 1988). Year-to-year variability in infaunal densities may be pronounced, suggesting that other parameters (e.g., variability in plankton recruitment, pore-water and surface water salinity, DOCs, and soil pH) are important in determining seasonal and longer term population dynamics of benthic and epiphytic invertebrates in tidal marshes.

Exclusions

The NPP model excludes consideration of large filter-feeding bivalves (oysters, clams, and mussels). Because these organisms are less vulnerable to predation by most small natant marsh predators, and because their turnover rates are relatively low, these populations are not expected to fit the model. Some other large, conspicuous marsh invertebrates (e.g., periwinkles, *Littorina* spp., and fiddler crabs, *Uca* spp.) are also not likely to be represented in the model. Meiofauna (benthic organisms that pass through a 500-µm sieve but are retained on a 63-µm sieve) are also not explicitly considered in the model. Although certain meiofaunal taxa (e.g., harpacticoid and cyclopoid copepods, ostracods) are known to be important prey resources for larval and juvenile fish and macrocrustaceans in tidal marshes (Bell and Coull 1978; Ellis and Coull 1989; Feller, Coull, and Hentschel 1990; Kneib 1993; Yozzo and Smith 1995), the sample processing and taxonomic resources required for validation of meiofaunal population characteristics are probably beyond the scope of HGM efforts. Tidal marsh meiofauna population dynamics are largely determined by the same factors that influence macrofaunal distribution (e.g., salinity, inundation frequency, vegetation characteristics, disturbance/predation); thus meiofauna probably do not warrant separate consideration from the macrofauna in the model.

The NPP model considers production of prey resources only on the intertidal marsh surface, as this habitat is the primary forage habitat for natant predators such as killifish and grass shrimp. However, it should be recognized that the creeks and channels draining the marsh also contain a diverse and abundant infaunal community, often (in the case of tidal freshwater marshes) in association with submerged aquatic vegetation. In consideration of the widely accepted view of the intertidal marsh surface as an important source of energy for estuarine consumers (Bell and Coull 1978; Kneib and Stiven 1982; McIvor and Odum 1988; Kneib and Wagner 1994), and in maintaining consistency with other HGM functions, which focus primarily on processes occurring on the vegetated intertidal marsh surface, the model excludes consideration of prey resources in subtidal habitats.

Macrofaunal production estimates typically require detailed information on size-frequency distributions and age-specific growth rates. However, assuming similar turnover rates, simple estimation of standing stocks (biomass) may reflect relative production of many small benthic macroinvertebrates (polychaetes, oligochaetes, ostracods, tanaids, amphipods, etc.) commonly found in tidal wetlands. For model validation purposes, it is feasible to obtain relatively quick estimates of standing stocks rather than calculation of secondary production.

Description of variables

Flooding duration V_{FD}. Standing stocks of macrobenthic invertebrates in tidal marshes are controlled largely by the availability of suitable moist habitat and the presence of aquatic predators. In the absence of predators, macrobenthic standing stocks should be relatively high in areas that are inundated regularly. However, increased inundation frequency and duration provide increased foraging access and opportunity for predatory fishes and macrocrustaceans. For measurement of the variable index V_{FD}, see description of flooding duration under previous section, "Nonresident Nekton Utilization."

Aquatic edge V_{AE}. This variable is a direct linear measure of the amount of edge between the intertidal marsh surface and adjacent aquatic habitats. Intertidal and subtidal creeks and shallow embayments represent staging areas for natant marsh predators. A large amount of edge is assumed to provide these organisms greater access to foraging areas on the intertidal marsh surface. For a description of how to measure V_{AE}, refer to the section "Resident Nekton Utilization."

Total percent vegetative cover V_{COV}. This variable is a measure of the relative proportion of the site that is covered with emergent macrophytic vegetation. Vegetation provides structure that increases the available habitat and can mediate the effects of predation. Therefore, the presence of vegetation, especially dense vegetation, should have a positive effect on macrofaunal abundance.

Functional index

The nekton prey pool (NPP) functional index can be calculated using Equation 9:

$$NPP = \frac{V_{AE} + V_{FD} + V_{COV})}{3} \tag{9}$$

Wildlife Habitat Utilization

Definition

This function describes the potential utilization of the marsh by resident and migratory avifauna, herpetofauna, and mammals. A quantitative measure of this function would be abundance of birds, reptiles, amphibians, and mammals per unit area (hectare).

Importance of the function

A variety of birds, mammals, reptiles, and amphibians (including many threatened and endangered species) utilize tidal fringe wetland habitats either as permanent residents or occasional visitors. Many wildlife species are important consumers in tidal wetlands and may figure prominently as trophic links to adjacent terrestrial or aquatic/marine ecosystems.

Discussion of function

This model is intended to represent the general habitat quality of tidal fringe wetlands for "marsh-dependent" species of avifauna, herpetofauna, and mammals, with the recognition that individual species within these groups may have different, even conflicting, habitat requirements. Use of tidal fringe wetlands varies in terms of the type and number of activities in which they engage (e.g., feeding, breeding) and the amount of time spent there (i.e., year-round residents to occasional visitors). Some species may spend their entire lives in marshes (e.g., clapper rails, rice rats), others migrate seasonally to breed or feed there, and still others are occasional users of these areas as stopover points during migration. Attempts to identify key factors governing the use of marshes by these organisms are further complicated by the differential use of elevational zones or portions of a marsh by different species or groups of species (e.g., wading birds, shorebirds) across either single or multiple purposes. For example, shorebirds and wading birds typically feed in different parts of a marsh. Shorebirds prefer the open shoreline edge of a marsh, adjacent mud flats, or large tidal creeks, while wading birds prefer the shallow water along creeks and pools. Species that breed and feed in marshes may use different zones for each activity: the clapper rail prefers to nest in low marsh zones, while it feeds across the entire marsh. Further, because the model considers all birds, reptiles, and mammals as a group, factors that may favor one group may have the opposite effect on another. The presence of an adjacent upland, for example, may provide a suitable and beneficial high-tide refuge for mammals that may use the marsh as feeding grounds (e.g., raccoons, marsh rabbits), but at the same time might exert a negative effect on prey (e.g., macrofauna such as fiddler crabs, marsh clams, and mussels). Despite these conflicting factors and processes, the model does provide a coarse measure of the ability of a site to support some "optimal" combination or assemblage of birds and mammals. This estimate of function incorporates the concepts of habitat complexity (for all possible groups of birds and mammals and all possible activities) and the relative amount of access to and use of a site from both aquatic (aquatic edge) and upland areas. Future research regarding the relationships between form and function may allow for separate considerations of these groups.

The selection of regional habitat subtypes for the variable V_{WHC} is based on their functional roles in supporting wildlife communities (Table 9). Because the habitat types likely to be represented in the regional reference set are principally defined by vegetation type, this variable embodies a variety of concepts of importance to wildlife, including hydrology, exotic plants, vegetation structure, and shelter. Identification of habitat types should include the full range of habitat types and edge characteristics in the project vicinity, which may or may not be included in specific project boundaries. For example, marsh-dependent animals require refuge from low-tide events (pools), as well as high-tide events (hummocks and/or adjacent uplands). The complex issue of upland shelter is dealt with in a separate variable (V_{UE}), but the issue of shelter within a marsh must be captured by the Wildlife Habitat Complexity variable V_{WHC}.

Table 9
Examples of Habitat Types and Associated Wildlife

Habitat Type	Wildlife
Submerged aquatic bottom	Waterfowl
Unvegetated subtidal bottom	Wading birds, shorebirds, diving ducks, furbearers, reptiles, and amphibians
Shellfish beds	Wading birds, shorebirds, marine mammals
Mud flats	Wading birds, shorebirds, raptors, waterfowl
Vegetated marsh zones	Marsh-resident birds, marsh-resident mammals, songbirds, waders, raptors, large shorebirds, furbearers, reptiles, and amphibians
Unvegetated ponds	Furbearers, reptiles, amphibians, wading birds, shorebirds
Vegetated ponds	Waterfowl, furbearers, reptiles, and amphibians
Tidal channels	Wading birds, resident birds, shorebirds, furbearers, reptiles, and amphibians
Pans	Shorebirds
Supratidal habitats (i.e. hummocks, large logs, muskrat lodges, etc.)	Refuge and nesting habitat for all groups

It is important to note that this model does not address issues of patch size and shape, connectivity, or other landscape scale concerns. Issues related to adjacent land use and degree of human disturbance are also not covered. It may be appropriate for regional experts to develop modifications to reflect these issues where necessary.

Description of variables

Aquatic edge V_{AE}. See previous description.

Upland edge V_{UE}. This variable is similar to aquatic edge in that it is an estimate of the amount of edge between the intertidal vegetated and adjacent upland areas. Unlike aquatic edge, however, the index for V_{UE} is calculated based on the *amount* and *quality* of the existing upland edge, rather than a simple linear measure of the amount of upland edge:

$$V_{UE} = \frac{\dfrac{natural\ upland\ edge}{total\ upland\ edge} + \left(1 - \dfrac{total\ upland\ edge}{project\ perimeter}\right)}{2} \tag{10}$$

The first component of V_{UE} results in a higher index of wildlife habitat function in direct proportion to the amount of edge dominated by native vegetation (measures refuge as a positive habitat component). The second component of V_{UE} causes the index to decline in direct proportion to the amount of edge that is upland (measures access to the wetland as a negative habitat component). These two components work in opposition to each other, with a wetland being downgraded for having an upland edge, but at the same time being upgraded if the existing edge provides quality wildlife habitat. The rationale for considering upland edge as a general detriment to wildlife functions is the probability that it will provide access for feral animals and native predators, thereby having a negative influence on the marsh-dependent species of interest.

Wildlife habitat complexity V_{WHC}. Habitat complexity is a measure of the heterogeneity of a site, based on the comparison of the number of habitats actually present at a site to the number of possible habitats known to occur in the appropriate regional subclass. Separate variables have been defined for V_{NHC} (nekton habitat complexity) and V_{WHC} (wildlife habitat complexity) to reflect differential usage of available habitats by these faunal groups.

Functional index

The functional index for wildlife habitat utilization (WHUP) is calculated using Equation 11:

$$WHUP = \frac{(V_{AE} + V_{UE} + V_{WHC})}{3} \tag{11}$$

4 Application Steps and Protocols

The final component of the HGM Approach that must be developed by the A-Team is the application steps and protocols. Once the Development Phase is completed, the application procedures outlined in the regional guidebook can be used to assess wetland functions in the context of regulatory, planning, or management programs (Smith et al. 1995). The Application Phase includes characterization, assessment and analysis, and application components. Characterization 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. Assessment and analysis involves collecting the field data necessary to run the assessment models and calculating the functional indices for the wetland assessment areas under existing (i.e., preproject) conditions and, if necessary, postproject conditions.

The procedure should be field-tested by an A-team that develops regional reference standards. It is also necessary to spend some time and money on quality control, including a comparison of the repeatability of the results among users and the reliability of the indicators, thresholds of indicators to verify a variable, and sensitivity of the equations to detect differences in functioning. Training of regulatory personnel, consultants, and other anticipated users should be an integral part of implementing functional assessments.

The following sources of information and equipment are required for applying the Tidal Wetland HGM Approach:

a. Regional maps or charts showing the entire hydrologic unit (e.g., estuary).

b. Tide tables, soil salinity tables, and other available references relative to local tidal conditions and regional wetland types.

c. Aerial photographs of the WAA and adjacent areas on as detailed a scale as possible (the recommended scale of photos is 25.4 mm = 60 m (1 in. = 200 ft)).

d. A planimeter or other device for measuring area.

e. A map measurer for measuring linear distances (e.g., aquatic edge).

The user of this method proceeds to collect required information for project area characteristics and model variables. The procedure is a simple progression through the list of site-specific characteristics and model variables until all required information is obtained. Units of measurement (i.e., metric, non-SI units) must be consistent for all numerical variable determinations. Some variables can be measured from photos and maps, while others can be determined only from observations or measurements made during a field visit.

Determining the Wetland Assessment Area and the Indirect Wetland Assessment Area

The first task involves the determination of the boundaries of the assessment area and the type of tidal wetland that is being assessed. Defining the boundaries of a site is a logical step that sets limits within which variables used in any assessment method must be measured or estimated.

The Wetland Assessment Area (WAA) and Indirect Wetland Assessment Area (IWAA) are determined from information provided by a permit application or some a priori information about the site. The WAA does not have to constitute a given hydrologic unit, but is assigned solely on the basis of the area directly impacted by the project (i.e., the project "footprint"). In some cases, other parts of the wetland not directly impacted, but for which hydrologic flow or connection is altered, would be designated as the IWAA. If warranted, a separate assessment could be done on this area.

This section briefly describes the WAA and adjacent IWAA. Definition of the WAA is outlined in more detail in the procedural manual of the HGM Approach (Smith et al. 1995). Definition of an IWAA is somewhat more subjective given the difficulty in estimating the distance over which impacts at the WAA may affect adjacent areas.

As noted in this discussion, some variables are obtained directly from region-specific profiles of designated wetland types. In order to identify the appropriate "profile" from which these data can be obtained (and to which model results will be compared), the user of this method must first determine which regional wetland type or types are being assessed and whether or not more than one assessment is warranted. This task is accomplished by first defining the WAA and/or IWAA, followed by a determination of the wetland type or types that are present. The user compares data collected at the sites of interest to those provided in the regional profiles.

Wetland Assessment Area (WAA)

The WAA is the wetland area directly impacted by a proposed project and is typically reported as part of the project description portion of a permit application. The WAA marks what is often referred to as the footprint of a proposed project. Its importance to the assessment method lies largely in defining specific boundaries within which many of the model variables are determined and as direct input into calculations for other variables (e.g., maximum aquatic and upland edge). If the WAA includes more than one regional subclass, however, separate assessments may be required for each subclass. In this case, the WAA should be divided into two or more Partial Wetland Assessment Areas (PWAA). Methods for the determination of WAA and PWAA are discussed in more detail in the procedural manual of the HGM Approach (Smith et al. 1995). In the case of a reference wetland, the boundaries of the WAA should be logical ones that help to define a finite area that can be assessed. Examples of such boundaries include (a) upland edges, (b) marsh boundaries with tidal rivers or embayments, or (c) large tidal channels.

Indirect Wetland Assessment Area (IWAA)

The IWAA is defined here as any adjacent portions of a hydrologic unit that, while not directly affected by a project, may be indirectly affected through the alteration of hydrologic flow or connection to the rest of the hydrologic system to which it belongs. A typical example would be an adjacent portion of a marsh system that is isolated from tidal flow by the blockage of a tidal creek. The importance of designating an IWAA in the assessment method lies in the recognition that wetlands directly adjacent to a project area, although not necessarily directly impacted by a project, may nonetheless be altered by it. If this condition is suspected or documented, then any application for alteration should include assessments of potential loss of function for both the WAA and the IWAA.

Determining Wetland Type

Functional profiles for each wetland subclass provide the user with a set of reference standard values for comparison with functional indices calculated for the WAA.

The wetland type or types are determined by comparing the hydroperiod, salinity regime, and vegetation structure of a site with those described in the suite of wetland type profiles for each region. Each regional profile contains a series of descriptions for each wetland type recognized for that region. These descriptions, in conjunction with knowledge of the salinity regime, can be used to determine which wetland type or types are being assessed. It is possible that a WAA or IWAA may contain more than one type or zone. Some functional models include variables that recognize the potential for a site to have multiple subhabitats that may include one or more zones.

As previously described, salinity is a key factor that defines tidal wetland types along the gradient from fresh to hypersaline waters. Knowledge of the salinity regime of the area, along with information about the frequency and/or duration of flooding at the site, is key to determining which type of wetland is being assessed. Plant communities respond to both salinity and flooding regime and can be used as indicators of wetland type. Each regional wetland type profile provides descriptions of the vegetation present and the salinity and hydrological conditions for that wetland type. Using information on the salinity regime and the regional profiles, all wetland types present within the WAA must be recognized and recorded.

The salinity regime of the area can be determined by consulting available references on salinity and or wetland distribution. Data on average salinity or the range of salinity is used to place the site into one of the four categories of the Cowardin system (Table 3). If this information is not available, it can be estimated from observations of the wetland vegetation present at the site. Because vegetation characteristics (i.e., the species or combination of species present) can reflect the salinity regime, this factor can be determined by matching observed vegetation characteristics with those reported in regional profiles.

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The following persons contributed to the development of the models outlined in this report through their participation in the National Tidal Fringe HGM Workshop held in Charleston, SC, in September 1996, or through their involvement in the development of regional models.

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Appendix B Regional Guidebook Development Sequence

Task I: Organize Regional Assessment Team (A-Team)

A. Identify Assessment Team members
B. Train A-Team in the HGM Approach

Task II: Identify and Prioritize Regional Wetland Subclasses

A. Identify Regional Wetland Subclasses
B. Prioritize Regional Wetland Subclasses
C. Define Reference Domains
D. Initiate Literature Review
E. Develop Preliminary Characterization of the Selected Regional Subclass

Task III: Construct the Conceptual Assessment Models

A. Review Existing Assessment Models
B. Identify and Define Functions
C. Identify Assessment Model Variables
D. Identify Field Measures and Scale of Measurement
E. Define Relationship Between Model Variables and Functional Capacity
F. Define Relationship Between Variables by Developing the Aggregation Equation for the Functional Capacity Index (FCI)
G. Complete Precalibrated Draft of the Regional Guidebook (PDRG)

At this point the document should include a preliminary characterization of the wetland, potential functions with definitions, list of model variables for each function, and a conceptual assessment model and preliminary rationale for each function.

Task IV: Peer Review of PDRG

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 PDRG

Task V: Calibrate and Field Test Assessment Models

A. Identify Reference Wetland Field Sites
B. Collect Data from Reference Wetland Field Sites
C. Analyze Reference Wetland Data
D. Calibrate Model Variables Using Reference Wetland Data
E. Verify/Validate Assessment Models
F. Field Test Assessment Models for Repeatability and Accuracy
G. Revise PDRG Based on Calibration, Verification, and Validation into a Calibrated Draft Regional Guidebook (CDRG)

At this point the document should include a final characterization of the wetland subclass, functions with definitions, model variables with definitions, calibrated assessment models, a summary matrix of reference data (not raw data sheets) with explanation of how reference data were analyzed and used to calibrate assessment models and reference wetland location map.

Task VI: Peer Review of CDRG

A. Distribute CDRG to Peer Reviewers
B. Revise CDRG to Reflect Peer Review Recommendations
C. Distribute CDRG to Peer Reviewers for Final Comment on Revisions
D. Incorporate Final Comments from Peer Reviewers on Revisions into the Operational Draft of the Regional Guidebook (ODRG)

Task VII: Field Test of ODRG

Task VIII: Transfer Technology in ODRG to End Users

A. Train End Users in the Use of the ODRG
B. Provide Continuing Technical Assistance to End Users of the ODRG

Task IX: Revise ODRG and Publish

Appendix C
Definitions of Functions and Variables for Tidal Fringe Wetlands

Hydrogeomorphic Functions

Tidal Surge Attenuation
The capacity of a wetland to reduce the amplitude of tidal storm surges.

Tidal Nutrient and Organic Carbon Exchange
The ability of a wetland to import and export nutrients and organic carbon from the wetland. Mechanisms include leaching, flushing, and erosion.

Sediment Deposition
Deposition and retention of inorganic and organic particulates from the water column, primarily through physical processes.

Habitat Functions

Maintenance of Characteristic Plant Community Composition
The ability of a wetland to support a native plant community of characteristic species composition.

Resident Nekton Utilization
Describes potential utilization of the wetland by resident fishes and macrocrustaceans.

Nonresident Nekton Utilization
Describes potential utilization of the wetland by nonresident (transient) fishes and macrocrustaceans.

Nekton Prey Pool

Describes the potential for the wetland to produce and maintain a characteristic benthic and epiphytic invertebrate prey pool.

Wildlife Habitat Utilization

Describes potential utilization of the wetland by resident and migratory avifauna, herpetofauna, and mammals.

Variables

Aquatic Edge V_{AE}

The amount of edge between the intertidal vegetated, intertidal unvegetated, and subtidal areas is considered to be an important factor governing the exchange of organisms. The measured linear edge of recognizable tidal creeks, rivulets, ponds and pans is scaled against the linear edge at reference standard sites. In the absence of regional reference standards, the measured edge at site may be compared to a theoretical maximum edge based on the area of the site (i.e., the linear expression of the Wetland Assessment Area (WAA)).

Community Composition V_{COMP}

Similarity index comparing the emergent macrophyte species composition of a particular site with the species composition of reference standard sites within the regional subclass.

Distance V_{DIST}

The width of vegetated marsh surface across which storm surges must travel. The greater the width of the marsh, the greater the reduction in wave energy. Marsh width generally depends on regional geomorphologic characteristics, tidal range, and slope of the shoreline. Two methods of calculating distance are suggested, depending on whether the assessment is being conducted in relationship with a proposed project or in the absence of a project.

Flooding Duration V_{FD}

The proportion of time that the marsh surface is flooded due to tidal inundation, compared with reference standard sites in the region. An accurate determination of flooding duration requires the installation and monitoring of water level recorders. In the absence of such data, the value of this variable is assumed to be 1.0 unless tidal restrictions such as culverts, dams, etc., are present.

Mean Plant Density V_{DEN}

Mean density of the dominant macrophytic vegetation at a site relative to regional subclass reference standard sites. If more than one plant community type or zone occurs, estimate separate values for each zone, then combine and average.

Mean Plant Height V_{HGT}
Mean height of the dominant macrophytic vegetation at a site divided by mean height of the dominant macrophytic vegetation at reference standard sites. If more than one plant community type or zone occurs, estimate separate values for each zone, then combine and average.

Nekton Habitat Complexity V_{NHC}
A measure of the habitat heterogeneity of a site, based on the comparison of the number of subhabitat types present at a site relative to the number of possible subhabitats known to occur in the appropriate regional reference standard site.

Opportunity for Marsh Access V_{OMA}
V_{OMA} is calculated by adding the perimeters of all the tidally connected waterways (channels, embayments, and ponds), then dividing by the area of the WAA. The density of connected waterways across the WAA is an indirect measure of the surface of the marsh that is occupied by access routes for aquatic organisms. Unlike aquatic edge, which includes all possible interfaces (including areas that lack a tidal connection to the estuary, e.g., isolated ponds), this variable estimates the contribution that water bodies with connections to the estuary alone have on the potential access of transient organisms, thereby reflecting the assumed relative importance of this form of edge over others.

Percent Vegetative Cover by Exotic or Nuisance Species V_{EXOTIC}
The proportion of a site covered with exotic or other undesirable plant species.

Proximity to Source Channel V_{PSC}
Distance between the center of the WAA and the nearest large distributary channel, river, bay, or ocean.

Surface Roughness V_{ROUGH}
This variable describes the potential effects of emergent vegetation, obstructions, and microtopographic features on the hydrodynamics of tidal floodwaters.

Total Percent Vegetative Cover V_{COV}
The proportion of a site covered with macrophytic vegetation compared with reference standard sites in the region.

Upland Edge V_{UE}
The amount of upland edge at a site is calculated using the following formula and scaled to the amount of upland edge present at reference standard sites in the region:

$$V_{UE} = \frac{\dfrac{\textit{natural upland edge}}{\textit{total upland edge}} + \left(1 - \dfrac{\textit{total upland edge}}{\textit{project perimeter}}\right)}{2}$$

Wildlife Habitat Complexity V_{WHC}
A measure of the habitat heterogeneity of a site, based on the comparison of the number of subhabitat types present at a site relative to the number of possible subhabitats known to occur in the appropriate regional reference standard site.

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13. ABSTRACT *(Maximum 200 words)*

The Hydrogeomorphic (HGM) Approach is a suite of concepts and methods used collectively to develop functional indices and apply them to the assessment of wetland functions. A National Action Plan (NAP) to implement the HGM Approach has been cooperatively developed by the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highways Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS). Implementation of the Hydrogeomorphic Approach is accomplished in two phases: a Development Phase and Application Phase. The Development Phase is achieved by an interdisciplinary team of regional experts responsible for developing a regional guidebook by classifying wetlands, characterizing a regional subclass, developing assessment models for that subclass, and calibrating the models with data from reference wetlands. This guidebook provides a template for developing regional HGM guidebooks for wetlands belonging to the tidal fringe class.

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