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An integrated approach to assess broad-scale condition of coastal wetlands—the Gulf of Mexico Coastal Wetlands pilot survey

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Abstract The Environmental Protection Agency (EPA) and U.S. Geological Survey (USGS) initiated a two-year regional pilot survey in 2007 to develop, test, and validate tools and approaches to assess the condition of northern Gulf of Mexico (GOM) coastal wetlands. Sampling sites were selected from estuarine and palustrine wetland areas with herbaceous, forested, and shrub/scrub habitats delineated by the US Fish and Wildlife Service National Wetlands Inventory Status and Trends (NWI S&T) program and contained within northern GOM coastal watersheds. A multi-level, stepwise, iterative survey approach is being applied to multiple wetland classes at 100 probabilistically-selected coastal wetlands sites. Tier 1 provides information at the landscape scale about habitat inventory, land use, and environmental stressors associated with the watershed in which each wetland site is located. Tier 2, a rapid assessment conducted through a combination of office and field work, is based on best professional judgment and on-site evidence. Tier 3, an intensive site assessment, involves on-site collection of vegetation, water, and sediment samples to establish an integrated understanding of current wetland condition and validate methods and findings from Tiers 1 and 2. The results from this survey, along with other similar regional pilots from the Mid-Atlantic, West Coast, and Great Lakes Regions will contribute to a design and implementation approach for the National Wetlands Condition Assessment to be conducted by EPA's Office of Water in 2011.

Keywords Coastal wetlands · Condition assessment · Gulf of Mexico · Multi-scale assessment approach · Regional pilot study

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Introduction

The diverse array and vast extent of coastal wetland and estuarine ecosystems along the northern Gulf of Mexico coastline provide numerous ecological and economic benefits, including improved water quality, nurseries for fisheries species, wildlife habitat, flood buffers, erosion control, and recreational opportunities (Millennium Ecosystem Assessment 2005; Hein et al. 2006; Twilley 2007). Sustainability of the Gulf Coast wetlands is increasingly under pressure from modified hydrology, sediment transport, rising sea levels, increased storm activity, contamination, and habitat loss due to land use changes. Monitoring and assessment of wetland resources has been widely recognized as important for detecting these adverse impacts and informing management actions (NRC 2001; NWQMC 2006). Monitoring is typically limited to the project scale and thus regional trends in condition are difficult to detect. Comprehensive condition assessments of coastal wetlands are of increasingly high priority across federal agencies and programs in order to identify priorities and evaluate the effectiveness of wetland protection policies and programs (U.S. Commission on Ocean Policy 2004; Coastal America 2005; Scozzafava et al. 2007). For this reason, there is a continuing need for more accurate, statistically valid surveys of our coastal wetlands at regional scales (USGAO 2000; Heinz Center 2002; USEPA 2003).

The Gulf of Mexico Alliance (2006, p. 26) established the identification and characterization of coastal wetlands as one of five priority areas for creating a workable, achievable and comprehensive strategy for enhancing the protection and conservation of the Gulf of Mexico. Within this priority area is a long-term goal to identify, inventory and assess the current status and trends in coastal Gulf of Mexico habitats, including wetlands, to inform resource management decisions. Most coastal wetland surveys across the Gulf region have assessed the spatial extent of wetlands (Dahl 2006), focused on the watershed scale (White et al. 2002, 2004, 2005, 2006, 2007), or were designed to meet an individual state's needs (Steyer et al. 2003; Reiss and Brown 2007). Due to the heterogeneity of wetland types and individual program reporting requirements, these surveys do not necessarily employ common indicators or share compatible assessment time scales to generate a seamless combination of multiple surveys that results in a single Gulf-wide estimate of wetland condition. Consequently, these surveys do not collectively meet the needs of the priority area set forth by the Gulf Alliance for a coordinated effort to assess and document the condition and trends in wetland quality across northern Gulf of Mexico coastal wetlands.

The Gulf of Mexico Coastal Wetlands Pilot Survey described here is a first attempt to produce a comprehensive evaluation of wetland quality and quantity across the entire northern Gulf of Mexico coastline using common protocols to measure wetland condition and provide a baseline assessment for some wetland types. This survey also provides an opportunity to test and refine a rapid assessment protocol for this region as one has not yet been developed specifically for use across the entire northern Gulf coast wetland habitats. Furthermore, this regional pilot survey will also inform survey design and indicator selection decisions for the USEPA's 2011 National Wetlands Condition Assessment, part of an ongoing series of National Water Resource Surveys and the first comprehensive evaluation of both the quantity and condition of wetlands across the nation (Scozzafava et al. 2007). This paper presents an interim update on the approach development and progress of this survey.

General overview of approach

The US Environmental Protection Agency Office of Research and Development (EPA-ORD) and the U.S. Geological Survey National Wetlands Research Center (USGS-NWRC) collaboratively initiated a 2-year regional pilot survey with sampling starting in August 2007 of the ambient environmental condition of coastal wetlands of northern Gulf of Mexico, from the Rio Grande, Texas to Florida Bay, Florida. This survey was designed according to the Environmental Monitoring and Assessment Program (EMAP) approach (McDonald et al. 2002a, b), developed cooperatively with the U.S. Fish and Wildlife Services' Status and Trends Program, and was built upon existing wetland monitoring and assessment strategies (Turner et al. 1995; Fennessy et al. 2004, 2007; Dahl 2006; Sutula et al. 2006; USEPA 2006; Collins et al. 2007). Field teams are currently conducting on-site monitoring activities at

100 randomly selected sites from across the five Gulf States using a probabilistic survey design. Quality control protocols to quantify and account for error due to measurement variation will include a duplication of field samples at 10% of the survey sites. High and low quality reference sites for each wetland type (estuarine marsh, palustrine marsh, palustrine forested, estuarine shrub, and palustrine shrub) will be identified and assessed in the same manner as each of the sample sites.

Sample frame and survey design

Sites assessed through the Gulf of Mexico Coastal Wetlands Pilot Survey are located within a regionally-consistent watershed delineation defined by all USGS eight-digit Hydrologic Unit Code (HUC) system segments that intersect the coast of the Gulf of Mexico (within Texas, Louisiana, Mississippi, Alabama, and Florida). The NOAA Coastal Assessment Framework Estuarine Drainage Areas (EDAs) were used to subdivide the Everglades' eight-digit HUC to enable our target population to include only those areas that flow into the Gulf of Mexico (Figs. 1 and 2).

The U.S. Fish and Wildlife Service developed the National Wetlands Inventory Status and Trends (NWI S&T) study specifically to monitor the extent of the nation's wetlands using a single, consistent definition and study protocols (Dahl 2006). Using aerial photography, this program has monitored and reported changes in wetland acreage on public and private lands of the lower 48 states since the mid-1950s (Frayer et al. 1983; Dahl and Pywell 1989; Dahl and Johnson 1991; Dahl 2000, 2006). Nationally, there are 4,682 randomly selected NWI S&T sample plots analyzed, with each plot comprising 10.46 km^2. The sample frame for the Gulf of Mexico Coastal Wetlands Pilot Survey was comprised of the 1,071 NWI S&T plots that fell completely within the GOM coastal boundary as described above (Fig. 1). Landcover within these 10.46 km^2 plots is represented by multiple polygons in a GIS database and each polygon is classified as one of several estuarine, palustrine, or upland habitat types according to the Cowardin wetlands classification system framework (Cowardin et al. 1979). The wetlands classes targeted for sampling included estuarine and palustrine systems with herbaceous and shrub/scrub habitats, as well as palustrine

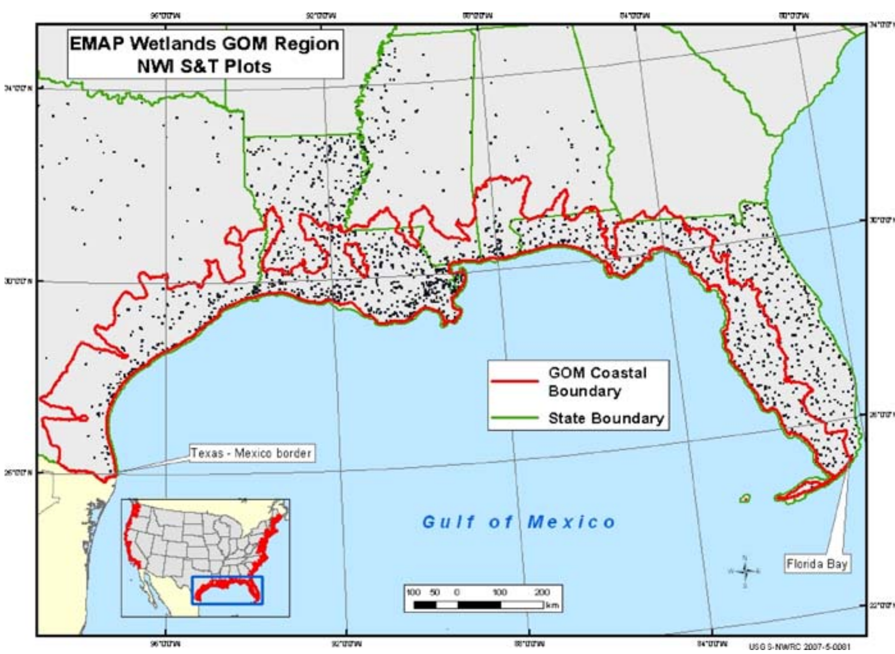

Fig. 1 Distribution of the National Wetlands Inventory Status and Trends (NWI S&T) plots across all wetland habitat types in the Gulf of Mexico coastal region as defined by all USGS eight-digit Hydrologic Unit Code (HUC) system segments that touch the coast and modified by NOAA's Estuarine Drainage Areas (EDAs) where needed

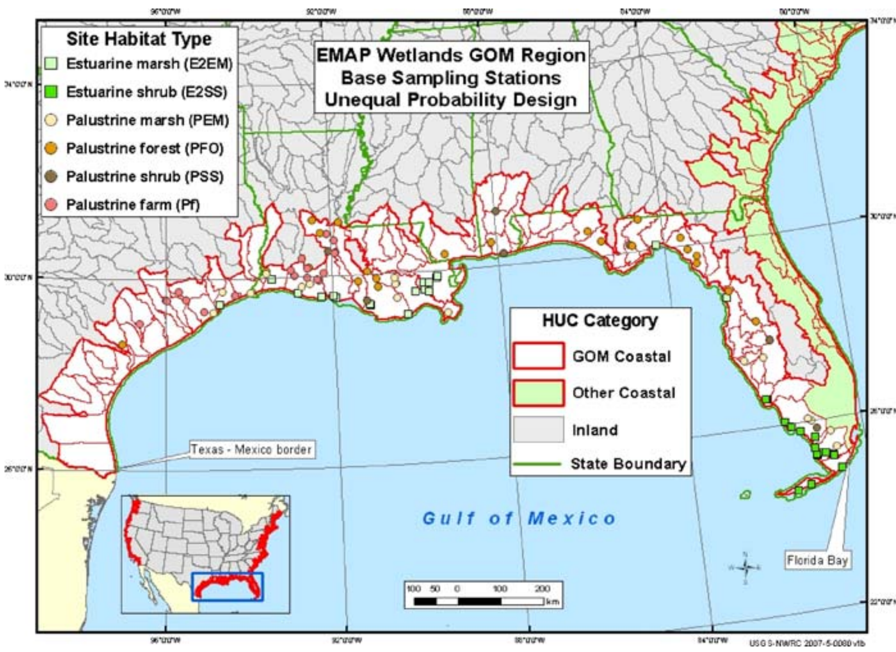

Fig. 2 Distribution of primary sampling sites across target wetland habitat types in the Gulf of Mexico coastal region as defined by all USGS eight-digit Hydrologic Unit Code (HUC) system segments that touch the coast and modified by NOAA's Estuarine Drainage Areas (EDAs) where needed

forested and farmed habitats (Cowardin et al. 1979; Table 1).

Point locations (latitude/longitude coordinates) were selected from these polygons within the sample frame using a probability-based survey design (USEPA's EMAP) to ensure that sampling sites chosen have a known probability of including at least one of the six wetland types desired. Points

Table 1 U.S. Fish and Wildlife Service National Wetland Inventory Status and Trends (NWI S&T) Wetland classes (Dahl 2006) included in the Gulf of Mexico (GOM) Coastal Wetlands pilot survey sample frame

NWI S&T habitat code	NWI S&T description	NWI S&T definition	Total area (ha) within sample frame (% of total)	Sample sites to be visited in GOM Wetlands Pilot
E2EM	Estuarine Intertidal Emergents	Salt marsh, mixed salinity, substrate exposed and flooded by tides, rooted herbaceous hydrophytes, excluding mosses and lichens	90,862.4 (28.9%)	18
E2SS	Estuarine Intertidal Forested/Shrub	Mangroves or other estuarine shrubs, mixed salinity, substrate exposed and flooded by tides, woody vegetation	17,228.4 (5.5%)	16
PEM	Palustrine Emergents	Inland marshes/wet meadows, freshwater, nontidal, rooted herbaceous hydrophytes, excluding mosses and lichens	47,288.9 (15.0%)	17
PFO	Palustrine Forested	Forested swamps, freshwater, nontidal, woody vegetation >6 m	104,194.6 (33.1%)	22
PSS	Palustrine Shrub	Shrub wetlands, freshwater, nontidal, woody vegetation <6 m	24,010.3 (7.6%)	7
Pf	Palustrine Farmed	Farmed wetlands/rice, freshwater, nontidal, habitat altered for crop production	31,095.8 (9.9%)	20

within these polygons designated to be one of these wetlands types were assigned a high probability of being selected for sampling whereas points within polygons with open water or upland classifications were assigned low (or zero) selection probabilities.

To ensure that each of the six wetlands types were represented in the pilot study in an appropriate proportion to test applicability of survey indicators, an unequal probability General Random Tessellation Stratified (GRTS) design (Stevens and Olsen 2004) was used to select 100 primary sample sites within the six targeted wetland types (Fig. 2). An additional 500% oversample was used to generate a list of alternate sites to visit if the primary site was inaccessible, posed risk to the field crew, or a landowner denied access. This survey design offers an unbiased estimate of the condition of the targeted wetland resources over a large geographic area from a small number of samples.

Due to the high seasonal and annual variability which exists within coastal wetlands (i.e. vegetative biomass, water levels, salinity) and to capture peak vegetation biomass, sampling for the Pilot Study will occur during a defined index period between June and September (Turner et al. 1995). This survey is not intended to supply information on the precise conditions at a specific location where measurements are not made, or of the populations during times when measurements are not made (i.e. if habitats are sampled only in the summer, the sample reveals nothing about those habitats in the spring or winter), or of regions not included in the sampling design (Olsen et al. 1999).

Assessment methodology

The Gulf of Mexico Coastal Wetlands Pilot Survey incorporates wetland evaluations for each assessment level within a 'three-tier framework" assessment strategy (Fennessy et al. 2004, 2007; USEPA 2006). This approach breaks the evaluation into a hierarchy of three levels, varying in spatial scale and laboratory/field sampling effort, which range from broad, landscape assessments Tier 1 using readily available GIS and remote sensing data (Ebert and Wade 2004), to rapid field assessment methods (Tier 2) that incorporate simple measures and a large degree of professional judgment (Fennessy et al. 2004, 2007; Sutula et al. 2006), to intensive, on-site collection of detailed biological, physical, and chemical measures (Tier 3) (Turner et al. 1995). Each site is accessed only once during the survey and on-site visits for Tiers 2 and 3 measures are limited to approximately 4 hours.

The Tier 1 analysis uses the USEPA's Analytical Tools Interface for Landscape Assessments (ATtILA), an ArcView (ESRI 1999) extension to calculate many commonly used landscape metrics (Ebert and Wade 2004). Data layers used in this analysis include Digital Orthophoto Quarter Quadrangle (DOQQ) and Soil Survey Geographic (SSURGO) Databases from the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), Multi-Resolution Land Characteristics (MRLC) Consortium 2001 National Land Cover Database, USGS National Elevation Database and National Hydrography Dataset, 2000 US Census data, and state- and local-level roads and transportation corridor datasets. Data layers incorporated into the Tier 1 landscape assessment were also used to generate appropriate maps for site-specific landscape scale metrics measured during the Tier 2 assessment and to orient field crews during the Tier 2 and 3 assessment site visits.

The landscape metrics produced by ATtILA fall into five different categories: Landscape Characteristics, Riparian Characteristics, Human Stresses, and Physical Characteristics, and Near-Sample Point metrics (Ebert and Wade 2004). These metrics, combined with other indices of wetland condition including the Landscape Development Index (LDI) (Brown and Vivas 2005), a wetland landscape profile (USEPA 2006), and hydrology indices (Richter et al. 1996, 1998) will be aggregated to reflect an overall "integrated" condition (or final Tier 1 score) to assess landscape-level wetland condition for each eight-digit HUC and the wetland polygon (representing one of the targeted wetland classes) within the NWI S&T plot for each of the 100 sample locations in this survey. This level of detail was deemed appropriate for this pilot survey based on the immediate availability and spatial resolution of regionally consistent geospatial data layers for the entire GOM coastal region.

The Tier 2 rapid assessment evaluates the integrity or health of the wetland area, at a finer scale than evaluated during the Tier 1 assessment, as well as the stressors and other drivers of overall wetland condition (Sutula et al. 2006; Mack 2001). Rapid assessment methods have been shown to be effective tools to assess anthropogenic impacts to wetland systems (Fennessy et al. 1998, 2004; Bartoldus 1999; Mack 2001; Sutula et al. 2006) and the development and testing of rapid assessment methods is gaining interest because of their utility to wetland managers to consistently evaluate best management practices, restoration and mitigation projects, and prioritize resource management decisions in a straightforward and consistent manner (Fennessy et al. 2004). Furthermore, once calibrated, a rapid method can be used where intensive data are lacking or too expensive to collect (Collins et al. 2007). Because no rapid method currently exists for all wetland types across the Gulf of Mexico coastal region, we are using the California Rapid Assessment Method (CRAM) (Sutula et al. 2006; Collins et al. 2007) as a springboard. We are applying adaptive development approaches (Fennessy et al. 2004) to generate a rapid assessment protocol, applicable to multiple wetland types within estuarine and palustrine systems in the Gulf of Mexico coastal region, that will score wetland sites from least impacted to highly-degraded relative to a reference condition range. This adapted Rapid Assessment Method (RAM) for the Gulf wetlands uses presence/absence checklists and other semi-quantitative and narrative metrics that rely on best professional judgment and on-site evidence to measure aspects of landscape, hydrology, and physical and biological structure to generate individual attribute and aggregate scores to reflect the condition of the site.

We define the Tier 2 Assessment Area (AA) as a fixed area delineated by a 25 m radius circle around the center point location generated by the probability-based survey design. This approach means that very large, conterminous wetlands are not being sampled as a whole in the traditional sense, but the data collected are consistent across sites and provide a standardized way to measure the ambient condition of the wetland resources at each site (Fennessy et al. 2007; Wardrop et al. 2007). This information may also be used to verify and validate scores generated through the Tier 1 assessment.

Intensive site assessment (Tier 3) provides higher resolution information on the condition of wetlands within an AA. The Tier 3 assessment generates empirical data used to evaluate the effectiveness of and refine Tier 2 metrics that are being used, together with Tier 1, to estimate the overall ecological condition for each site and wetland class included in this survey. The GOM Coastal Wetlands Pilot survey Tier 3 indicators include field samples or metrics related to sediment, vegetation, pore water, and surface water (Table 2), some of which may be directly related back to the Tier 2 metrics (e.g., plant species composition and vigor can be related to Tier 2 biological structure attributes; surface and pore water measures can be related back to Tier 2 hydrology attributes; contaminants, nutrient loading in water measures, and plant community measures may be related back to Tier 2 stressors). The

Table 2 Tier 3 indicators collected from each site during the Gulf of Mexico (GOM) Coastal Wetlands Pilot Survey

Vegetation	Water	Sediment
Above- and belowground biomass (herbaceous)	Porewater nutrients	C:N:P
Species composition and vigor (trees/shrubs)	Surface and porewater salinity, temperature, pH	Cation exchange
C:N:P		Contaminants
Stable isotope ratio ($\delta^{15}N$)		Grain size, bulk density
		Water holding capacity
		Microbial biomass
		Total Organic Carbon

majority of Tier 3 sample types are collected from three random 0.25-m^2 plots within the Tier 2 AA. Aboveground plant biomass samples are collected by harvesting and bagging all live and dead plant material present within the perimeter of each plot. Sediment cores (10 cm diameter by 16 cm depth) are collected from each plot for the analysis of C:N:P, cation exchange, contaminants, grain size, bulk density, water holding capacity, microbial biomass, and total organic carbon. Unfiltered and filtered (0.45 μm membrane) pore water samples (50 ml) are collected from each plot by using a sipper hand pump probe to extract interstitial water from a depth of 30 cm for the analysis of total nitrogen and phosphorus and dissolved nitrogen and phosphorus, respectively. An additional sample (50 ml) of unfiltered pore water is collected from the first plot and measured for salinity, conductivity, temperature, and pH using a handheld multiparameter water quality meter. Laboratory methodologies for the analysis of sediment and pore water samples are described in detail in Heitmuller (2007). Other samples and measurements, including surface water salinity, conductivity, temperature, and pH and leave tissue samples for plant C:N:P and stable N isotope ratios (Wigand et al. 2004), are collected within the Tier 2 AA.

Conclusion

At the time of this writing, 24 of the 100 sites were visited and assessed in 2007. We are currently planning for the second year of the survey and continuing to review and refine approaches as needed. The Gulf of Mexico Coastal Wetlands Pilot Survey addresses the need for more accurate, statistically valid surveys of coastal systems across broad spatial scales expressed by several federal agencies and programs. It also demonstrates a comprehensive approach to assess wetland condition across broad spatial scales beyond the current inventory and trends that is reported by the NWI S&T program. This collaborative project will continue to (1) evaluate the feasibility of implementing a probabilistic survey design on a regional scale, (2) evaluate the applicability of indicators across multiple wetland types, and (3) assess the condition of Gulf of Mexico coastal wetlands using the “three-tier assessment framework” hierarchy, and (4) advance the science of wetland monitoring and assessment by informing the 2011 National Wetlands Condition Assessment. Remaining assessment activities include demonstrating and documenting links between each of the three assessment levels through calibration and validation of the landscape (Tier 1) and rapid (Tier 2) assessment approaches with data from intensive (Tier 3) assessments. Establishing links between scores at each assessment level may provide a more comprehensive understanding of the current condition of the Gulf’s wetland ecosystems and allow us to be able to infer or assess condition of wetland resources in areas where all three levels of the assessment process might not be able to be accomplished or detailed information is lacking at the individual wetland or smaller scales.

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