

# A PROPOSED COAST-WIDE REFERENCE MONITORING SYSTEM FOR EVALUATING WETLAND RESTORATION TRAJECTORIES IN LOUISIANA

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**Abstract.** Wetland restoration efforts conducted in Louisiana under the Coastal Wetlands Planning, Protection and Restoration Act require monitoring the effectiveness of individual projects as well as monitoring the cumulative effects of all projects in restoring, creating, enhancing, and protecting the coastal landscape. The effectiveness of the traditional paired-reference monitoring approach in Louisiana has been limited because of difficulty in finding comparable reference sites. A multiple reference approach is proposed that uses aspects of hydrogeomorphic functional assessments and probabilistic sampling. This approach includes a suite of sites that encompass the range of ecological condition for each stratum, with projects placed on a continuum of conditions found for that stratum. Trajectories in reference sites through time are then compared with project trajectories through time. Plant community zonation complicated selection of indicators, strata, and sample size. The approach proposed could serve as a model for evaluating wetland ecosystems.

**Keywords:** monitoring, wetland restoration, Louisiana, reference, HGM

## 1. Introduction

The Coastal Wetlands Planning, Protection and Restoration Act of 1990 (CWPPRA), also called the “Breux Act”, was enacted to create, restore, enhance and protect coastal wetlands, primarily those in Louisiana. The restoration plan developed pursuant to this act specifically requires: (1) “an evaluation of the effectiveness of each coastal wetland restoration project in achieving long-term solutions to arresting coastal wetland loss in Louisiana;” and (2) “a scientific evaluation of the effectiveness of the coastal wetlands restoration projects carried out under the plan in creating, restoring, protecting and enhancing coastal wetlands in Louisiana.” A monitoring program was established to evaluate project-specific goals and objectives based on sound scientific procedures and relies heavily on the establishment of appropriate paired reference areas. Monitoring both project and reference areas provides a means to achieve statistically valid comparisons and is the most reliable way to assess project effectiveness.

Forty-seven Breux Act projects have been constructed with another 75 authorized for funding through January 2001. These projects average over 5,700 hectares in size and utilize a variety of techniques ranging from simple shoreline protection projects to complex projects which manipulate hydrology (LCWCRTF, 1997). Many of the projects are close to each other, increasing the possibility of



cumulative, indirect influences on landscape level processes. These cumulative effects are not being effectively evaluated at the project-specific level because they require a characterization of the landscape outside of the project areas.

The proposed Coast-wide Reference Monitoring System (CRMS) was developed to address Breaux Act Monitoring Program needs, and it has two objectives to address gaps in the current monitoring strategy. The first objective is to determine collectively the effectiveness of the projects carried out under the Breaux Act restoration plan by providing a network or “pool” of reference sites against which to evaluate project effectiveness, eliminating the need for one-on-one pairs of reference and project areas. Reference areas are fairly easy to find for small-scale projects such as shoreline protection but extremely difficult for large-scale, complex projects such as hydrologic restoration. The CRMS will provide an array of reference sites for the many projects for which no appropriate paired reference areas exist. Data collected under the CRMS will characterize typical conditions within various vegetation types for both project and nonproject areas and provide a basis of comparison (i.e., a standard) to evaluate differences in response to Breaux Act projects.

The second objective is to ensure that the strategic coastal plan for Louisiana (Coast 2050) is effective in re-creating a sustainable coastal ecosystem (LCWCRTF, 1998). This plan lays out a restoration strategy that depends on the cumulative effects of many individual projects that should collectively lead to the general restoration of Louisiana’s coastal estuaries. Because these estuaries are open ecological systems, driven by complex hydrological circulation patterns that will be further altered by the combined effect of individual projects, it is imperative to develop a program to evaluate these cumulative effects. Therefore the second CRMS objective is to determine the ecological condition of the coastal wetlands based on the variables measured. The CRMS will provide an avenue to evaluate the effectiveness of the restoration plan and determine whether whole coastal ecosystems are being restored, not just the areas directly affected by individual projects.

The programmatic questions that CRMS will address are: (1) Did the projects carried out under the restoration plan contribute to reducing coastal wetland loss in Louisiana as well as within each hydrologic basin?; (2) Did the Breaux Act sustain a diversity of vegetation types in the hydrologic basins?; (3) Is the Breaux Act effective in reducing the effects of major stressors on wetlands (i.e., flooding regime, salinity, marsh elevation change)?; and (4) Which project types are the most effective in creating, restoring, protecting, and enhancing wetlands?

## **2. Approach**

### **2.1 REFERENCE SITE ISSUES**

The selection of reference sites has philosophical and practical implications. In studies that address the condition of landscapes or ecosystems, an attempt is often

made to find “pristine” sites for comparison (i.e., areas that show little human impact). In the absence of natural sites, “ideal” conditions are sometimes assigned as reference standards. Reference standards are typically expected to be biotically diverse and to exhibit high productivity, two conditions that are usually considered to identify “valuable” ecosystems. Given the degree of human activity in Louisiana estuaries, there are no pristine sites.

An alternative approach in determining reference sites is to select multiple sites ecologically similar to a project area (rather than some ecologically ideal site). From a statistical point of view, although project performance can be evaluated against ideal goals, the evaluation of project performance may be best made against nonproject areas of comparable condition. Then changes in both project and reference areas can be compared over time.

Thus, for a coast-wide monitoring system in Louisiana, two options for reference sites are: (1) sites that reflect some ideal ecological condition against which project site restoration can be gauged (reference standards); or (2) sites similar to preproject conditions (controls). On the Louisiana coast there are few, if any, reference areas that are sufficiently similar to project areas to qualify as controls. Individual wetland characteristics vary independently in different wetlands because conditions of local sites are determined by an extremely complex spatial pattern of structure and process. Further, the prevalence of human impacts everywhere in the coastal estuaries means that there are no “natural” reference areas. Any local site is probably significantly influenced, either directly or indirectly, by human actions.

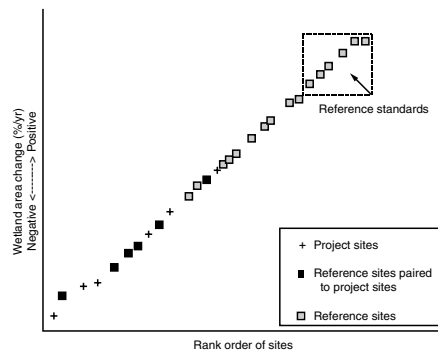
The design proposed here contains features of both alternatives. It is based primarily on recommendations for the hydrogeomorphic (HGM) approach (Brinson, 1993; Brinson *et al.*, 1994; Brinson and Rheinhardt, 1996) to wetland functional assessment and the EPA Ecological Monitoring and Assessment Program (EMAP) (Leibowitz *et al.*, 1991; Novitzki, 1994; Thornton *et al.*, 1994). EMAP classifications and HGM ideas for reference areas are used extensively, including: (1) the classification of the coastal wetlands into relatively homogeneous classes (which are blocked in the statistical design); (2) the selection of reference sites that span the whole range of ecological response characteristics of each class; and (3) the identification of those reference sites that most closely approach the sustainable functional potential of each class, as reference standards (Figure 1). Reference sites might be paired with project sites, but that is not necessary for the statistical design.

## 2.2 STATISTICAL DESIGN

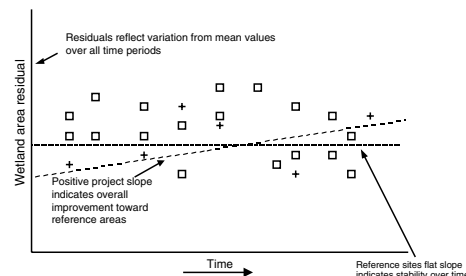
The basic statistical design is an asymmetric analysis derived from BACI (Underwood, 1991; 1992; 1994), with the addition of multiple reference sites as well as multiple project sites. Underwood compared the power between BACI design and multiple-reference site design to detect impacts of various types. He

found the multiple-reference site design is much more powerful than the traditional BACI, which is currently used to monitor wetland restoration on the Louisiana coast. He also found that increased replication of reference sites increased the power of the analysis.

We have adapted the classification and reference ideas, but the functional assessment in Louisiana is driven by the objectives of the Breaux Act projects. The proposed design of the monitoring program entails classifying the coast into a discrete number of similarly functioning regions and basins, and into project and nonproject areas. Marsh classes (also referred to as vegetation types) are also identified within each basin. A strength of the design is that the division of coastal habitats into vegetation types by basin allows analysis at a meaningful watershed scale, yet it also allows regrouping of the data to a more regional scale when desirable. The population sample within a basin encompasses all project and reference sites monitored through time. The design will provide: (1) an instantaneous “snapshot” that places project sites within the functional continuum of all reference sites; (2) the trajectory of change of project sites through time with respect to changes in functionally equivalent reference sites; and (3) comparisons to a group of reference standards (see Figure 2).



**Figure 1.** Monitoring sites showing range in response, paired project/reference sites, and reference standards.



**Figure 2.** Trajectories of reference sites compared to project sites over time.

### 3. Design Attributes

#### 3.1 MONITORING VARIABLES

The variables measured at each site are those necessary to address the objectives of the CRMS. These variables are crucial in determining the effectiveness of the Breaux Act program as well as those considered most important in affecting growth of vegetation. The frequency of sampling is that which is minimally required to evaluate long-term trends, while maintaining information on seasonal trends. At a

minimum, the recommended variables to be monitored include land:water ratio, vegetation composition and cover, elevation, duration and frequency of flooding, salinity and sedimentation/erosion. Sampling methodologies for these variables are described in Steyer *et al.* (1995).

### 3.2 SAMPLE POPULATION AND STRATIFICATION

Chabreck and Linscombe (1997) assembled a vegetation data base that provides a grid of stations located along 157 transect lines that cover the majority of the Louisiana coastal zone from Mississippi to Texas. These transects were extended north to cover bottomland hardwood and swamp vegetation types by using the 1988/90 National Wetlands Inventory habitat data. The transects were also extended across saline bays and associated saline marsh islands in the Terrebonne, Barataria, and Pontchartrain Basins to complete polyhaline oystergrass coverages in the Louisiana coastal zone. The data base of coastal vegetation at 6,298 stations is evenly distributed over the entire coast (Figure 3) and provides a representative sample of the vegetation communities in the Louisiana coastal zone; therefore, random selection of sample sites from this sample population should be representative of the whole coast.

Traditionally, the Louisiana coastal marshes have been divided based on salinity into four vegetation zones: fresh, intermediate, brackish, and saline (Chabreck, 1972). A recent analysis by Visser and Sasser (1998) of coast-wide vegetation data obtained by Chabreck and Linscombe in 1997 identified 12 vegetation types that occur under five salinity regimes in the Louisiana coastal zone. These vegetation types, plus the swamp and bottomland hardwood types, are distributed over nine hydrologic basins as shown in Figure 3. Hydrologic basin and project/nonproject were selected as the strata for purposes of analysis and reporting. Samples were also proportionally allocated by vegetation type. Using vegetation type as an allocation strata reduces the number of samples needed in the overall design, while at the same time ensuring that all the major vegetation types in a basin are represented. This allows for comparisons within vegetation type among basins as needed.

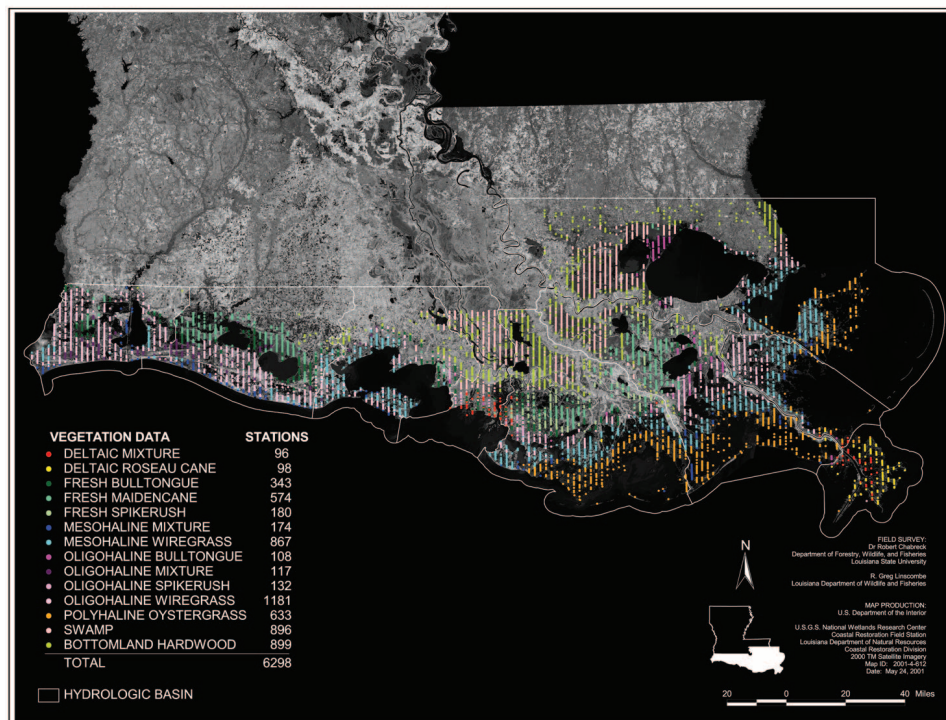
### 3.3 SAMPLE SIZE

The number of reference sites monitored affects the quality of the analyses. The number of replicates reflects a trade-off between the increased cost of additional sample sites and improved confidence in results. We investigated three approaches in the preparation of our recommendation for the number of reference sites: central limit theorem, a power analysis of water salinity data, and a Monte-Carlo type resampling of existing vegetative composition data.

The Central Limit Theorem suggests using 30 samples per stratum as a starting point for a sound statistical design. With 18 strata (9 basins and project/nonproject),

this approach would suggest a total of 540 reference sites in CRMS. Power analysis of salinity data was explored by Malaeb (1997) to evaluate the number of reference sites required. This investigation was of limited utility because the data were not complete enough and were spatially and serially correlated. Resampling techniques following Crowley (1992) were utilized to evaluate the sample size needed to describe the vegetative composition of the coast, and to detect changes in the vegetative composition over time.

This resampling technique evaluated the number of samples needed to avoid two types of potential error in statistical analyses. We used the coastal vegetation data base (Figure 3) consisting of observations of current vegetation types at 6,298 stations in coastal Louisiana. The number of reference sites needed to avoid a Type I Error is also the minimum number of sites required to accurately represent the current vegetation type distribution. We evaluated sample size and Type I Error by randomly selecting stations from the 6,298 stations, determining the vegetation type composition of that sample, and then using a chi-square statistic to test if the vegetation type composition of the sample differed from the vegetation type composition of the full data set. The sample sizes used to estimate vegetation type composition were 25, 50, 100, 150, 250, 300, 350, 400, 450, 500, 600, 800, 1000, 1200, 1400, 1600, and 2500. Each sample size was tested with 5,000 different

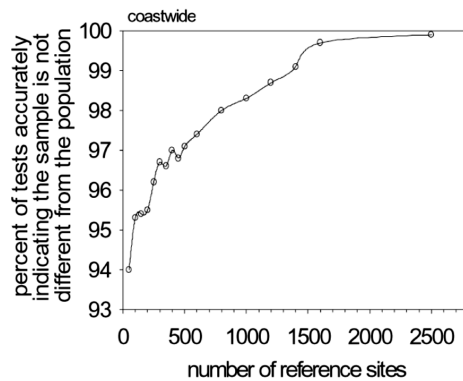


**Figure 3.** The 1997 geographic distribution of vegetation sites as established by Chabreck and Linscombe (1997) and classified according to Visser and Sasser (1998).

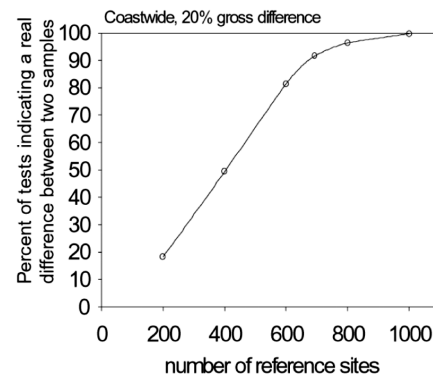
random samples. For instance, vegetation type composition was calculated by using 25 randomly selected stations 5,000 times. For each sample, the vegetation type composition was tested to determine if it was significantly different from the vegetation type composition of the full data set. For each sample size, we calculated an accuracy as the percent of times that the sample was not significantly different from the full data set. This approach indicated that 100 reference sites would indicate the true coastwide vegetation type composition 95% of the time (Figure 4). In addition to coastwide sampling, we evaluated the sample number needed to avoid a Type I Error on two of the eight hydrologic basins within the Louisiana coastal zone: Barataria Basin and Mermentau Basin. Based on these analyses, 100 reference sites were required to indicate the true basin-wide vegetation type composition with 95% confidence. The sample sizes for coastwide and basin are similar because this procedure only determines the sample size necessary to detect a statistical difference in composition. This difference is independent of area sampled but dependent on the complexity of the vegetation composition. Barataria Basin contains 13 and Mermentau 7 of the 14 vegetation types found coast-wide. Based on these analyses, the other hydrologic basins were assigned to two groups (one with a similar number of vegetation types to Barataria and the other similar to Mermentau). This assignment estimated that 650 reference sites are needed for the CRMS.

We evaluated the sample size needed to avoid a Type II Error by using the chi-square statistic to test if samples from a “time-one” were different from a “time-two” (Green, 1979). The vegetation type of each of the 6,298 stations was used as the time-one vegetation type. Each of the 6,298 stations was assigned a time-two vegetation type based on the most likely vegetation type shift anticipated by regional wetland experts using a marine intrusion scenario. The time-two vegetation type was the same as the time-one vegetation type for 80% randomly selected stations. The vegetation type was changed in the remaining 20% of the stations. A number of stations were then randomly selected and the time-one and time-two vegetation type compositions were compared with the chi-square statistic. This process was repeated 5,000 times for each sample size evaluated. We defined accuracy as the percentage of those tests that indicated a statistically significant difference between time-one and time-two. These analyses indicated that approximately 800 reference sites were needed to detect this difference 95% of the time (Figure 5).

We further investigated a possible reduction in sample size required by reducing the number of vegetation types using the change detection (Type II Error) approach. We collapsed the vegetation types into six vegetation classes: forested wetland, fresh, intermediate, brackish, saline, and deltaic marsh; however, very little reduction in the number of sites could be achieved in this manner. More importantly, combining classes would make the analyses less sensitive to one of the most important changes believed to proceed wetland loss in Louisiana: stress



**Figure 4.** Resampling methodology indicating that 100 randomly selected samples (reference sites) would represent the true coastwide vegetative composition 95% of the time.



**Figure 5.** Resampling methodology indicating that 800 randomly selected samples (reference sites) would detect a 20% change in marsh type between time-one and time-two 95% of the time.

induced changes in vegetative composition. We therefore rejected combining classes of vegetation as a means of reducing sample size.

Based on the statistical approaches described above which estimated the number of reference sites from 540 to 800, and on the extensive professional experience of participating wetland scientists, we recommend a total of 700 reference sites in this sampling design. This level of replication should be sufficient to represent the functional variation of the various response variables measured.

Our methods for sample size determination can be adapted by other programs depending on the amount of existing information and the questions that the monitoring program is trying to address. Monitoring planners should consider resampling existing data to explore the consequences of various sample sizes on statistical power if existing data are available. The ability to avoid a Type I Error was achieved with relatively small sample sizes. Avoiding Type II Error was the more important consideration. Future analyses should evaluate the effect of the number of vegetation classes on statistical power, and should evaluate the effect of sample size on variables other than vegetative composition.

#### 4. Sampling Locations and Distribution

The 700 reference sites were selected from the 6,298 station sample population based on the location of a random sample point in the space defined by the strata (Figure 6). This unequal probability design ensures representation of all vegetation types within the basin strata. The 700 reference sites will be spatially fixed to increase the likelihood of detecting temporal variability and correlations, which are critical to restoration evaluations. The random distribution of sites will be de-

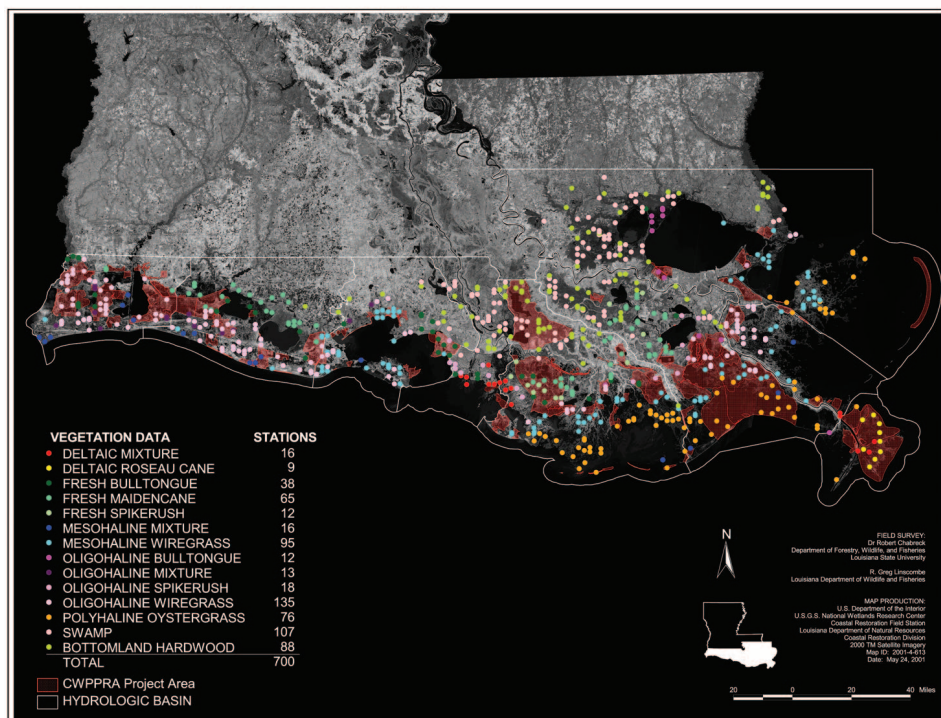


defined as project sites or nonproject sites for reporting purposes. There is no defined sample allocation to project sites because over time, new projects will be added and some existing project sites may revert to nonproject sites. Based on the current distribution of projects, 190 reference sites fall within project boundaries.

To provide a powerful “backbone” of sample stations, we suggest that 200 (28%) of the stations will be sampled every year. The 200 annual stations should represent the true coastwide vegetation composition with greater than 95% confidence. Of the remaining 500 stations, approximately one third will be sampled each year without replacement. In this arrangement, approximately 367 (52%) of the stations will be measured each year. Overall, this schedule should greatly enhance the coverage of temporal variation in the design, provide reference sites that are measured in the same year as the project sites, and at the same time provide efficiency in use of personnel and equipment.

## 5. Discussion

The proposed plan adequately addresses the twin reference area monitoring problems embodied in the two objectives set forth in the beginning of this document. The plan provides an adequate network or “pool” of reference sites that can be



**Figure 6.** Distribution of 700 randomly selected reference sites to be sampled in the CRMS design.

used to address the serious problem of lack of suitable paired reference areas associated with most Breaux Act projects, and it also provides a framework of data collection on a large enough scale that evaluates the effectiveness of the Breaux Act restoration plan in creating a sustainable coastwide ecosystem.

The 700 recommended reference sites will provide adequate spatial representation of the Louisiana coastal marshes and adjacent, small waterbodies. The base of 200 annual sampling sites will provide sufficient replication for within year comparisons and the three year sampling period for the remaining stations will provide resource and cost efficiencies while not reducing our ability to compare long term trends in reference versus project sites.

Remaining design activities include: (1) identifying an additional indicator that exhibits quick response to environmental change in order to rapidly gauge effectiveness of projects; (2) testing the optimal power of the design in characterizing temporal versus spatial variability; and (3) developing ecological functional models following HGM methodologies.

The plan presented allows an evaluation of the cumulative effects of the many individual projects that should collectively lead to the general restoration of Louisiana's coastal estuaries.

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