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COASTAL WETLANDS INDICATOR STUDY: EMAP-ESTUARIES LOUISIANIAN PROVINCE - 1991

by

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This report represents data from a single year of pilot study operations of the Environmental Monitoring and Assessment Program (EMAP). Because the probability-based scientific design used by the EMAP necessitates multiple years of sampling, there may be significant levels of uncertainty associated with some of these data. This uncertainty will decrease as the full power of the approach is realized by the collection of data over several years. Similarly, temporal changes and trends cannot be reported, as these require multiple years of observation. Please note that this report contains data from research studies in only one biogeographic region (Louisianian Province) collected in a short index period (July-August) during a single year (1991). Appropriate precautions should be exercised when using this information for policy, regulatory or legislative purposes.

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PREFACE

This document is the first pilot study summary for the Coastal Wetlands component of the Louisianian Province of the Estuaries component of the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program for Estuaries (EMAP-E).

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EXECUTIVE SUMMARY

This document describes the rationale, objectives, approach, and strategy for testing biological indicators of ecological condition in coastal wetlands. This coastal wetlands program is part of the Environmental Monitoring and Assessment Program (EMAP) administered by the Environmental Protection Agency's (EPA) Office of Research and Development.

The overall goal of EMAP-Coastal Wetlands is to provide a quantitative assessment of the status and long-term trends in coastal wetland condition on regional and national scales with known confidence. The specific, long-term objectives of EMAP-Coastal Wetlands are to:

1) Quantify the regional status and monitor changes through time of coastal wetlands by measuring indicators of biological condition.

2) Quantify the change in extent of coastal wetlands through time on regional and national scales.

3) Identify associations between coastal wetland condition and hydrologic stress, pollution exposure, and other factors affecting wetland condition.

4) Provide timely data and interpretive summaries, reports, and assessments of wetland condition and trends.

The purpose of this report is to begin the process of indicator selection and testing to produce the appropriate field measurements, statistical metrics, and reporting indices to assess status or condition of coastal wetlands. In short, how do we define and measure coastal wetland condition?

The use of biological indicators to assess coastal wetland condition or "health" is central to the EMAP concept. It assumes that meaningful information can be obtained for regional and national assessments of important coastal wetland attributes on a fairly constrained and limited set of indicator measurements. The development and selection of indicators for EMAP-Coastal Wetlands is viewed as a continual process, now in its early stages.

This study examined the evaluation of 21 wetland indicators related to sediment characteristics, vegetation, and hydrology. The study focused on the quantification and evaluation of five endpoints with regard to these indicators:

1) Spatial and Temporal Variability - Indicators exhibiting low natural temporal and spatial variability at the sampling site significantly assist in the ability to ascertain differences in status and detect trends.

2) Responsiveness - Indicators exhibiting high responsiveness reflect change in ecosystem condition and respond to either stressors of concern or management strategies.

3) Interpretability and Ambiguity - Indicators related unambiguously to a biological endpoint, exposure, or habitat increase the clear interpretation of findings.

4) Integration - Indicator integrates numerous aspects of environmental stress over time and space.

5) Cost Effectiveness -Indicators can be collected and evaluated at low cost relative to information value.

The objective of the pilot study for coastal

wetlands was to evaluate 21 indicators in the above five categories to ascertain those that might be of use to determine condition in a regional/national monitoring program.

The report is in three major sections describing:

1) Methodologies used in the design, field sampling, laboratory processing, and statistical analysis of the study,

2) Results of the indicator evaluation, the quality of the collected data, and the interpretation of the findings, and

3) Recommendations for the further suitability of any of these 21 indicators for regional monitoring, as well as any new indicators determined as candidates but untested by this pilot study.

The indicators evaluated can be grouped into three broad categories:

1. Soil Parameters
   - Salinity
   - Bulk Density
   - Percent Organic
   - Sulfide
   - pH
   - eH
   - Hydraulic Conductivity
   - Water Levels
   - Chemical constituents - trace metals
   - Chemical constituents - nutrients
   - Sediment/organic accumulation

2. Vegetation Parameters
   - Cover
   - Biomass
   - Stem Density
   - Stem Length
   - Stem Diameter
   - Chemical constituents - trace metals
   - Chemical constituents - nutrients
   - Species presence

3. Other
   - Water levels (time series measurements)
   - Spectral Reflectance

The initial selection and classification of sites as either healthy or impaired were made based on a basin-scale habitat map, Chabreck (1978), that showed the extent of salt marsh habitats. Healthy sites and impaired sites were selected, using aerial photography, from each of the three basins (Barataria, St. Bernard, Terrebonne) in the Louisiana coastal salt marshes. The judgment (determining what was healthy and what was impaired) was based upon: 1) the rate of recent land loss, 2) obvious internal marsh breakup, and 3) severe alteration of natural hydrology or impoundment by canals and spoil banks.

The sampling occurred at "Healthy" and "Impaired" sites in three hydrologic basins within the Louisiana Coastal zone (Terrebonne Basin, Barataria Basin and St. Bernard Basin). These Basins were formed by various distributary lobes of the Mississippi River over the last ~5,000 years. The St. Bernard marshes are the least likely to receive new sediment from the Mississippi River and are the most stable salt marshes in the coastal zone. The Terrebonne and Barataria marshes both have some external sediment input, although the degree of input varies for each basin. The stratification of sampling by drainage basin was intended to account for possible variation due to the different sedimentary history and age of the three basins sampled.

The general sampling scheme at a site consisted of a circular sampling cluster with a center sampling point surrounded by 5 sampling plots 10 m from the center, arranged like spokes on a wheel. The center point is located 50 m inland to ensure that edge effects will not influence the data. This scheme allowed for the collection of up to six replicates within a study site to address site-level sampling variability.

Within each of the basins, six "Healthy" and six "Impaired" marsh health classes were sampled, using the scheme described above. In addition, triplicate sampling was conducted at one of the sample sites within each basin-health class to address within-site variability at a 50-to 100-meter scale. The triplicate sampling provided replicates for the accretion cores, the leaf tissue and the sediment constituents.

The overall data return (all sites combined) for the project was 94%. The major data loss was from the St. Bernard basin, primarily due to rough weather.

In general, most of the indicators show the minimum variance at the within-sample site level, with increasing variance as the spatial scale increased from sample site to co-located site to basin or marsh health level. This increase in variance is small enough (<25% increase) for some indicators to be unimportant. Indicators that exhibit essentially constant or consistent variance across all spatial scales are:

- Total Biomass
- *Spartina alterniflora* biomass
- Water cover
- Number of stems
- Mean stem length
- Mean stem diameter
- Wet bulk density
- Dry bulk density
- eH
- Sulfide
- Bottom salinity (>20 cm depth)
- Depth to 1963 137Cs peak

The sampling replication of these indicators, within a site, could be decreased in favor of greater spatial coverage. Similar results can be seen with the sediment and leaf constituent data.

There are reasonable relationships between the morphology of the plant and total biomass that may be used to non-destructively estimate standing live biomass for this species. In practice this procedure would, for example, result in measuring the morphological aspect on all samples and bringing back some samples (25%) for biomass determinations. The empirical relationships can be established in the lab and compared to previous measurements, resulting in a significant increase in efficiency (i.e., less equipment and fewer samples in the field and fewer lab measurements). It will be useful to investigate morphometric indices for other species (especially for *Juncus* sp.). Not all species are amenable to this approach. Measurements of plant stem morphology may be used to distinguish healthy from impaired sites in this plant community.

There is an apparent relationship between the sulfide concentration in the soil at the time of sampling and the density of tassels. There are no tassels above a sulfide concentration of 30 ppm indicating a minimal tolerance for sulfides or another factor that co-varies with sulfides. The sulfide measurements are representative perhaps of soil conditions over the previous half-day to a few days. The tassel density is indicative of growing conditions for the previous several weeks.

Soil hydrologic conductivity, sulfide and total sulfur concentration may be useful indicators to distinguish between healthy and impaired *S. alterniflora* marshes. These measurements should be continued over a wider area and expanded to examine other species-dominant groups.

There appear to be some statistical relationships between plant spectral reflectance (particularly those measured at the 200 ft. and 400 ft. altitudes) and marsh health. Although the spectral indices were not well correlated with plant vigor, a weak relationship among plant vigor and some of the spectral indices was detected. These results suggest that a more in-depth investigation of the use of spectral

reflectance in assessing marsh plant vigor is warranted.

The discriminant model showed that marshes can be classified into healthy or impaired with an error of ~29% for the healthy and 22% for the impaired using the following variables:

- The sum of the stem diameters
- The log of the number of tassels (stems with seed heads)
- The log of the sulfide concentration
- The log of the "hydraulic conductivity"
- The log of the sediment sulfur concentration.

The Canonical Discriminant Analysis model showed that healthy and impaired sites separate (statistically). Although this model seems reasonable, it still needs to be verified, perhaps by using either part of the data to develop the model then testing it with the remaining data or by collecting a new data set. We feel that the latter approach should be used, because the data set is fairly small. This verification can be accomplished by applying the model developed during this Indicator Study to the data to be collected during the next phase of EMAP.

Recommendations from the study are:

- Plant morphology and structure (e.g., stem width and reproductive structures) are potentially biomass-independent indicators of stress.

- Soil properties (e.g., eH, bulk density, carbon, hydraulic conductivity, sulfide and total S) are sources or consequences of stress that are easily measurable and probably essential properties to measure in EMAP. Interpreting the significance of variations in these properties requires additional measures that may eventually be reduced (e.g., accretion rates, water level, etc.).

- Accretion rates are a valuable addition for data interpretation, especially for evaluating controlling factors causing plant stress. These new data should be used to address questions about long-term marsh accretion and the relationship between biomass and accretion rates. These relationships remain prevalent issues for both indicator development and resource management.

- Pre-sampling aerial surveys should be made available for site selection, and logistical support and a 2-or 3-segment historical comparison of the sites is very informative for determination of whether the sites are healthy or impaired.

- Installation of water-level gages may be too labor intensive to continue for most sites, but water-level is an essential measurement to continue in some fashion, if only to determine important relationships among stressors and plant responses. It may be informative to examine the tide gage records of nearby field sites or to choose field sites for indicator development on the basis of their proximity to good tide gage records.

- It is very cost-effective to collect some soil samples for archival purposes. The toxic effects of pollutants are frequently a threat, and these data could be integrated with the other EMAP studies (e.g., EMAP Estuarine). It may be good to include a screening for some organic pollutants for the same reason. Furthermore, the constituents may be giving us signals to interpret about marsh health and indicator responses.

- This study was initiated as a preliminary attempt to identify whether spectral reflectance measurements of the marsh surface from a helicopter platform could be used to assess marsh health and, thus, would warrant continued investigation. The results presented above indicate that differences in marsh vigor may be definable with this technique. However, the sources of variation

in the data must be identified, and a larger number of sampling stations must be employed.

- pH measurements seem quite useless for the program. The variability among sites was low and ephemeral where it varies; thus, the biological basis for continuation is unclear.

- Sampling efficacy may be improved by investigating the relationship between sample frequency and variability. For example, there are two ways to improve upon the previous sampling efforts for estimating plant biomass. One is to sample fewer plots, and the other is to further develop morphometric measures for non-destructive sampling. Modification of sampling scheme will reduce overall sampling effort with a small loss of replicability. Specifically, the number of replicates for biomass harvest can be reduced from 6 to 5 plots. This should be examined further and may have a potentially long-term consequence for field sampling efficiency.

- EMAP-Wetlands has expanded its scope beyond ecosystem health of monocultural stands of *Spartina alterniflora* to include ecosystem health and general resource condition of coastal wetlands comprised of multiple species and habitats. In practice, this may mean that indicators of fish habitat quality, for example, are appropriate areas for indicator development.

- Non-destructive sampling techniques are desirable, especially in view of the desirability of long-term landowner cooperation.

- Below ground biomass is a potentially important parameter to measure in subsequent studies.

- Indicator development for individual species of homogenous macrophyte cover will be easier than for development of heterogeneous plant cover. There is a drastic change in species dominance between salt and freshwater marshes. The difficulties involved in sampling the brackish marshes are much greater than in sampling monotypic salt marshes. Caution is urged in expecting too much too soon when expanding the vegetation types analyzed from salt marsh to other plant communities.

- The response of plants to a stressor is not necessarily linear. There may be a threshold effect (e.g., to tidal energy or submergence) or an optimum response level (e.g., a pollutant, sulfide or salinity). The range of conditions found in the Louisiana field trials may not represent all ranges of factors affecting the status of plant health in Gulf of Mexico wetlands. For these reasons and others, it is prudent to continue using more rather than fewer of the tested indicators.

- Soil salinity was never an important component of any of the statistical cluster or discriminant analyses. However, it may be an especially important parameter to include in Gulf of Mexico-wide sampling, in view of the hypersaline conditions anticipated in Texas estuaries.

2 INTRODUCTION

2.1 OVERVIEW OF EMAP

This document describes the rationale, approach, objectives, and strategy for the testing of biological indicators of ecological condition in coastal wetlands. This activity is one element of a larger strategy for the establishment of a monitoring program to assess the status and trends in the ecological condition of the Nation's coastal wetlands. This coastal wetlands monitoring program is a single element of the Environmental Monitoring and Assessment Program (EMAP), a nationwide program administered by the Environmental Protection Agency's (EPA) Office of Research and Development (ORD). EMAP is designed to characterize the changing conditions of the Nation's ecological resources on large geographic scales over long periods of time. Although EMAP is designed and funded by ORD, other offices and regions within EPA (e.g., Office of Water) and other federal agencies (e.g., National Biological Survey, U.S. Fish and Wildlife Service) have contributed to its development and will participate in the collection and use of EMAP data.

The overall goal of EMAP is to monitor the condition of the Nation's ecological resources, to evaluate the success of current policies and programs, and to identify emerging problems before they become widespread or irreversible. In addressing this goal, EMAP has four primary objectives:

1) Estimate the current status, trends, and changes in selected indicators of the Nation's ecological resources on a regional basis with known statistical confidence.

2) Estimate the geographic coverage and extent of the Nation's ecological resources with known statistical confidence.

3) Identify associations between selected indicators of natural and anthropogenic stresses and indicators of condition of ecological resources.

4) Provide annual statistical summaries and periodic assessments of the Nation's ecological resources.

2.2 OBJECTIVES OF EMAP-COASTAL WETLANDS

The overall goal of EMAP-Coastal Wetlands is to provide a quantitative assessment of the status and long-term trends in coastal wetland conditions on regional and national scales. The specific, long-term objectives of EMAP-Coastal Wetlands are to:

1) Quantify the regional status and monitor changes through time of coastal wetlands, by measuring indicators of biological condition.

2) Quantify the change in extent of coastal wetlands through time, on regional and national scales.

3) Identify associations among coastal wetland condition and hydrologic stress, pollution exposure, and other factors affecting wetland condition.

4) Provide timely data and interpretive summaries, reports, and assessments of wetland condition and trends.

The first objective of the EMAP-Coastal

Wetlands Program (EMAP-CW) requires the identification of biological indicators of coastal wetland condition to ascertain status and monitor changes. In other words, we will be reporting on selected wetland indicators on regional and national scales and on the status and trends in wetland extent as important indicators of wetland condition. This goal raises many challenging questions that converge on two general themes: the selection of indicators and the sampling/analytical design that would permit the extrapolation of specific measurements to represent large spatial regions.

The purpose of this report is to begin the process of indicator selection and testing to produce the appropriate field measurements, statistical metrics, and reporting indices to assess status or condition of coastal wetlands. In short, how do we define and measure coastal wetland condition?

2.3 EMAP FRAMEWORK FOR INDICATOR DEVELOPMENT

The use of biological indicators to assess coastal wetland condition or "health" is central to the EMAP concept. It assumes that meaningful information can be obtained for regional and national assessments of important coastal wetland attributes on a fairly constrained and limited set of indicator measurements. Identification of the best set of indicators to achieve this objective is critical to the success of EMAP-CW.

The development and selection of indicators for EMAP-Coastal Wetlands is viewed as a continual process, now in its early stages. The basic framework for indicator identification and evaluation is described fully in Barber et al. (1993) and is summarized in Figure 2.1. It is important to the success of EMAP-Coastal Wetlands that the indicators selected, upon which assessments of status and condition will be made, establish a foundation for interpretation by identifying the primary environmental values, assessment endpoints, and assessment questions of concern for the resource. These values, endpoints, and questions are the roadwork to the selection of indicators appropriate to meet EMAP-CW's objectives (Figure 2.2). Once these attributes are established, the process of indicator selection and evaluation can begin.

The three primary, common environmental values associated with the resources being examined by EMAP are:

1. Biological Integrity
2. Consumptive Uses
3. Non-Consumptive Uses.

2.3.1 BIOLOGICAL INTEGRITY

Wetlands perform many functions that can translate into the maintenance of biological integrity. Wetland habitats offer unique physical and biotic features not found in other ecosystems. They are productive resources that support breeding, nesting, developmental, and feeding activities for many species of fish and wildlife. In addition to providing habitat for numerous obligate wetland species, approximately 20% of the species listed as threatened and endangered depend upon wetland habitats during some part of their life cycles. Wetland productivity is often greater than that of surrounding ecosystems and supports both internal trophic relationships and biomass export. Wetlands provide important hydrologic functions including water storage and flood abatement. Coastal wetlands can also contribute to water quality improvement through sedimentation, pollutant immobilization, and uptake of various pollutants and nutrients.

2.3.2 CONSUMPTIVE USES

Coastal wetlands provide critical spawning and nursery habitat for commercially-and

EMAP INDICATOR EVOLUTION

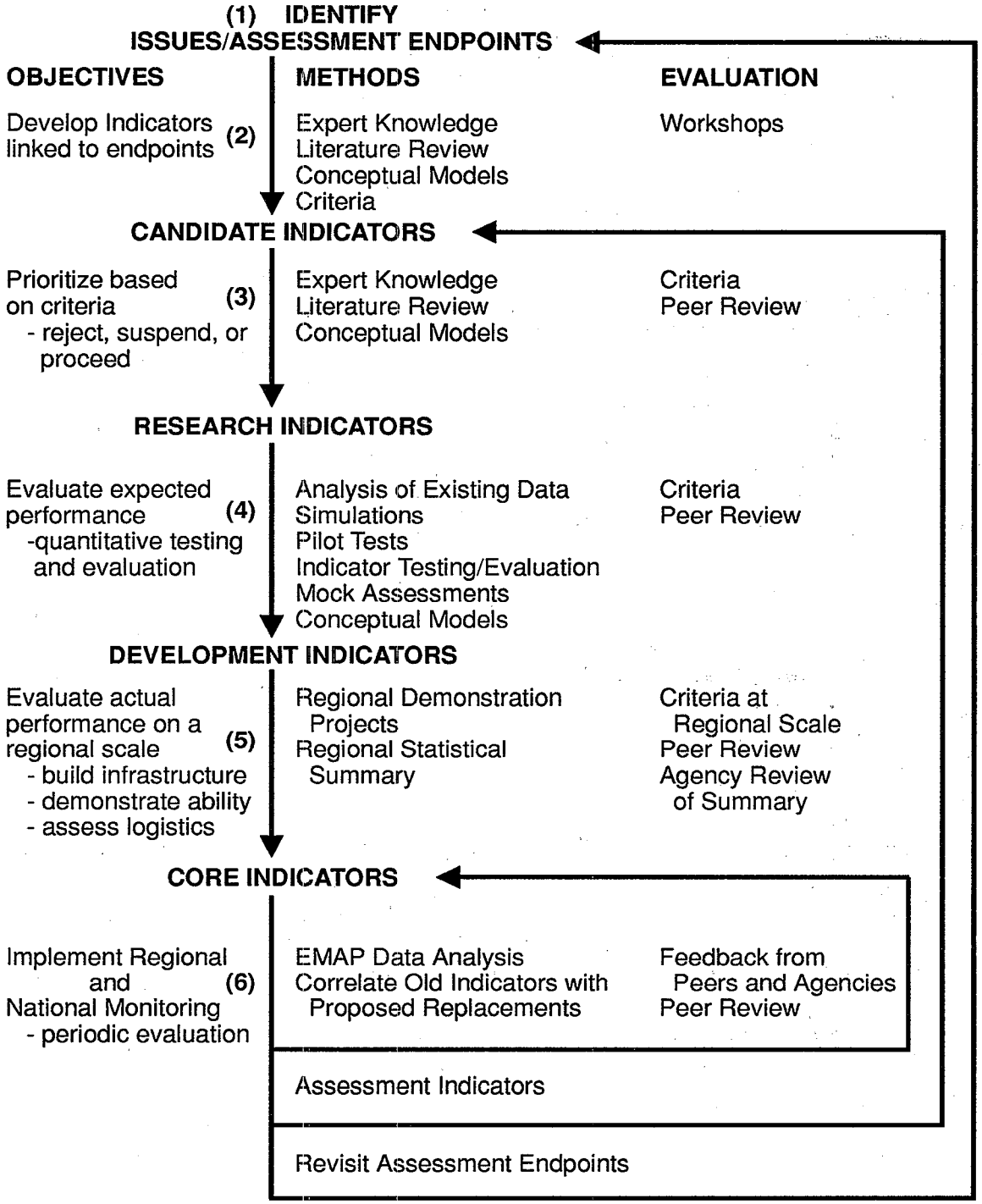

Figure 2-1. Framework for indicator development.

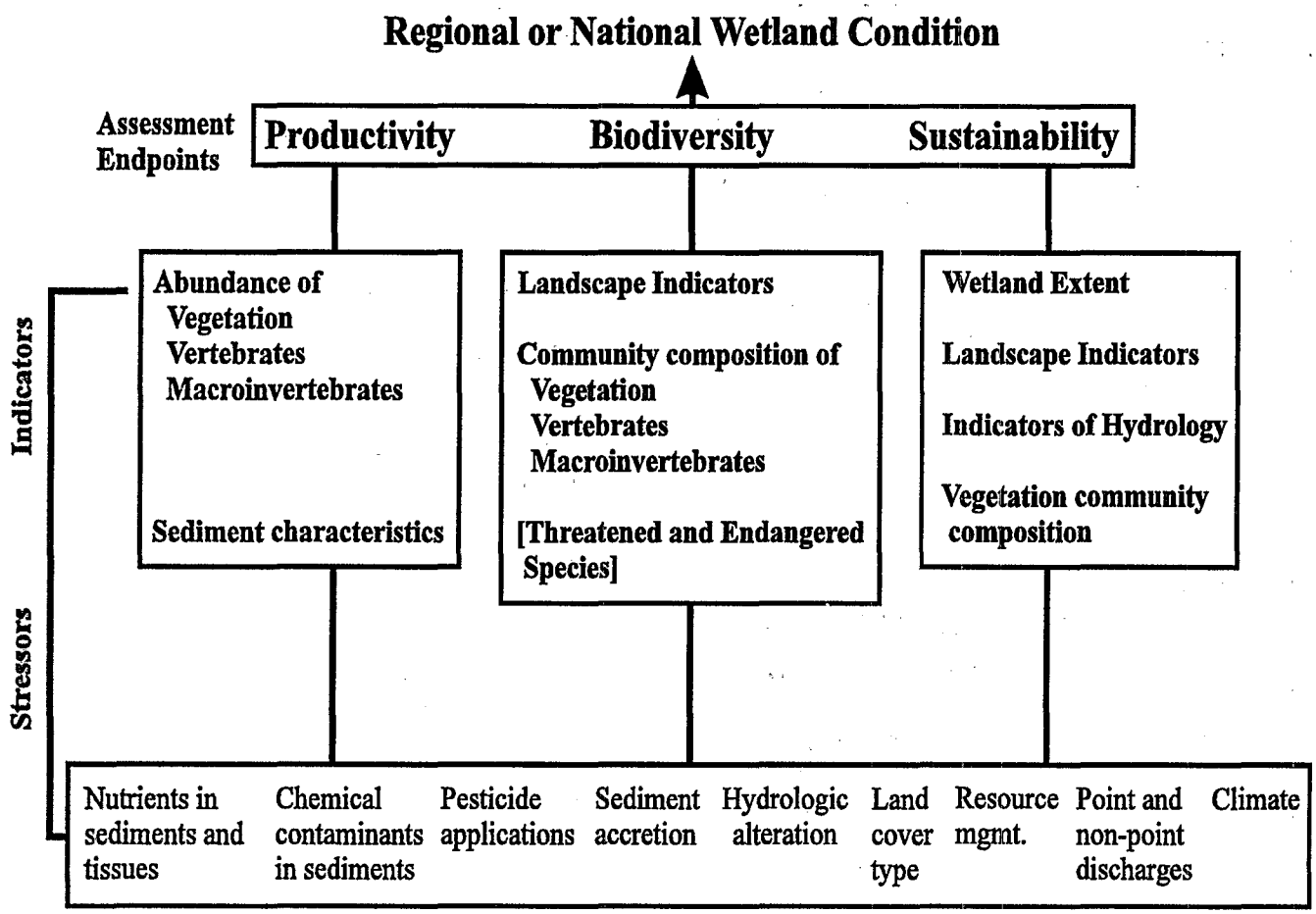

Figure 2-2. The basic framework for indicator identification and evaluation for EMAP-Coastal Wetlands.

recreationally-important fish and shellfish and serve as primary nesting, feeding, and resting habitats for many species of birds including migrating waterfowl. By providing recreational opportunities and serving as a source of commercial products, coastal wetlands are important economic resources. The sporting industry is dependent on the continued productivity of coastal wetlands (i.e., biological integrity) for sport fishing and waterfowl hunting. Coastal wetlands support an annual harvest of fish and shellfish.

2.3.3 NON-CONSUMPTIVE USES

By providing recreational opportunities beyond the extraction of consumptive items like shellfish, waterfowl, and fish, coastal wetlands provide a unique ecosystem for many public users. Non-consumptive users of coastal wetlands are attracted by their diversity of plant and animal life. Many wetlands provide educational and research opportunities that provide significant non-consumptive value.

2.3.4 PILOT TESTING OF INDICATORS OF WETLANDS--ENVIRONMENTAL VALUES

An earlier evaluation of environmental values and assessment endpoints produced a list of potential indicators of coastal wetland condition (Leibowitz et al., 1991). The result of that activity is in Table 2.1 which lists candidate indicators for coastal wetlands.

2.4 PURPOSE AND OBJECTIVES OF PILOT STUDY

This present study examined the evaluation of 20 specific metrics (Table 2.2) of several of the coastal wetland indicators relating to sediment characteristics, vegetation, and hydrology. This study focused on the quantification and evaluation of six endpoints with regard to these attributes:

1) Spatial and Temporal Variability --- Indicators exhibiting low natural temporal and spatial variability at the sampling site significantly assist in the ability to ascertain differences in status and detect trends.

2) Responsiveness --- Indicators exhibiting high responsiveness reflect change in ecosystem condition and respond to either stressors of concern or management strategies.

3) Interpretability and Ambiguity --- Indicators related unambiguously to a biological endpoint, exposure, or habitat increase the clear interpretation of findings.

4) Integration --- Indicator integrates numerous aspects of environmental stress over time and space.

5) Cost Effectiveness --- Indicators that can be collected and evaluated at low cost relative to information value.

6) Regional Applicability --- Indicator is meaningful over geographic space.

The evaluation of these indicators was only within one type of coastal wetland, making any assessment of regional applicability (the last of the EMAP indicator selection criteria) pertinent only to a single marsh type.

The objective of the pilot study for coastal wetlands is to evaluate each of the tested indicators in the above five categories to ascertain which ones might be of use to determine conditions in a regional/national monitoring program.

Indicator	Category	Relevant	Priority	Compatibility Endpoints with Other Resources
Groups				
Wetland Extent	Response & Exposure	S	High	High
Landscape Indicators	Exposure & Response	S	High	High
Indicators of Hydrology	Exposure	S P B	High	Low
Sediment Characteristics	Exposure & Response	S P	High	Low
Community Composition and Abundance of Vegetation	Response	B P S	High	Moderate
Community Composition and Abundance of Vertebrates	Response	B P		
Herpetofauna			Low	Moderate
Mammals			Low	Moderate
Birds				
Community Composition Abundance of Macroinvertebrates	Response	P B	Low	Low, except for adjoining surface water
Chemical Contaminants in Sediment	Exposure	S	Low	Low, except for adjoining surface water
Bioaccumulation in Tissues	Exposure	S B P	Low	Low
Nutrients in Sediment and (or) Vegetative Tissues	Exposure	P S	Low	Moderate

S = Sustainability
B = Biodiversity
P = Productivity

Table 2-1. Candidate Coastal Wetland Indicators for EMAP.

Indicator Category	Specific Indicators Samples
Wetland Extent	Water Levels
Landscape Indicators	None
Indicators of Hydrology	Water Levels Time Series
Sediment Characteristics	Salinity
	Bulk Density
	Percent Organic Carbon
	Sulfide Concentration
	pH
	eH
	Hydraulic Conductivity
	Sediment/Organic Accumulation
Community Composition and Abundance of Vegetation	
	Cover
	Biomass
	Stem Density
	Stem Length
	Species Presence
	Number of Tassels
Community Composition and Abundance of Vertebrates	None
Community Composition and Abundance of Macroinvertebrates	None
Chemical Contaminants in Sediments	Trace Metal Concentrations
Bioaccumulation in Tissues	Trace Metal Concentrations
Nutrients in Sediment and/or Vegetative Tissues	Nutrients in Sediment
	Nutrients in Plant Tissue

Table 2-2. Coastal wetlands indicators evaluated in this pilot study.

2.5 STRUCTURE OF REPORT

The remainder of this report is organized into three major sections describing: 1) methodologies used in the design, field sampling, laboratory processing, and statistical analysis of the data,

2) results of the indicator evaluation, the quality of the collected data, and the interpretation of the findings, and

3) recommendations for the further suitability of any of these 20 indicators for regional monitoring, as well as any new indicators determined as candidates but untested by this pilot study.

3 STUDY DESIGN AND INDICATOR SELECTION

3.1 SITE SELECTION

3.1.1 PURPOSE OF NON-RANDOM SITES--INDICATOR DEVELOPMENT

The purpose of EMAP Coastal Wetlands monitoring is to estimate wetland condition based on a probabilistic sampling design. However, the testing of the efficiency of indicator condition (i.e., can they differentiate between "healthy" and "impaired" conditions) requires the use of a non-probabilistic design to efficiently ascertain the power of the selected indicators. The use of judgmental sites of known condition (based on previous knowledge) is the more effective design to test the strength of individual indicators or groups of indicators. This indicator testing program sampled sites at the two ends of the marsh health continuum ("Healthy" and "Impaired") and developed indicators that could differentiate between these health conditions. The sites were classified as either being healthy or impaired and were sampled to determine variability in a wide variety of physical, biological and geological parameters. These parameters are called "indicators" within the framework of this program, because we were looking for ways to characterize differences among levels of ecological conditions. If the differences were strongly differentiated, then these parameters would be examined for their general applicability in a regional scale-monitoring program.

3.1.2 SITE SELECTION CRITERIA

The initial selection and classification of sites as either healthy or impaired were made based on a basin-scale habitat map, Chabreck (1978), that showed the extent of salt marsh habitats. Healthy sites and impaired sites were selected, using aerial photography, from each of the three basins (Barataria, St. Bernard, Terrebonne) in the Louisiana coastal salt marshes. The judgment (determining what was healthy and what was impaired) was based upon: 1) the rate of recent land loss, 2) obvious internal marsh breakup, and 3) severe alteration of natural hydrology or impoundment by canals and spoil banks.

Candidate sites were evaluated using an inventory of the NASA overflights for various time periods within the Louisiana Coastal zone and using loss/accretion maps. We used the most recent overflight (1988-1989) and the USACOE land loss maps (i.e., showing land loss from ~1935 to 1978) to determine areas that have remained stable and areas that are breaking up. Defining whether a marsh is healthy or impaired is somewhat subjective and also complicated by the varying scales of the available photography. The 1988 aerial photography is high-altitude photography (scale approximately 1:24,000), while the U.S. Army Corps of Engineers land loss maps were at a coarser resolution (1:62,500). However the ACOE map scale did not permit us to assess vegetation and open water in the same manner as they could be assessed from low altitude overflight or finer-scale photography.

The following steps were used to select field sampling sites:

1. Using most recent aerial photographs and vegetation maps, salt marsh areas were located that were characterized by <40% open water and those with >60-70% open water.

2. The recent photos were compared with the USACOE maps to determine if the site had changed during the time period.

3. If the site had remained stable at <50% open water, it was classified as healthy. If the site showed an increase from <40% open water in 1978 to >60% open water in 1988, then it was classified as impaired.

4. Procedures 1 through 3 were repeated until 6 healthy and 6 impaired sites were identified within the salt marshes of each of the three basins.

5. The sites were checked to ensure that each could be considered a unique site and that no two sites of a given classification (healthy, impaired) were hydrologically controlled by the same local drainage network.

The intent was to select sites at the two ends of the marsh health continuum ("Healthy" and "Impaired"). The original classification procedure called for the sites to be flown over before sampling to confirm that the classification was reasonable. However, time constraints did not allow for the photos to be collected prior to the field sampling. As a result, some sites were misclassified. An incorrectly classified site was defined as a site that was determined upon sampling to be (1) not salt marsh or (2) not meeting the classification criteria for healthy or impaired sites described above. A re-classification scheme was developed, based upon the Pilot Study sampling and the analyses of the aerial photos that were obtained after the sampling. [If the photos had been available before sampling, we believe that several sites would not have been sampled.]

A reclassification scheme was developed based upon the aerial photos and our field sampling experience. We reclassified the sites without looking at the indicator data to minimize any bias. The results of the re-classification are described in Table 4.6 which presents the justification used for the classification and reclassification for each of the sites sampled. The reclassification is summarized in Table 4.7. Of the initial classification for the Terrebonne basin, 75% were not changed. We had difficulty actually finding a healthy marsh in the Barataria basin. Only one site that we initially classified as healthy in Barataria turned out to be a healthy site, and two turned out to be impaired sites. The percentage of sites initially classified correctly for Barataria basin was 42%. In the Bernard marshes, one site initially classified as an impaired site was reclassified as healthy. The percentage of sites initially classified correctly for the St. Bernard basin was 75%. In summary, of the 45 sampled clusters, 15 were re-classified as healthy sites, 17 were reclassified as impaired sites, and 13 were reclassified as "in-between or undetermined" sites. Twelve of the 45 sites (27%) required a change in classification.

Sites were selected on the basis of examination of these aerial photographs and knowledge of the field sites. A "healthy" site had relatively high and constant habitat areas from 1978 to 1988 (the most recent photographs available at the time). An "unhealthy" site had relatively low and constant (low variability) plant cover from 1978 to 1988 or had declining plant cover from 1978 to 1988. This was a somewhat subjective analysis but was also based on personal knowledge of the field conditions in south Louisiana. Further, these decisions were discussed among three experienced marsh ecologists, and sites with indecisive or unclear classification results were not used in this study.

3.2 STUDY DESIGN

3.2.1 GEOGRAPHIC SCOPE --- WITH RATIONALE

Sites were selected to provide broad geographic coverage, geographic variability, and sampling variability of monocultural stands of *Spartina alterniflora*. The peak standing crop of live biomass in healthy salt marshes varies among marshes. Gosselink et al. (1977) and Hopkinson et al. (1978, 1980) described variations in peak biomass during late summer within Barataria Basin. They observed that live biomass tended to be higher in the southern part of the basin and on the eastern border and that biomass was higher in Barataria Bay compared with similar positions in a nearby basin (eastern Terrebonne Bay). Likely explanations for these variations are associated with salinity gradients in the bay and proximity to new sediment sources. We expected similar variations among northern Gulf of Mexico salt marshes (e.g., Turner and Gosselink 1975). Therefore, we sampled from three bay systems: St. Bernard, Barataria Bay and Terrebonne Bay, representing three different deltaic coastal estuaries in south Louisiana. The sampling was within three drainage basins to account for probable variation due to the different sedimentary history and age of the three basins sampled. In the 1991 field season, 45 salt marsh sites were sampled (Figure 3.1).

3.2.2 LOCATION AND TIMING OF SAMPLING

Salt marshes are not homogeneous, even within one locality. Figure 3.2 shows some examples of variability in soil, water and plant characteristics from stream-side to inland sites. Sample variability typically reaches the lowest level by 50 m inland from the bayou. In general, the sampling variability increases with increasing biomass. Stream-side marshes generally comprise 10% or less of the entire saltmarsh (Kirby 1971), and their conversion to open water

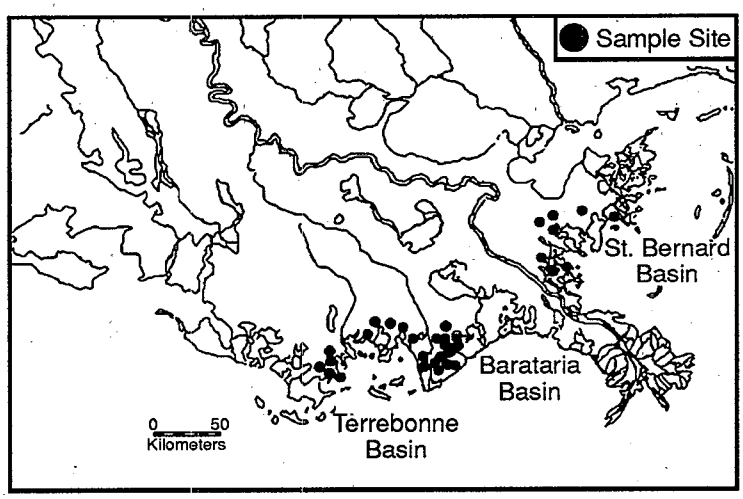

Figure 3-1 Sampling locations in south Louisiana for the 1991 field season.

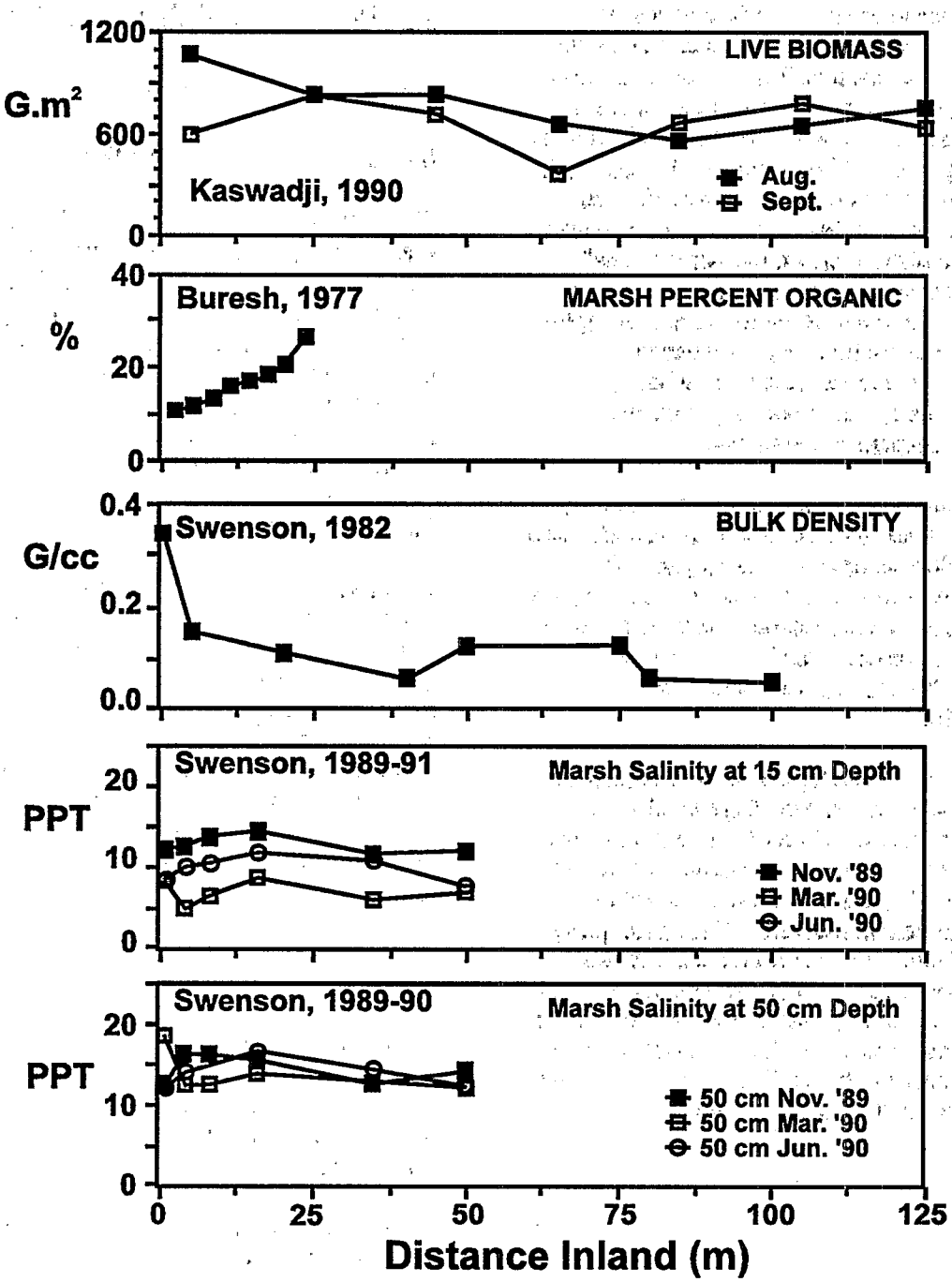

Figure 3.2 Variations in different parameters measured with distance into a salt marsh. (1) Live biomass in August and September (from Kaswadji et al. 1990). (2) Percent organic matter (from Buresh 1978). (3) Bulk density (from Swenson 1983). (4) Marsh salinity at 15 cm depth in November, March and June (from Swenson, Peterson and Turner, unpublished). (5) Marsh salinity at 50 cm depth in November, March and June (from Swenson, Peterson and Turner, unpublished).

is mostly due to erosion, not fragmentation. Further, the last marshes left in a natural marsh are stream-side marshes, because their substrates are at a slightly higher elevation than those in inland marshes. The National Wetland Inventory is mapping these erosional losses. Variability in the stream-side zone confounds sampling and data interpretation; therefore, it is wise to sample far enough inland to avoid the "stream-side" effect. It appears that starting a transect about 50 m into the marsh is sufficient to reduce sampling variability due to this elevation gradient. Samples were taken at least 50 m inland to reduce variability and to thereby improve statistical comparisons of marshes.

The original classification procedure called for aerial photography of the sites to be sampled two months before sampling. The purpose of this photography was to ensure that the classification was accurate. Time constraints did not allow for the photos to be collected before the field sampling. As a result, some sites were misclassified.

Variability with soil depth is also considerable but diminishes with depth. Figure 3.3 shows examples of this variability for soil salinity and pH. Data on the vertical distribution of salinity in a marsh (Figure 3.3) indicates that salinity varies most near the surface. Thus, a sampling depth > 30 cm should be used to help reduce some of this upper-level variation and to increase chances of detecting long-term trends. However, we measured vertical profiles of marsh salinities over the upper 50-75 cm of the marsh during the development of the sampling protocol.

3.3 INDICATOR SELECTION

3.3.1 GENERAL CRITERIA

Indicators of Wetland Condition

The term "indicator" within EMAP refers to the specific environmental characteristics to be measured or quantified through field sampling, remote sensing, or compiling of existing data. The selection of indicators is viewed as a multi-year process, now in its fairly early stages. The indicators proposed in this document are considered research indicators; each requires additional field testing and evaluation and, in some cases, methods development prior to full-scale implementation.

It is critical to the success of EMAP-Wetlands that the characteristics of the environment monitored are appropriate to meeting the program's assessment goals. The first step in the indicator development process, therefore, is to define a framework for indicator interpretation by identifying the environmental values, assessment endpoints, and major stressors of concern for the resource. The interpretation of the EMAP-Wetlands monitoring results will focus around three major assessment endpoints:

1. **Productivity,** including both floral and faunal components.

2. **Biodiversity,** defined by the variety of floral and faunal species inhabiting the wetland in terms of both community composition and structure, as well as by the functional niches that are represented.

3. **Sustainability,** defined as the robustness of the wetland, its resistance to changes in structure and function and its persistence over long periods of time, as measured by both the size and hydrology of a wetland.

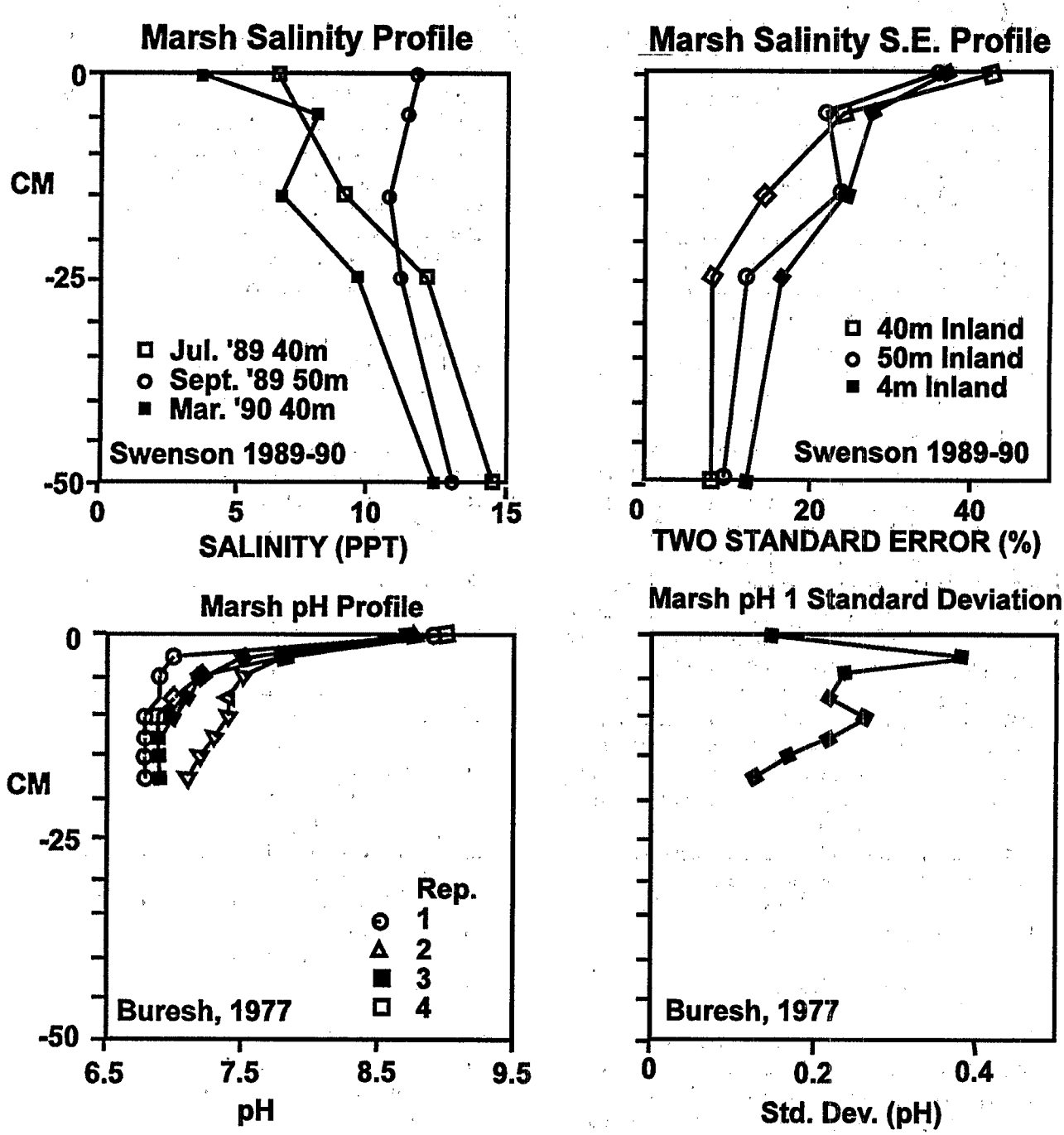

Figure 3.3 Sampling variations in parameters and their statistical variability with depth. (Top left) Interstitial soil salinity vs. Depth for samples taken in July, September and March, 1990, at a station located 40 m into the marsh. (Top right) The statistical variability (+/-2S.E.) for 10 monthly samples at depth for three locations in salt marsh: 4, 30 and 40 m into the marsh (from Swenson and Peterson, unpublished). (Bottom left): pH measurements in a salt marsh taken 4 times with depth. (Bottom right) Standard deviation of the 4 samples for pH, as shown in the left panel (from Buresh, 1978, for samples taken in 1977).

Wetland condition will be judged, therefore, in relation to the productivity, biodiversity, and sustainability of the system as inferred from the measured EMAP indicators. The objective is not to maximize the wetland attribute, such as productivity, but to evaluate the measured indicator values relative to expected norms for a wetland of that type and region. Natural wetlands are not always highly productive (e.g., ombrotrophic bogs) nor highly diverse (e.g., coastal salt marshes). The proposed EMAP-Wetlands indicators and their relationships to these assessment endpoints are illustrated in Figure 3.4.

As a group, the set of indicators measured for EMAP-Wetlands must provide an adequate basis both to assess wetland condition and to conduct the diagnostic analyses described below. Four types of indicators will be monitored: (1) response indicators that provide a measure of biological condition (e.g., vegetation community composition); (2) exposure indicators that assess the occurrence and magnitude of contact with a physical, chemical, or biological stressor (e.g., nutrient concentration); (3) habitat indicators that characterize the natural physical, chemical, or biological conditions necessary to support an organism, biological population, or community (e.g., wetland hydrology); and (4) stressor indicators that quantify natural processes, environmental hazards, or management actions that result in changes in exposure or habitat (e.g., changes in land cover type).

Assessing Wetland Health

The assessment of ecosystem condition or, by human analogy, "health" requires both (1) the occurrence of certain criteria considered indicative of a healthy sustainable resource and (2) the absence of known stressors and detectable symptoms of ecosystem stress. The challenge for EMAP-Wetlands is to conduct such an assessment using the types of information and measurements that can be collected within the constraints of the EMAP design. No indices of wetland condition currently exist that are widely accepted in the scientific literature and tested and applied on a regional scale. The development of techniques for assessing wetland health will require, therefore, innovative approaches to data analysis and interpretation and are the subject of substantial future research within the EMAP-Wetlands program.

In general, for each wetland class in each region, wetland condition will be judged by comparing the measured indicator values with:

- expected normal ranges for each response variable, derived from measurements at reference sites, historical records, the available literature, and (or) expert judgment; and

- information on stress-damage thresholds for each exposure indicator, obtained from the literature and available data.

The terms nominal and subnominal within EMAP refer to "healthy" and "unhealthy" conditions, respectively. Wetlands classified as nominal are assumed, by definition, to be performing as expected for a wetland of that type, within that region, and for the specific assessment endpoint of interest. Classification of a wetland as nominal or subnominal will rely not on any single indicator, but on the full set of monitored response, exposure, habitat, and stressor indicators. Specific approaches for dealing with apparent inconsistencies in indicator signals, or for formally combining indicators into a joint index of wetland condition, will be explored as part of the EMAP-Wetlands indicator development process. Estimation of the numbers of nominal (deemed healthy and sustainable) and subnominal (unhealthy) wetlands in the United States (e.g., Figure 3.4) and trends through time in wetland health are important assessment objectives for the EMAP-Wetlands program. Previous research

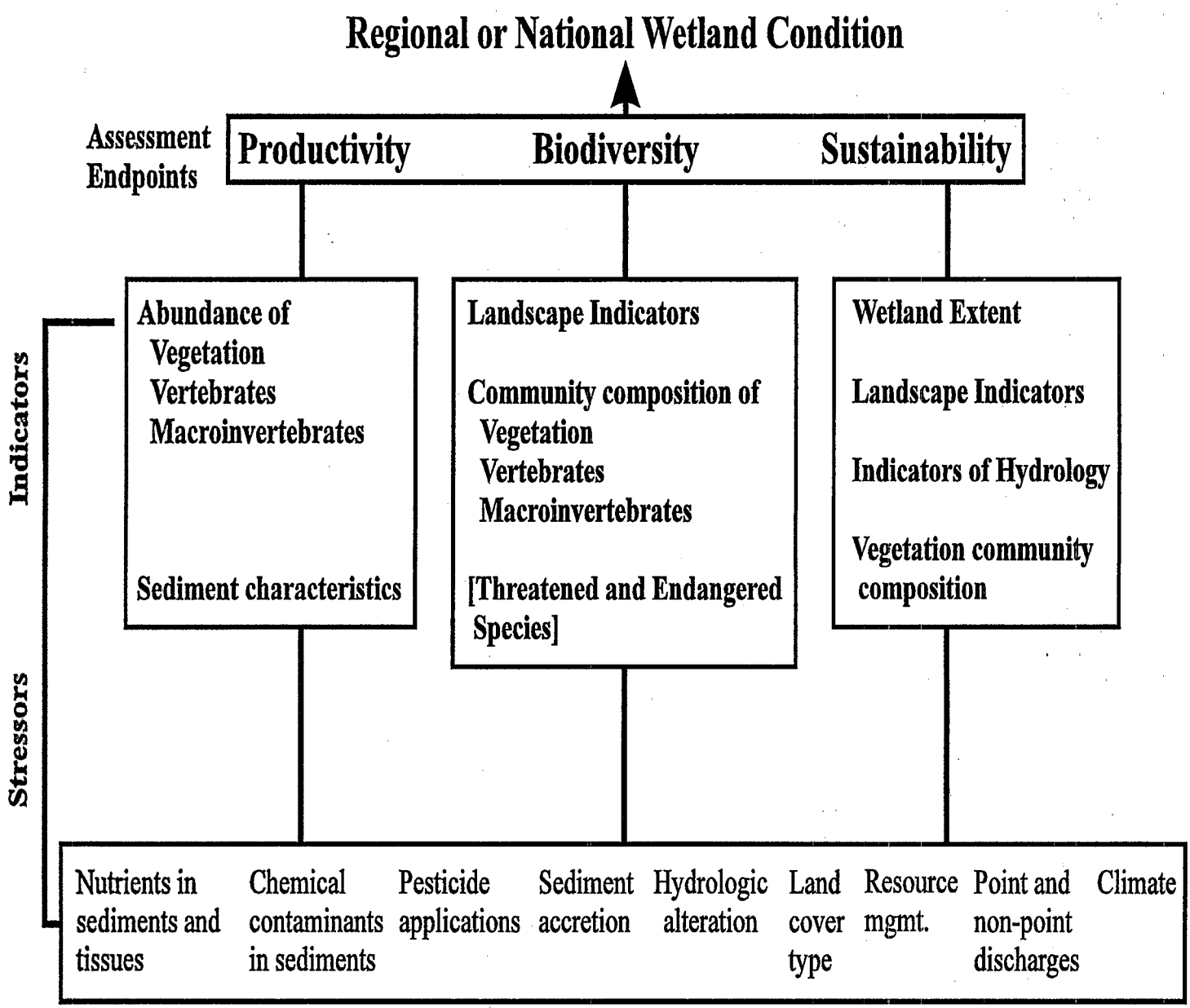

Figure 3.4 Conceptual model showing linkages to salt marsh values and assessment questions.

has demonstrated that plant biomass (Hardisky et al., 1984) and plant stress (Mendelssohn, McKee and Ewing, 1990) can be determined with high-resolution spectral measurements of the marsh canopy and leaf tissue, respectively. Stress is typically manifested as higher reflectance spectra in the 400-600 nm and 800-1100 nm ranges. An advantage of this bio-indicator is the potential to correlate the results of these measurements taken at a very low altitude with high altitude remote sensing techniques such as the Landsat thematic mapper and Airborne Imaging Programs of NASA.

3.3.2 SAMPLING INDEX PERIOD

Seasonal and annual variability exist with biomass, salinity, water levels, as well as with other factors. Figure 3.5 contains examples of this variability. Annual variations occur in salt-marsh biomass (Morris et al., 1990), salinity (Wiseman et al., 1990), average water level and monthly variations in water level (Turner 1991), and water-column nutrients. Although August is the peak month in the accumulated above-ground live biomass of *Spartina alterniflora*, that peak does not last for long and the standing crop of live biomass declines quickly within a 1-2 month period (Figure 3.5). Reproductive structures begin to appear in August; therefore, it is important to sample both before the decline in biomass and after the peak production period. However, the appearance of reproductive structures may be indicative of healthy plants, and their presence/absence can be used as an indicator of stress.

Soil chemistry differences in stressed salt marshes, as indicated by eH measurements (Figure 3.5), are likely to be greatest during the period of maximum soil flooding and highest plant biomass. Further, it is important to sample in as short a time period as possible, perhaps within one week, to minimize the variable impacts of seasonal changes in flooding that are common during late summer. Samples were, therefore, taken in the index period between late August and September.

3.3.3 LIST OF INDICATORS CHOSEN

The indicators evaluated can be grouped into three broad categories:

1. Soil Parameters
   - Salinity
   - Bulk Density
   - Percent Organic
   - Sulfide
   - pH
   - eH
   - Hydraulic Conductivity
   - Water Levels
   - Chemical Constituents - trace metals
   - Chemical Constituents - nutrients
   - Sediment/Organic Accumulation

2. Vegetation Parameters
   - Cover
   - Biomass
   - Stem Density
   - Stem Length
   - Stem Diameter
   - Chemical Constituents - trace metals
   - Chemical Constituents - nutrients
   - Species Presence

3. Other
   - Water Levels (time series measurements)
   - Spectral Reflectance

3.4 SAMPLING SCHEME

The sampling occurred at "Healthy" and "Impaired" sites in three hydrologic basins within the Louisiana Coastal zone (Terrebonne

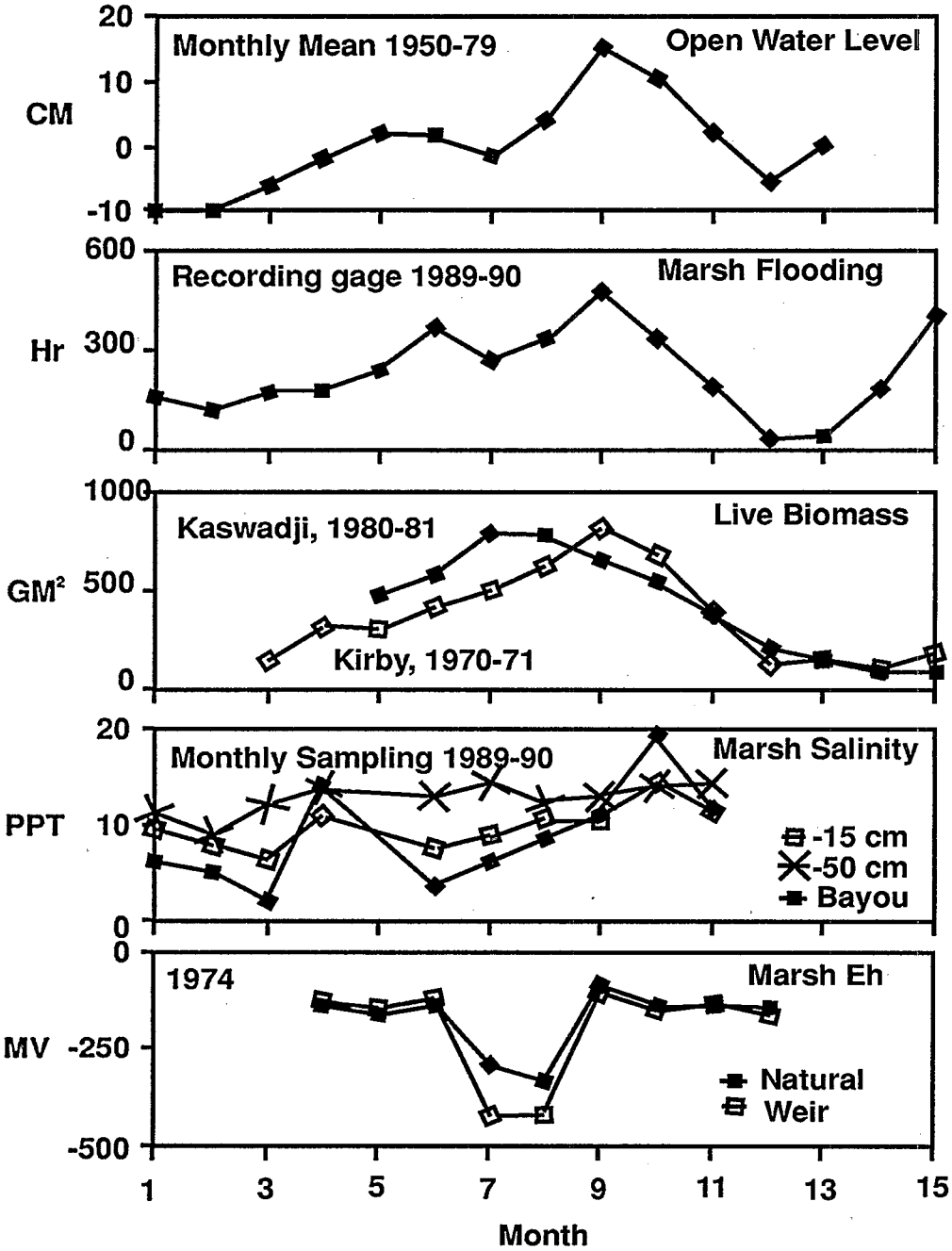

Figure 3.5 Monthly variations in the marsh for different parameters to be measured in this project. (1) Water level at Bayou Rigeau on Grande Isle. Monthly deviations from the mean level from 1950-1979 are plotted to compensate for sea level rise and subsidence (adapted from Turner 1991). (2) Hours of marsh flooding at a salt marsh near Cocodrie, Louisiana (from Swenson, Peterson and Turner, unpublished). (3) Monthly standing crop of live *Spartina alterniflora* near Airplane Lake in 1970-1971 (Kirby 1971) and in 1980-81 (adapted from Kaswadji et al. 1990). (4) Salinity in a salt marsh near Cocodrie in the bayou and at 15 and 50 cm depths, in the inland marsh (from Swenson, Peterson and Turner, unpublished). (5) Monthly eH values for a salt marsh measured at 10 cm in a salt marsh with and without a weir (from Hoar 1975).

Basin, Barataria Basin and St. Bernard Basin). These Basins were formed by various distributary lobes of the Mississippi River over the last ~5,000 years. The St. Bernard marshes are the least likely to receive new sediment from the Mississippi River and are the most stable salt marshes in the coastal zone. The Terrebonne marshes and the Barataria marshes both have some degree of possible sediment input, although the degree of input for each may be different. The stratification of sampling by drainage basin accounts for possible variations due to the different sedimentary histories and ages of the three basins sampled.

The general sampling scheme at a site consisted of sampling a cluster of points located in the marsh. The cluster was circular with a center point, surrounded by 5 sampling plots that radiated out from the center with a constant distance of 10 m, like spokes on a wheel (Figure 3.6). The center point was 50 m inland to ensure that any edge affects would not influence the data. This distance (50m) was measured from the back edge of the natural berm or spoil bank. Thus, the sampling was 50 m into the interior marsh vegetation. This scheme allowed for the collection of the required number of replicates (up to a maximum of six) within a study site to address site-level sampling variability.

The number of replicates within a plot was based upon literature estimates of the effect of sample size on the estimated mean weight of *Spartina alterniflora* biomass (Kaswadji et al., 1990). This study showed that the variation began to level off around seven samples and was unchanged for 8 (or greater) samples. Similar results were obtained for the measurements of bulk density and eH (Figure 3.7). Based upon these results, six sampling plots within a sample site were used for Biomass, Cover, Bulk Density, Percent Organic and Water Depth. Leaf Tissue samples and Sediment Constituent samples were collected at all six plots but were combined (in the field) into a single sample. The cost of the analyses precluded the testing of more than ~50 samples for each of these variables. The same was true for the sediment accretion cores. The time involved in sample processing and analysis limited the number of samples to one per site.

Within each of the basins, six "Healthy" and six "Impaired" marsh health classes were sampled using the scheme described above. In addition, triplicate sampling was conducted at one of the sample sites within each basin-health class to address within-site variability at a 50-to 100-meter scale. In addition, the triplicate sampling gave site replicates for the accretion cores, the leaf tissue and the sediment constituents. The sites where the triplicate sampling was made were chosen randomly from the sites to be sampled within a basin-health class. At a triplicate site, the sampling cluster was set up, sampled, then a second sampling cluster was established 50 meters from the first cluster. This was accomplished by extending the line 90 degrees from Replicate A another 50 meters and making this point the center of the new cluster (Replicate B). If the Replicate B was in an area that was closer than 50 meters from the back edge of the berm or spoil, Replicate C was established 50 meters inland and was used instead (this was repeated using Replicates D, E, F, if needed). This second cluster was set up and sampled. A third cluster was then set up and sampled using the same procedures (Figure 3.8). The overall sampling design is shown in Figure 3.9.

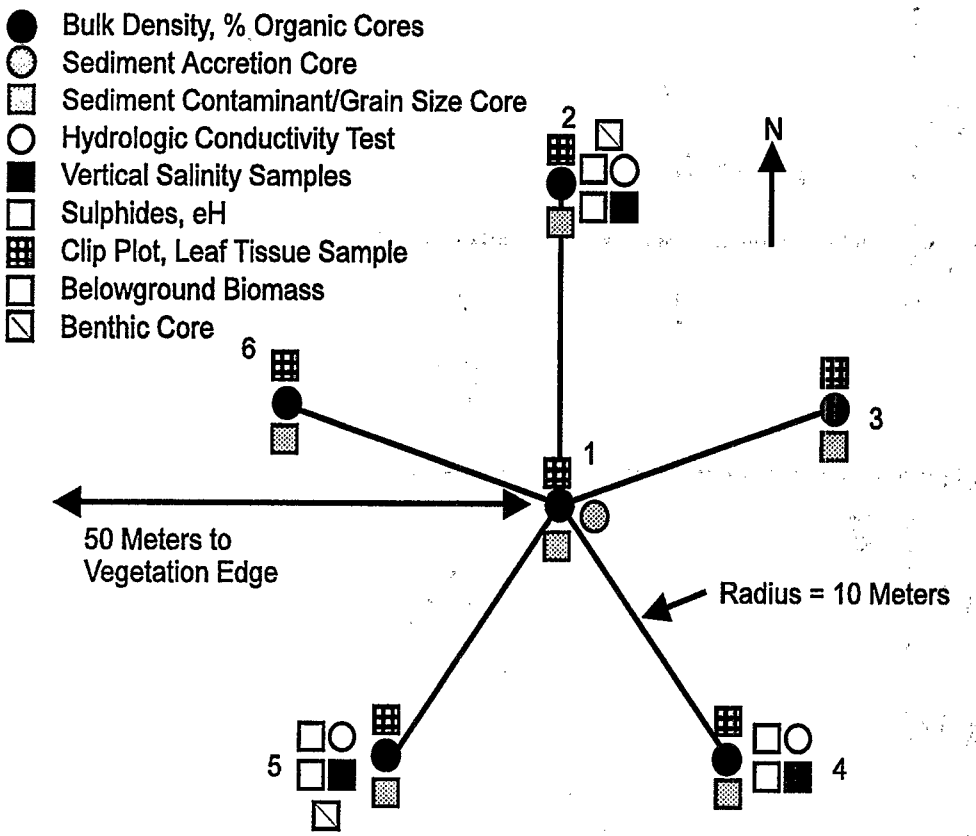

Figure 3.6 The sampling distribution and frequency within the field plot.

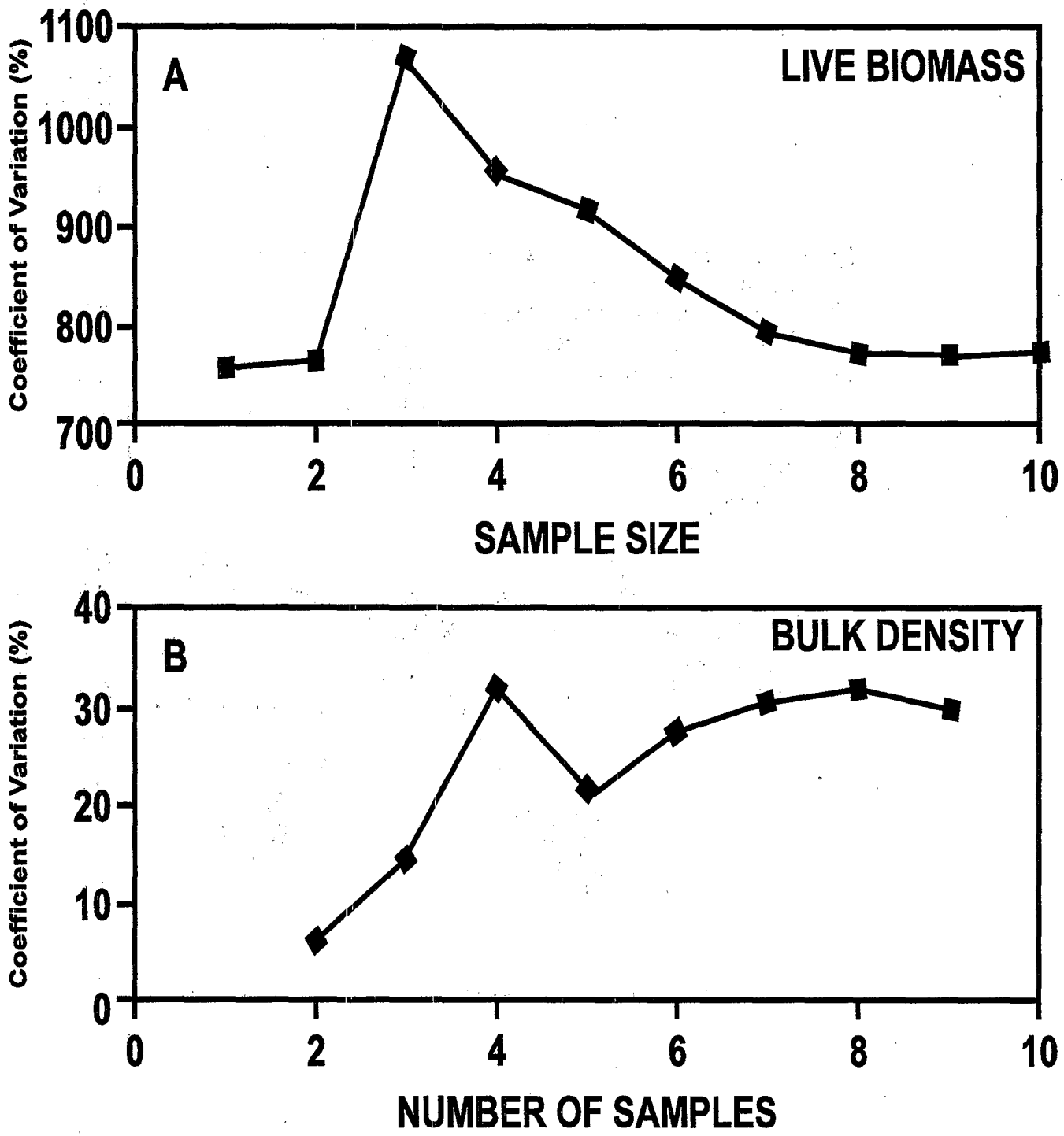

Figure 3.7 The effect of the number of samples on (A) the mean weight of *Spartina alterniflora* biomass (Kaswadji et al. 1990), and (B) the coefficient of variation (%) of bulk density.

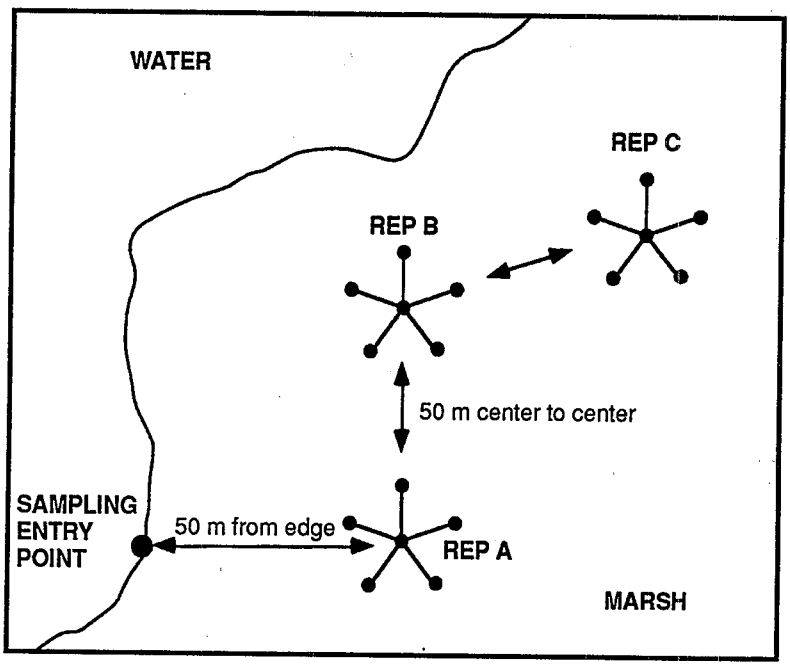

Figure 3.8 The layout of the triplicate sites.

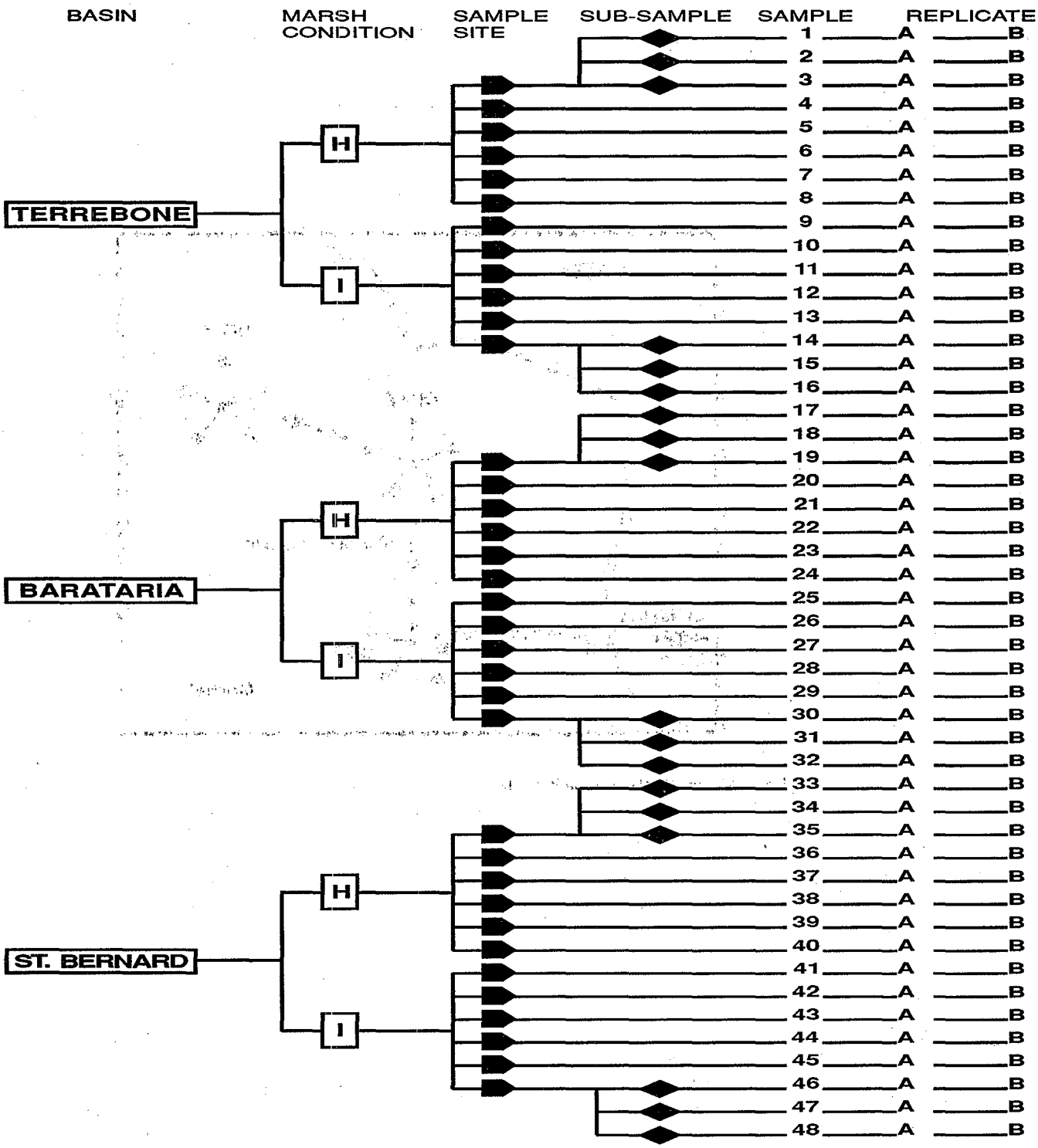

Figure 3.9 The overall sampling design. "H" refers to a "healthy marsh" and "I" refers to an "impaired marsh."

3.5 SAMPLING PROCEDURES

Details of the sampling methods used in the 1991 sampling season are provided in the Coastal Wetlands Pilot Study Quality Assurance Project Plan (Swenson et al., 1992a). The methods are summarized in general terms below. The indicators were grouped into field and laboratory procedures.

3.5.1 SOIL PARAMETERS - FIELD

Salinity Samples

Vertical salinity profiles were measured using sampling pipes made from 1.3-cm (1/2") diameter PVC plumbing pipe. The pipe was cut to the desired length, a PVC point was cemented on the end, and a series of small holes were drilled in the pipe about 10 cm above the point. The pipes were inserted into the marsh sediment until the holes were at the desired depth for sampling and were allowed to stay in place for about 30 minutes. The pipes were then withdrawn from the marsh, and the water that had collected in the pipe was withdrawn and placed in small vials. Samples were collected at depths of 0, 10, 20, 35, and 50 cm. The amount of sample collected was too small (~1.5 ml) for the use of a field conductivity probe. The samples were returned to the laboratory for salinity determination using a digital chloridimeter that only required ~100 microliters of sample.

Bulk Density/Percent Organic Cores

Near-surface cores (11 cm length) were collected using a small piston corer which collected an uncompacted core with a volume of 50 cc. The corer base was placed on the marsh surface in a relatively flat area (avoiding the tops of clumps, if possible), and the core barrel was pushed into the marsh substrate using the attached handle. When the proper depth was reached (there was a depth stop on the corer), the barrel was withdrawn from the marsh substrate and the cores were extruded into clean, pre-weighed plastic centrifuge tubes. The samples were taken to the laboratory for analysis.

Sulfide Samples

Interstitial water samples were collected using a Teflon sampling tube connected to a syringe. The tube was inserted to the sampling depth, (30 cm); then a sample was carefully withdrawn from the substrate (the first sample is used to rinse out the system and is discarded). The sample was fixed in the field with an antioxidant buffer solution and stored on ice until taken to the Laboratory for analysis.

eH and pH Measurements

Soil eH was measured in the field at 30 cm depth using five replicate probes (brightened platinum) calibrated in the laboratory before and after the field trip. Soil eH was measured (using a digital voltmeter) as the potential (in mV) of a calomel electrode against the eH probe. The half-potential of the calomel electrode (+244 mV) was added to the measured potential to calculate eH.

Interstitial water pH was measured using a hand held pH meter with a sensing well. Two drops of water collected from the sulfide sample were placed in the sensor well and a reading were made. The pH meter was calibrated using pH 4.0 and 7.0 buffers before use.

Hydraulic Conductivity Measurements

A simple and inexpensive method, developed to measure soil infiltration, was employed at each field site. The device was a plastic tube whose lower end was pushed into the marsh. Water was put into the top end and allowed to settle. After a few seconds, a valve was opened, allowing water to flow from the tube into the marsh through slits

in the buried end of the tube. The water fall rate was timed by watching water in a transparent tube connected on the outside of the larger tube holding water and was marked at 0.1 m intervals. The technique was easily learned, and the equipment was simple and reliable.

Water Depth Measurements

Water depth was measured in the center of each plot to the nearest centimeter, using a meter stick.

Sediment Constituent Samples

Soil samples were collected as a composite sample, using the bulk density corer. The material was placed in a clean (acid washed) Nalgene sample container. The sample was stored on ice and returned to the laboratory for analysis.

Sediment/Organic Accumulation cores

Cores were collected using a 10 cm (4") diameter x 50 cm long PVC core tube. The tube was inserted carefully into the marsh with a twisting motion, with a minimum of compaction. The distance the core was inserted into the marsh and the amounts of core collected were measured in the field to determine the amount of compaction, if any. The cores were capped, sealed with tape, then returned to the laboratory for analysis. The cores were kept upright during handling and transport.

3.5.2 SOIL PARAMETERS - LAB

Salinity Analysis

Salinity samples were titrated using a Haake-Buchler Digital Chloridometer. This device measured the amount of chloride in the sample by titrating it with silver. The corresponding salinity was then calculated. The machine was calibrated with a manufacturer-supplied standard during use.

Bulk Density/Percent Organic Cores

The bulk density cores were returned to the lab where they were cleaned, wiped dry and weighed (to the nearest 0.01 g). The caps were removed from the sample tubes and the cores were placed in an oven at 60° centigrade until dry. The cores were then removed from the oven, re-capped and re-weighed. The weights were used to calculate the wet and dry bulk densities (in g/cc). The cores were homogenized using a Wiley mill (with a #40 mesh screen). A sub-sample (~1.0 g) of the homogenized core was used to determine percent organic content by loss on ignition at 550 centigrade.

Sulfide Analysis

Soil Sulfide was measured (using the interstitial water fixed in the field with the anti-oxidant buffer solution) with a sulfide electrode (Lazar Research Laboratory, Los Angeles, CA). The electrode was calibrated before use by the preparation of laboratory standards.

Sediment Constituents Analysis

The caps were removed from the sample containers and the samples were placed in an oven at 60 centigrade until dry. The samples were then removed from the oven, homogenized using a Wiley mill (with a #40 mesh screen) and placed into numbered and labeled containers for delivery to the analytical laboratory. Sediment constituents (micro-nutrients, trace metals, sulfur) were analyzed by an outside contract laboratory (Dynatech, Inc., now Benchmark Laboratories of Baton Rouge). The analysis techniques included either Flame or Furnace AA or ICP depending upon the element being analyzed. The samples were digested (using EPA Method 3050A) in nitric acid and hydrogen peroxide prior to analysis. The digestate was then refluxed with

either nitric acid (for furnace AA) or hydrochloric acid (for ICP and Flame AA). The samples for TKN were digested in hydrochloric acid only.

Sediment/Organic Accumulation Core Analysis

The accretion cores were frozen upon return to the laboratory. The frozen cores were extruded from the core tube using a thawing box that melted the outer edge of the core enough to allow it to be pushed from the core tube. The extruded core was measured, then placed in a labeled plastic bag and returned to the freezer to harden. The frozen cores were sectioned at 1 cm intervals, using a band saw. As the sections were cut, they were placed in numbered and weighed dishes. The wet weight of each sample was determined (to the nearest 0.1 g). The sections were dried, re-weighed, homogenized using a Wiley mill (with a #40 mesh screen) then placed into numbered and labeled containers. A sub-sample (~1.0 g) of each of the homogenized core sections was taken to determine percent organic content by loss on ignition at 550° centigrade. During core sectioning, the thickness of every fifth sub-section was measured with a digital micrometer to ensure the accuracy of the sectioning. The dried and ground samples were then counted for 137Cs using a 40% efficiency Germanium detector. 137Cs, a residual of bomb fallout, first appeared in 1954, peaked in the spring of 1963 with additional large amounts in 1964, and has declined since, with minor fluctuations. The activity of the 137Cs can be used to locate the 1964 horizon.

3.5.3 VEGETATION PARAMETERS - FIELD

Cover

Cover was visually estimated in the field for each species. Cover was estimated as absolute percentages and equaled 100% for each plot (when water was included).

Biomass Samples

Aboveground *Spartina alterniflora* biomass was harvested from 0.25m^2 plots. All standing live and dead culms and litter were removed and placed into pre-labeled plastic bags. The bags were kept in either a walk-in cooler or an air conditioned room until they were returned to the laboratory.

3.5.4 VEGETATION PARAMETERS - LAB

Biomass and Stem Morphometrics

Upon return, the biomass samples were placed in a walk-in cooler. During processing, the standing live portion of the samples was sorted by species, the standing dead was separated into standing dead *Spartina alterniflora* and standing dead other, and the litter from the surface was rinsed. The sorted samples were placed into labeled Kraft paper bags, then dried at 75° centigrade (~72 hours). During sorting, the length (to the nearest 1.0 cm) and diameter (to the nearest 1.0 mm) of the stems of *Spartina alterniflora* were measured and recorded. The number of *Spartina alterniflora* stems with seed heads (tassels) was noted and recorded. The live standing stems for other species were counted and recorded.

Leaf Tissue Analysis

The leaf tissue samples were refrigerated upon arrival at the laboratory. The samples were prepared by washing in distilled water to remove surface salt and mud, then placing them in Petri dishes. The samples were placed in an oven at 60 C° until dry (~36 hours). The samples were then removed from the oven, homogenized using a Wiley mill (with a #40 mesh screen), then

placed into numbered and labeled containers for delivery to the analytical laboratory. Leaf tissue constituents (micro-nutrients, trace metals, sulfur) were analyzed by an outside contract laboratory (Dynatech, Inc., now Benchmark Laboratories of Baton Rouge). The analysis techniques used were the same as those used for the sediment constituents (Table 3.1).

3.5.5 OTHER FIELD MEASUREMENTS

Water Levels (time series measurements)

Water levels above and below the marsh surface were monitored for ~2 month periods at eight of the sample sites and for ~6 month periods at four of the sample sites. The gages used, "Stevens Type A/F," are a float-counterweight system with a digital data logger. The gages were set to record water levels at 15-minute intervals. The gages were deployed on platforms built on the marsh surface, with the sensing float located in a PVC stilling well that was dug into the marsh surface. This deployment scheme allowed for measurement of water levels over a range from 50 cm below the marsh surface to 150 cm above the marsh surface. The gage elevations were surveyed to obtain the relative elevation of the gage in reference to the local marsh surface (mud surface and vegetation clump surface).

Spectral Reflectance

We utilized measurements of salt marsh vegetation spectral reflectance, measured with a portable Li-Cor spectroradiometer, as a potential indicator of plant vigor and marsh health. This instrument provides a spectral curve in the range of 400 to 1100 nm.

Previous research demonstrated that plant biomass (Hardisky et al., 1984) and plant stress (Mendelssohn, McKee and Ewing, 1990) can be determined with high-resolution spectral measurements of the marsh canopy and leaf tissue, respectively. Measurement protocols followed that of Hardisky et al. (1984).

3.6 QA FOR FIELD SAMPLING AND INSTRUMENTATION

QA methodology, as set forth in the QA Project Plan (Swenson et al., 1992a) was used to insure that the QA objectives of the study were met. All participants were impressed from the beginning with the importance of maintaining a commitment to quality control throughout the project. The training of field personnel was an important part of QC. All personnel were familiar with the procedures used and confident in their ability to use the equipment. The use of standard methods among teams minimized operator error associated with the data. Field personnel were given the opportunity to assess procedures and to suggest improvements, since this was a pilot study.

Field data forms were designed to prompt the field teams to follow the field standard procedures. Team leaders were supplied with a check-list to ensure that all data were collected. During the field, laboratory, and analysis portions of the study, internal QC checks were used to ensure data reliability, identify potential problems and identify sources of error.

Table 3.2 summarizes the QA/QC samples and procedures used. Table 3.3 presents the project QA goals in terms of data completion, accuracy and precision.

Sample Digestion

Leaf Tissue Trace Metals	HNO3	EPA Method 3050A
Sediment Trace Metals	HNO3	EPA Method 3050A
Leaf Tissue TKN	H2SO4	SM 421
Sediment TKN	H2SO4	SM 421

Leaf Tissue Analysis

Element	Method	Method Reference
TKN		SM 421
N	ICP	EPA Method 6010A
K	ICP	EPA Method 6010A
Ca	ICP	EPA Method 6010A
Mg	ICP	EPA Method 6010A
S	ICP	EPA Method 6010A
P	ICP	EPA Method 6010A
Na	ICP	EPA Method 6010A
Fe	ICP	EPA Method 6010A
Mn	ICP	EPA Method 6010A
Al	ICP	EPA Method 6010A
B	ICP	EPA Method 6010A
Cu	ICP	EPA Method 6010A
Zn	ICP	EPA Method 6010A
Mo	ICP	EPA Method 6010A
Ba	ICP	EPA Method 6010A
Pb	AA (Graphite furnace)	EPA Method 6010A
V	ICP	EPA Method 6010A

Sediment Constituent Analysis

TKN		SM 421
N	ICP	EPA Method 6010A
K	ICP	EPA Method 6010A
Ca	ICP	EPA Method 6010A
Mg	ICP	EPA Method 6010A
S	ICP	EPA Method 6010A
P	ICP	EPA Method 6010A
Na	ICP	EPA Method 6010A
Fe	ICP	EPA Method 6010A
Mn	ICP	EPA Method 6010A
Al	ICP	EPA Method 6010A
B	ICP	EPA Method 6010A
Cu	ICP	EPA Method 6010A
Zn	ICP	EPA Method 6010A
Mo	ICP	EPA Method 6010A
Ba	ICP	EPA Method 6010A
Pb	AA (Graphite furnace)	EPA Method 6010A
V	ICP	EPA Method 6010A

Table 3.1. Analytical techniques used for the Leaf Tissue and Sediment Constituents. SM = Standard Methods

Type of QC	Frequency	Purpose
Field Replicates at a sample location		
	6 clip plots per location	R
	6 bulk density cores per location	R
	3 hydrologic conductivity tests per location	R
	3 vertical salinity profiles per location	R
	3 eH samples per location	R
	5 eH probes per sample	R
	2 pH samples per location	R
	5 pH probes per sample	R
	6 leaf tissue samples per location	R
Sampling site replication		
	Three sampling locations in one healthy and one impaired marsh site (selected randomly) in each of the three basins	R
Re-measurements		
	2 measurements of eH per probe	P
	2 measurements of pH per probe	P
	re-measure every tenth stem	P
	re-weight 10% of samples	P
Lab Replicates		
	2 titrations/salinity sample	P
	3 sub samples every 6th core for percent organic	R
Standards		
	3 per organic batch	P, A
	3 every tenth salinity sample	P, A
Other		
	Vegetation Team members compare themselves at test plots during the sampling phase	C

Figure 3.2 Summary of QA/QC samples and procedures used. Indicated for each type of QC is the frequency with which it was used and the intended purpose of the measurement. (R = Representativeness, A = Accuracy, P = Precision, C = Comparability). The sample site was the marsh that was defined as either "healthy" or "impaired"; the sample location is the area within that site where samples were collected (the cluster location).

3.7 DATA ANALYSIS

3.7.1 DATA BASE CREATION

The data reduction details are discussed in depth in the Project QAPP and the Project Data Report (Swenson, et al., 1992a, b). The general procedure used for data base creation is outlined here. Data were entered into a computer data base on a Macintosh computer using commercially available word processing and/or spreadsheet programs (MS WORD 5.0®, EXCEL 4.0®). The data sets were printed out, then verified for data entry errors by comparing the printouts to the data sheets. Any corrections were noted (in red) on the printouts. These corrections were then made to the data sets. These data files are referred to as the "raw" data files and are the "machine form" of the field and/or laboratory data sheets. Thus, a field or lab sheet could be compared with the raw data file to verify that the data were entered correctly.

After the raw data sets had been corrected, they were transferred to the mainframe computer for permanent storage and analysis. The mainframe computer was used because data sets stored on it are routinely backed up by the operating system -- a distinct advantage over storing them on the desk-top computer where data could be lost if the users forget to back it up on a regular basis. The only valid raw data files are those stored on the mainframe computer. This is to eliminate confusion that may result if there were multiple copies. These raw files were used as input to a program that merged all of the data, applied any calibration factors and or unit change factors (English to metric), then constructed the data into a final file for analysis. The raw data files always remained unchanged. The program documented all of the processing applied to the raw data to obtain the final data set that was used for analysis.

I. Vegetation Data

Indicator or Data Type	Units	Expected values	Accuracy Goal	Precision Goal	Completeness Goal
Taxonomic ID	species		10%*	NA	95%
Biomass	g/m^2	1000	NA	±20%	95%
Stem Diameter	cm	1-2	NA	±20%	95%
Stem Height	cm	40-100	NA	±20%	95%
Tissue analysis					
N	ppm	~10000	±15%	±15%	95%
K	ppm	~10000	±15%	±15%	95%
Ca	ppm	~1500	±15%	±15%	95%
Mg	ppm	~3000	±15%	±15%	95%
S	ppm	~6000	±15%	±15%	95%
P	ppm	~1000	±15%	±15%	95%
Na	ppm	~100	±15%	±15%	95%
Fe	ppm	~100	±15%	±15%	95%
Mn	ppm	~25	±15%	±15%	95%
Al	ppm	~100	±15%	±15%	95%
B	ppm	~5	±15%	±15%	95%
Cu	ppm	~5	±15%	±15%	95%
Zn	ppm	~1	±15%	±15%	95%
Mo	ppm	~5	±15%	±15%	95%
Ba	ppm	~1000	±15%	±15%	95%
Pb	ppm	~10000	±15%	±15%	95%
V	ppm	~10	±15%	±15%	95%
II. Soils/Hydrology					
cH	mV	~-150	10 mV	±20%	95%
pH	0-14	7-8	0.1 pH	±20%	95%
Soil Salinity	ppt	10-20	0.3 ppt	±15%	95%
Bulk Density	g/cm3	0.5-1.1	0.1 g/cm3	±15%	95%
Percent Organic	% dry wt.	50-80	10 %	±15%	95%
Sulfides	ppm	~100	100 ppm	±25%	95%
Hydraulic Conductivity	cm/sec	1	1 cm/sec	±30%	95%
Water Levels	cm	-10-100	0.5 cm	±20%	95%
Accretion	cm	~1	0.5 cm	±40%	95%

Table 3.3 Quality Assurance goals for the project. Accuracy is given in absolute units where possible; precision is the Relative Percent Difference between replicated measurements. The precision goal refers to individual measurements as well as the precision between sampling crews.

II. Soils/Hydrology (*cont.*)

Indicator or Data Type	Units	Expected values	Accuracy Goal	Precision Goal	Completeness Goal
Sediment constituents					
N	µg/g	~100	±15%	±15%	95%
K	µg/g	~10	±15%	±15%	95%
Ca	µg/g	~0.5	±15%	±15%	95%
Mg	µg/g	~0.5	±15%	±15%	95%
S	µg/g	~100	±15%	±15%	95%
P	µg/g	~100	±15%	±15%	95%
Na	µg/g	~10000	±15%	±15%	95%
Fe	µg/g	~20000	±15%	±15%	95%
Mn	µg/g	100-1400	±15%	±15%	95%
Al	µg/g	10000	±15%	±15%	95%
B	µg/g	~1	±15%	±15%	95%
Cu	ppm	25	±15%	±15%	95%
Zn	µg/g	~25	±15%	±15%	95%
Mo	µg/g	~5	±15%	±15%	95%
Ba	µg/g	~100	±15%	±15%	95%
Pb	µg/g	~100	±15%	±15%	95%
V	µg/g	~100	±15%	±15%	95%

* Only 10% mis-identification is allowed.
µg/g refers to dry weight.

Table 3.3 (*cont.*) Quality Assurance goals for the project. Accuracy is given in absolute units where possible; precision is the Relative Percent Difference between replicated measurements. The precision goal refers to individual measurements as well as the precision between sampling crews.

Thus, it was possible to trace an indicator from the field or lab sheet to the final data set. Copies of the mainframe final data files were downloaded to the desk-top computer for analysis and preparation of final graphics. This final data file included a date in the file name to ensure that it was the correct file. If an error was discovered in the mainframe files that resulted in a change to the file, the new file was downloaded and replaced the file being maintained on the desk-top computer. The date of the file was changed when this was done. Figure 3.10 illustrates the data-base creation process. Inconsistencies in the final data file were checked using STATVIEW II® on a Macintosh Computer. This was accomplished by plotting various indicator variables and looking for outliers and/or "impossible" combinations. Outliers were points that plotted outside the main data distribution. These were determined by inspection of cumulative distribution plots for each of the indicator variables. For example, on a plot of cover against biomass, there can be no data points that show biomass with zero cover. Any points of this type were noted, then checked against the original data sheets to verify them. All outliers were also checked. These points were then verified by checking back to the original field and/or lab data sheets to ensure that there was not a data entry error. If the point was a valid entry, it remained in the data set; if it was a data entry error, the error was corrected. Outliers were not deleted from the data set. (There were very few data points that were considered outliers after verification.)

A similar procedure was followed for the water-level data. However, because all the data were digitally recorded, data base creation consisted of off-loading the data from the cartridges and then transferring it to the mainframe computer. Final data base creation consisted of putting the data in time-series format, creating station ID variables and computing water levels relative to the local marsh surface (using the elevation survey data). The data set was then ready for final analysis.

Spectroradiometer scans were conducted at each altitude within each marsh site. Stress is typically manifested as higher reflectance spectra in the 400-600 nm and 800-1100 nm ranges. An advantage of this bio-indicator is the potential to correlate the results of these measurements at a very low altitude, using high altitude remote sensing techniques. The operation of the spectroradiometer and the storage of spectral measurements were automatic or automatically controlled by a Licor 1800-01A portable terminal. Data were downloaded to a Zenith portable computer with Terminal Emulator and Graphics software (Licor 1800-14) for transfer onto floppy disks and for printing spectral responses, respectively. These data were later transferred to a Macintosh computer for further analyses.

3.7.2 QA/QC

The five general Measurement Quality Objectives listed below were observed during this project:

1. Accuracy--the degree that a measured value agrees with an accepted known value (Taylor, 1988). Accuracy was estimated by measuring a reference sample with a known value. Bias is the systematic error inherent in a method or caused by a particular measurement device. Accuracy was assessed through the use of standards whenever such standards existed. Laboratory standards (manufacturer supplied or from NBS) were used in chloride (salinity) analyses, leaf tissue nutrients, and soil constituents. The accuracy of the eH and pH measurements was ensured by calibrating the meter and probes with pH buffer solutions.

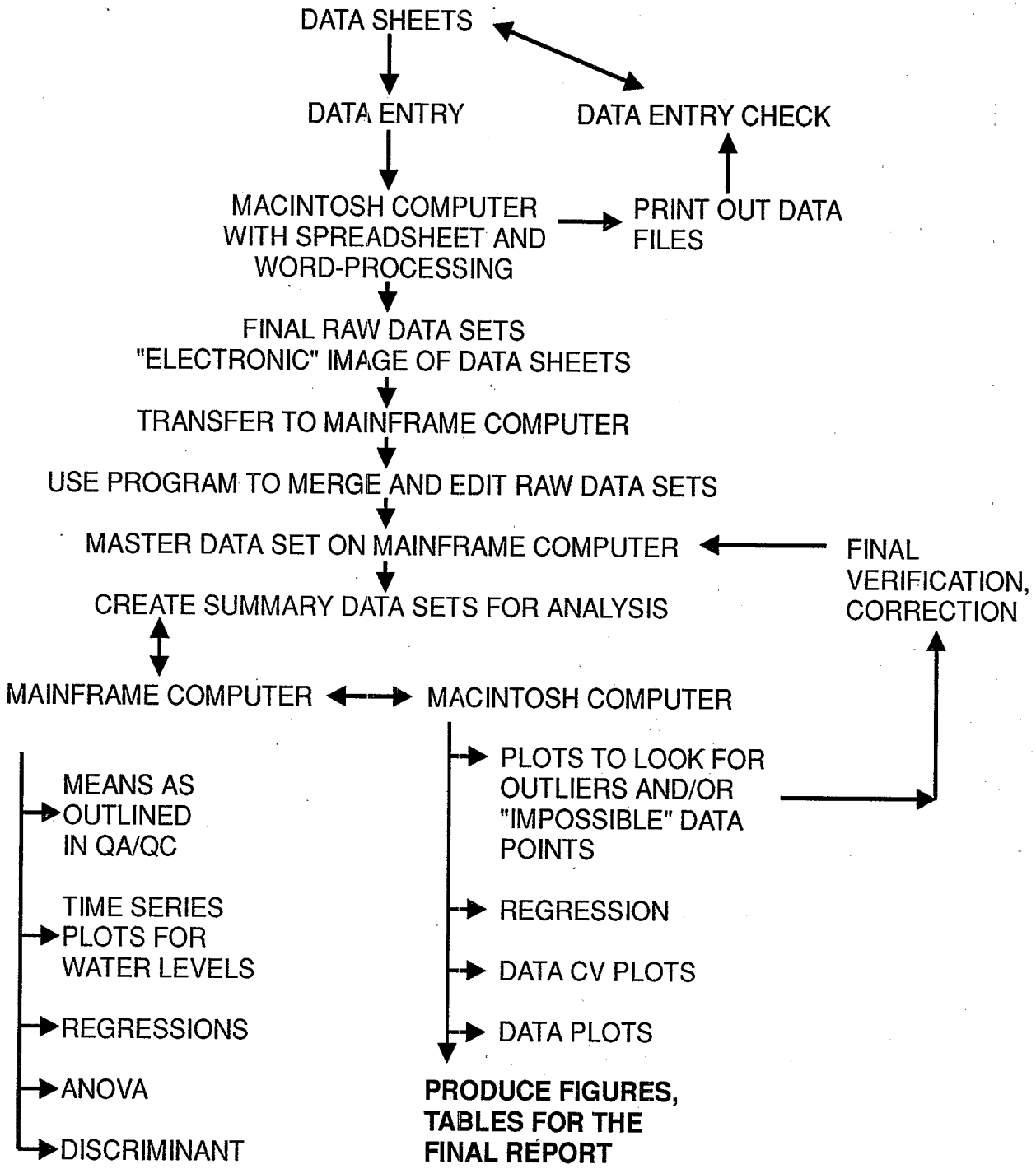

Figure 3.10 Outline of data entry, reduction and analysis procedures.

2. Precision---a measure of scatter among repeated independent observations of the same property under controlled similar conditions (Taylor, 1988). Precision was assessed by replicate measurements. Replicate field measurements were made on hydraulic conductivity, eH, and pH. Lab precision was measured by repeating measurements of a sample or by sample splits. Repeated laboratory measurements were made on stem length and diameter, biomass, and chloride (salinity). Sample splits were used on percent organic, sulfides, chloride (salinity), tissue nutrients and soil constituents.

3. Representativeness---or how well data truly characterize a population or environmental condition (Stanley and Verner, 1985; Smith et al., 1988)--was assessed by the use of the sub-sample sites within each of the basins. In the lab, representativeness of a sub-sample was assessed by taking multiple sub-samples and analyzing each one. This procedure was used for chloride analysis, percent organic, tissue nutrients, accretion, and soil constituents.

4. Comparability---the degree of confidence with which data sets may be compared. Comparability among the data sets was ensured by using standardized methods for the collection of all the data. The team members received training prior to the start of field data collection.

5. Completeness---or the ratio of the amount of valid data obtained to the amount expected (Stanley and Verner, 1985; Smith et al., 1988)--was used as an overall index for the project. If the completeness is not high enough (many missing data sets), the entire project is compromised. Completeness for the project is defined as the number of field samples actually collected as a percentage of the number of samples assigned to the sampling teams when sampling begins.

Field QA checks included discussions with the sampling teams to ensure that all team members were following the standard field procedures. Team members were assigned to collect certain measurements based upon their performance during training. Thus, measurements were collected by the "team expert" for each of the measurement techniques. The "team expert" for a particular measurement was the person who demonstrated consistency and accuracy for the measurement technique during training. (A person may qualify as "team expert" for several categories.) Thus, each team had a "vegetation expert," a "sediment core expert," an "accretion core expert," etc. The use of these assigned duties, based upon performance, ensured comparability among measurement teams and sample sites. In addition, replication of vegetation, water, and soil samples allowed for an estimate of precision in the field and lab procedures. Table 3.4 summarizes the QA checks used.

The following formulas were used to calculate each of the five QA objectives:

1. Accuracy was assessed by the relative percent difference between the measured parameter and the true value as set by a standard, using the following formula:

$$\% \text{ difference} = \frac{\text{true value - measured value}}{\text{true value}} * 100$$

In cases where more than two samples were involved (multiple readings of a standard), the Relative Standard Deviation (RSD), that is, the coefficient of variation (CV) expressed as a percentage, was used (Taylor, 1990):

$$CV = \text{standard deviation} / \text{mean}$$

$$RSD = CV * 100$$

2. Precision, Representativeness and Comparability were based on analyses of the replicate samples, using the following formula for comparing two samples (or two subsamples of a given sample), A and B:

$$\% \text{ difference} = \frac{(A-B)}{(A+B)/2} * 100$$

In cases where there were more than two replicates, the coefficient of variation was used.

3. Completeness will be assessed by the percent of data collected as a percentage of the number of proposed samples to be collected and will be determined by the following formula:

$$\% \text{ complete} = \frac{\text{samples collected - proposed samples}}{\text{proposed samples}} * 100$$

3.7.3 DATA ANALYSIS

Variability Assessment

The variability associated with the indicator measurements was assessed at the following levels:

1. Sampling error - by comparing the six replicated plots in a sampling cluster
2. Variability within a sample site - by comparing the triplicate sites
3. Variability within a basin - by using all sites in a basin
4. Variability among the basins - by comparing sites from among basins
5. Total variability - by using all sites
6. Marsh health class variability - by comparing sites by marsh health class
7. Analytical variability - by comparing laboratory replicates and/or standards

The variability was assessed at each of the above levels by computing the means and standard deviations, using the Statistical Analysis System (SAS, 1990 a, b, c, d, e).

Exploration

The distribution of data from all indicators measured was plotted in the form of cumulative percentile plots, using commercially available software (Statview IIr, Abacus Concepts, 1987) on a Macintosh computer. These plots were inspected visually to look for large departures from a normal data distribution. Simple linear correlations were performed among the indicator variables to ascertain which indicators were closely related. These correlations were performed on the mainframe computer using the Statistical Analysis System (SAS, 1990 a, b, c,d,e).

Analysis of Variance Modeling

All ANOVA modeling was conducted using the Statistical Analysis System (SAS, 1990 a, b, c). The following discussion of the method is based upon the description of the procedure found in the SAS/STAT Users guide (SAS, 1990 e).

ANOVA, using linear models, calculates the variance components from ratios using the expected mean square error. The general form of the linear model is:

$$\mathbf{Y = XB + e}$$

where:

Y represents the univariate data,

B is an unknown vector of fixed-effect parameters with a known model matrix **X**,
e is an unknown vector of independent random variables.

The standard linear model is used to model the mean of **Y** using the fixed effects **B**. The variance of each element of e is assumed to be constant.

The mixed model approach is a modification of the standard linear model. The general form of a mixed model is:

$$\mathbf{Y} = \mathbf{XB} + \mathbf{Zv} + \mathbf{e}$$

where:

Y represents the univariate data,
B is an unknown vector of fixed-effect, parameters with a known model matrix **X**,
v represents an unknown vector of random effects with a known model matrix **Z**,
e is an unknown vector of independent random variables.

The variance of each element of **e** is not required to be independent. The mixed model approach can model both the mean of **Y** as well as the variance of **Y**. In this case the variance components can be estimated by a maximum likelihood method, a restricted maximum likelihood method (REML), or a minimum variance quadratic unbiased estimation (MIVQUEO). In our analysis we used the REML method.

Discriminant Analysis

All Discriminant analyses were conducted using the Statistical Analysis System (SAS, 1990a, b, c). The following discussion of the methods employed is based upon the description of the procedure found in the SAS/STAT Users Guide (SAS, 1990 e).

Discriminant analysis is used to classify data into groups by developing a classification function (Discriminant function) based upon measured quantitative data. The development of the function can be accomplished with parametric methods, if the data is multivariate normal. In the case of non-normally distributed data, non-parametric methods can be used. Discriminant analysis differs from cluster analysis in that cluster analysis is used to derive a classification, whereas in Discriminant analysis the classification is known beforehand. Thus, this method seems well suited to the EMAP data where the marsh health classification has already been assigned.

Discriminant analysis classifies the data by developing either a linear or a quadratic Discriminant function (for parametric methods). This function classifies the data through the uses of the generalized squared distance between points. The data are placed into the group from which they have the smallest squared distance. We analyzed our data using both a linear and a quadratic function and compared the results. The Discriminant function (also referred to as the classification criterion) is developed using either the individual within-group covariance matrices or the pooled covariance matrix. The procedure also allows for the specification of prior probabilities for each of the classes being used. The prior probabilities are used to specify the probability of a sample falling into one of the classes. In our analysis we set the probabilities equal to the proportion of the original data that was in each of the classes being considered.

We also analyzed the data using Canonical Discriminant Analysis. In this technique, linear combinations of the variables are derived, based upon quantitative measures made on several groups of observations. These combinations are derived to have the highest possible multiple

correlation within the groups. The maximum multiple correlation is referred to as the first canonical correlation (the coefficients of the linear combination are referred to as the canonical coefficients or canonical weights). The second canonical correlation is derived by finding a second linear combination of the variables, uncorrelated with the first canonical variable, that has the highest multiple correlation. This process can be repeated to find higher order canonical correlations up to a maximum of the number of original variables or classes minus one, whichever is smaller. The correlation can be calculated either from the pooled (within class) correlations or from the total sample correlation. In either case, the resulting canonical variables are un-correlated. We derived two canonical variables for the analysis performed for this project. The canonical variables were then plotted with the points identified as either coming from a healthy or an impaired marsh. The resulting plots can then be inspected to ascertain whether or not the marsh health classes are separately identified.

Regression Analysis

Regression analysis among various indicator variables was performed on a desktop computer (Macintosh) using a commercial software product (Statview IIr, Abacus Concepts, 1987). Regression analysis was used primarily as an exploration tool to investigate the relationships among various indicators. The results of the desktop analysis helped to determine which indicators to look at in greater detail.

Other Analyses

Water levels

The water level data (on solid-state data cartridges) were read using an IBM PC-XT computer. The resulting data files were transferred to the mainframe computer for analysis using the Statistical Analysis System (SAS 1990 a, b, c, d, e). Because all data were in time-series format, the same techniques were used for all sites. A preliminary analysis to check the data for missing values and/or outliers was performed after the data were transferred. During this check, any needed correction factors (for calibration) were applied. The data were then ready for final analysis. The final analysis consisted of the following:

1. Time series plots of the data
2. Computation of flooding statistics
3. Comparison of flooding data among sites

The flooding statistics were computed by calculating the length of time (in hours) the marsh was flooded relative to (1) the mud surface, and (2) the vegetated surface (top of vegetation clumps). The length of time flooded was summarized as the percent of time the marsh was flooded, on a weekly basis. These data were then used to estimate the total percent of time the marsh was flooded, at each site, over the gage deployment period (November 1991 through June 1992).

Spectral Radiometer Measurements

Indices of plant vigor were derived from the spectral reflectance data as described in Tucker (1954) and McKee, Mendelssohn and Ewing (1990). These 20 indices, presented in Table 3.4, were determined for each spectroradiometer scan conducted at each altitude within each marsh site. The values for green, red and near-infrared reflectances required to calculate the spectral reflectance indices were derived from spectral scans by averaging the reflectance values (determined at 2 nm intervals) for the spectral bands equivalent to those of the Landsat multi-spectral scanner: green=500-600 nm (Band 1), red=600-700 nm (Band 2), and near infrared=800-1100 nm (Band 3). A FORTRAN

computer program was developed for this purpose. These data were then put into the JMP statistical program, and one-way ANOVA's were performed on these indices to determine if any of them were significantly different healthy and unhealthy marsh classes. Also, these indices were regressed against total live biomass and total plant cover (ground-truth estimates of plant vigor) to determine if the reflectance indices could provide a statistically significant estimate of plant vigor.

1. Y1 - maximum plant pigment reflectance
2. Y2 - pigment reflectance (integrated area between 500 and 678 nm)
3. Y3 - near infrared plateau (height of plateau between 770 and 900 nm)
4. Red radiance (600 - 700 nm)
5. Infrared (IR) radiance (800 - 1100 nm)
6. IR/Red
7. Square root (SQRT) IR/Red
8. IR minus Red
9. IR plus Red
10. (IR - Red)/(IR + Red)
11. (IR + Red)/(IR - Red)
12. SQRT (IR - Red)/(IR + Red) + 0.5
13. Green radiance (500-600 nm)
14. Green/Red
15. SQRT (Green/Red)
16. Green minus Red
17. Green plus Red
18. (Green - Red)/(Green + Red)
19. (Green + Red)/(Green - Red)
20. SQRT (Green - Red)/(Green + Red) + 0.5

Table 3.4. Reflectance variables derived from the spectral wavelength scans.

4 RESULTS AND DISCUSSION

4.1 COMPLETION RATE, ACCURACY, AND PRECISION

Data completeness for each of the indicators is presented in Tables 4.1 through 4.3. These tables present the amount of data obtained as a percentage of the expected amount of data to be collected. Table 4.1 summarizes the number of sites sampled. The overall data return (all sites combined) for the project was 94%. This is very close to the project goal of 95%. All of the sites were sampled in Barataria and Terrebonne Basins. The major data loss was in the St. Bernard basin, where rough weather precluded the last day of sampling with the result that three of the impaired sites could not be sampled. Table 4.2 presents the data return for each indicator as a percentage of the target number of sites. Table 4.3 presents the data return for each indicator as a percentage of the sites sampled. A comparison of Tables 4.2 and 4.3 shows that when we sampled a site, we were able to sample all of the indicators (except pH and salinity) within the 95% completeness project goal.

Basin	Number of Clusters		Percent Complete	
	Target	Sampled	Target	Actual
Barataria Healthy	8	8	95	100
Barataria Impaired	8	8	95	100
St. Bernard Healthy	8	8	95	100
St. Bernard Impaired	8	5	95	62
Terrebonne Healthy	8	8	95	100
Terrebonne Impaired	8	8	95	100
All Sites	48	45	95	94

Table 4.1 Percent of sites sampled during the 1991 EMAP Pilot Study. The target completeness goal (number of samples, percent complete) for each indicator (as defined in the QAPP) is listed along with the actual project completeness (number of samples, percent complete).

The estimate of accuracy for each of the indicators is presented in Table 4.4. The standard used, the number of measurements of the standard made, and the mean value (± 95% confidence interval) obtained from these measurements are listed in the table. The mean Relative Percent Difference (RPD) between the standard and the measurements, along with the 95% confidence interval, is also given. The last column in the table indicates whether or not the project accuracy goals were met. The project accuracy goals were met for all of the indicators except accretion core storage compaction. The original quality objective for accretion core field compaction was less than 20% but did not state a value for an acceptable storage compaction. The storage compaction was not considered in the Quality Assurance Project Plan but was noted during data analysis. However, our total compaction (field plus storage) was within the project goal. The precision estimates for each of the indicators are presented in Table 4.5. This table presents the results of cases where multiple measurements of an indicator were made. These multiple measurements were either replicated field measures, replicated laboratory measures or sample splits. A description of the replication used, the number of measurements made, and the mean Relative Percent Difference (RPD) of the measurements, along with the 95% confidence interval, are given. The last column in the table indicates whether or not the project precision goals were met. The project precision goals were met for all of the indicators except hydraulic conductivity, some of the sediment constituents and some of the leaf tissue constituents. In the case of the hydraulic conductivity, sampling

Indicator	Number of Clusters		Percent Completeness	
	Target	Sampled	Target	Actual
Biomass	288	270	95	94
Cover	288	270	95	94
Bulk Density Cores	288	270	95	94
Accretion Cores	48	45	95	94
Sediment Constituent Samples	48	45	95	94
Leaf Tissue Samples	48	45	95	94
eH Readings	1440	1215	95	84
pH Readings	288	239	95	83
Sulfides	192	176	95	92
Salinity	960	816	95	85
Hydraulic Conductivity	1152	1051	95	91

The target number of samples was calculated using the following formulas:

Sample Cluster (sample site) = 6 plots (in all cases)

Biomass = 6 samples/cluster

Percent cover = 6 estimates/cluster

Leaf tissue = 6 samples/cluster

Constituent cores = 1 core/cluster

Accretion cores = 1 core/cluster

Bulk Density cores = 6 cores/cluster

eH = 3 plots/cluster x 5 readings/plot x 2 (replicate readings) 30 readings/cluster

pH = 3 plots/cluster x 2 readings/plot = 6 readings/cluster

sulfides = (3 samples/cluster + 1 replicate sample) = 4 samples/cluster

salinity = (3 samples/cluster + 1 replicate sample) x 5 depths = 20 samples/cluster

Hydraulic Cond. = 3 samples/cluster x 2 (replicate reading) x 4 depths = 24 readings/cluster

Table 4.2 Percent completeness for indicator variables measured during the 1991 EMAP pilot study based on expectations for all sites. The target completeness goal (number of samples, percent complete) for each indicator (as defined in the QAPP) is listed along with the actual project completeness (number of samples, percent complete).

Indicator	Number of Samples		Percent Completeness	
	Target	Sampled	Target	Actual
Biomass	270	269	95	99
Cover	270	270	95	100
Bulk Density Cores	270	270	95	100
Accretion Cores	45	45	95	100
Sediment Constituent Samples	45	45	95	100
Leaf Tissue Samples	45	45	95	100
eH Readings	1350	1215	95	90
pH Readings	270	239	95	88
Sulfides	180	175	95	97
Salinity	900	816	95	91
Hydraulic Conductivity	1080	1051	95	97

The target number of samples was calculated using the following formulas:

Sample Cluster (sample site) = 6 plots (in all cases)

Biomass = 6 samples/cluster

Percent cover = 6 estimates/cluster

Leaf tissue = 6 samples/cluster

Constituent cores = 1 core/cluster

Accretion cores = 1 core/cluster

Bulk Density cores = 6 cores/cluster

eH = 3 plots/cluster x 5 readings/plot x 2 (replicate readings) 30 readings/cluster

pH = 3 plots/cluster x 2 readings/plot = 6 readings/cluster

sulfides = (3 samples/cluster + 1 replicate sample_ = 4 samples/cluster

salinity = (3 samples/cluster + 1 replicate sample) x 5 depths = 20 samples/cluster

Hydraulic Cond. = 3 samples/cluster x 2 (replicate reading) x 4 depths = 24 readings/cluster

Table 4.3 Percent completeness for variables measured during the 1991 EMAP pilot study for indicator variables versus total expected as percent of sites actually sampled. The target completeness goal (number of samples, percent complete) for each indicator (as defined in the QAPP) is listed along with the actual project completeness (number of samples, percent complete).

Indicator Variable	Accuracy Standard Used	Accuracy Goal (RPD)	n	Mean of Measurements ±95% C.I.	Mean RPD ±95% C.I.	Was Goal Met?
Biomass	100 g	±5%	13	100±0.03 g	0.1±0.0%	Yes
Biomass	500 g	±5%	13	499.6±0.04 g	0.0±0.0%	Yes
Biomass	1000 g	±5%	13	999.30±0.05 g	0.1±0.0%	Yes
Bulk Density	10 g	±5%	31	10.0±0.00 g	0.0±0.0%	Yes
Bulk Density	20 g	±5%	31	20.00±0.00 g	0.0±0.0%	Yes
Bulk Density	50 g	±5%	31	50.0±0.01 g	0.0±0.0%	Yes
Percent Organic	16.8%	±10%	36	16.9±0.07 %	0.6±0.4%	Yes
Percent Organic	Blank	±10%	36	0.0±0.00 %	0.0±0.0%	Yes
Salinity	6.4ppt	±5%	230	6.3±0.02 ppt	1.6±0.3%	Yes
eH	41mV	±20%	519	47.7±0.4 mV	16.3±1.0%	Yes
eH	218mV	±20%	508	214.6±0.8 mV	1.6±0.4%	Yes
Accretion Core Field	comp. (%)	±20%	44	14.1±2.5%	NA	Yes
Accretion Core Storage	comp. (%)	±0%	36	3.7±1.3%	NA	No
Accretion Core sub-sample thickness	(1 cm)	±10%	45	1.0±0.03cm	0.0±3.0%	Yes
Water Level gage 1	7 point cal	±1%	21	NA	NA	Yes
Water Level gage 2	7 point cal	±1%	21	NA	NA	Yes
Water Level gage 3	7 point cal	±1%	21	NA	NA	Yes
Water Level gage 4	7 point cal	±1%	21	NA	NA	Yes
Water Level gage 5	7 point cal	±1%	21	NA	NA	Yes
Water Level gage 6	7 point cal	±1%	21	NA	NA	Yes
Water Level gage 7	7 point cal	±1%	21	NA	NA	Yes
Water Level gage 8	7 point cal	±1%	21	NA	NA	Yes
Sediment Al	200 mg/l Std	±15%	3	195.8±9.0 mg/l	2.1±4.5%	Yes
Sediment Al	100 mg/l Std	±15%	9	99.1±5.8 mg/l	0.9±5.8%	Yes
Sediment Cu	10 mg/l Std	±15%	3	9.8±0.66 mg/l		2.0±6.6%

Table 4.4 Accuracy for marsh health indicator variables measured during the 1991 EMAP pilot study. Results are given for each indicator variable where accuracy was assessed by means of comparison to a standard. The measurement accuracy goal [(standard value and expected relative percent difference (RPD) between the standard and the measurement (as defined in the QAPP)], the number of measurements made (n), the mean value measured for the standard (±95% Confidence Interval), and the mean RPD of the measurements (± the 95% Confidence Interval) are listed. The last column states whether or not the measurement accuracy goal was met. Although not defined as a goal in the QAPP, the percent spike recovery for the sediment and leaf tissue analyses are also listed.

Indicator Variable	Accuracy Standard Used	Accuracy Goal (RPD)	n	Mean of Measurements ±95% C.I.	Mean RPD ±95% C.I.	Was Goal Met?
Sediment Cu	5 mg/l Std	15%	9	5.11±0.13 mg/l	2.2±2.6%	Yes
Sediment Mn	10 mg/l Std	15%	3	10.01±0.53 mg/l	0.1±5.3%	Yes
Sediment Mn	5 mg/l Std	15%	9	5.05±0.13 mg/l	1.0±2.6%	Yes
Sediment Mo	10 mg/l Std	15%	3	9.95±0.34 mg/l	0.5±3.4%	Yes
Sediment Mo	5 mg/l Std	15%	9	4.88±0.11 mg/l	2.4±2.2%	Yes
Sediment Zn	10 mg/l Std	15%	3	9.94±0.06 mg/l	0.6±0.6%	Yes
Sediment Zn	5 mg/l Std	15%	9	5.06±0.10 mg/l	1.2±2.0%	Yes
Sediment V	10mg/l Std	15%	3	9.69±1.18 mg/l	3.1±11.8%	Yes
Sediment V	5 mg/l Std	15%	9	5.12±0.15 mg/l	2.4±3.0%	Yes
Sediment P	10mg/l Std	15%	3	9.83±0.42 mg/l	1.7±4.2%	Yes
Sediment P	5 mg/l Std	15%	9	4.97±0.12 mg/l	0.6±2.4%	Yes
Sediment Pb	10 mg/l Std	15%	3	9.90±0.46 mg/l	1.0±4.6%	Yes
Sediment Pb	5 mg/l Std	15%	9	4.95±0.13 mg/l	1.0±2.6%	Yes
Sediment B	10 mg/l Std	15%	3	9.82±0.65 mg/l	0.8±6.5%	Yes
Sediment B	5 mg/l Std	15%	9	4.98±0.15 mg/l	0.4±3.0%	Yes
Sediment K	200 mg/l Std	15%	3	196.5±0.4 mg/l	1.8±0.2%	Yes
Sediment K	100 mg/l Std	15%	8	103.6±1.2 mg/l	3.6±1.2%	Yes
Sediment Ba	10 mg/l Std	15%	3	9.81±0.83 mg/l	1.9±8.3%	Yes
Sediment Ba	5 mg/l Std	15%	9	5.05±0.10 mg/l	1.0±2.0%	Yes
Sediment Fe	200 mg/l Std	15%	3	196.0±0.3 mg/l	2.0±0.2%	Yes
Sediment Fe	100 mg/l Std	15%	9	110.3±2.0 mg/l	10.3±2.0%	Yes
Sediment Mg	200 mg/l Std	15%	3	194.1±1.9 mg/l	3.0±1.0%	Yes
Sediment Mg	100 mg/l Std	15%	9	98.9±11.2 mg/l	1.1±11.2%	Yes
Sediment Ca	200 mg/l Std	15%	3	196.9±1.1 mg/l	1.6±0.6%	Yes
Sediment Ca	100 mg/l Std	15%	9	106.4±1.0 mg/l	6.4±1.0%	Yes
Sediment Al	blank	<1 mg/l	9	0.69±0.58 mg/l	NA	Yes

Table 4.4 (*cont.*) Accuracy for marsh health indicator variable measured during the 1991 EMAP pilot study. Results are given for each indicator variable where accuracy was assessed by means of comparison to a standard. The measurement accuracy goal [(standard value and expected relative percent difference (RPD) between the standard and the measurement (as defined in the QAPP)], the number of measurements made (n), the mean value measured for the standard (±95% Confidence Interval), and the mean RPD of the measurements (± the 95% Confidence Interval) are listed. The last column states whether or not the measurement accuracy goal was met. Although not defined as a goal in the QAPP, the percent spike recovery for the sediment and leaf tissue analyses are also listed.

Indicator Variable	Accuracy Standard Used	Accuracy Goal (RPD)	n	Mean of Measurements ±95% C.I.	Mean RPD ±95% C.I.	Was Goal Met?
Sediment Cu	blank	<1 mg/l	9	0.010±0.005 mg/l	NA	Yes
Sediment Mn	blank	<1 mg/l	9	0.001±0.001 mg/l	NA	Yes
Sediment Mo	blank	<1 mg/l	9	0.001±0.001 mg/l	NA	Yes
Sediment Zn	blank	<1 mg/l	9	0.001±0.001 mg/l	NA	Yes
Sediment V	blank	<1 mg/l	9	0.009±0.003 mg/l	NA	Yes
Sediment P	blank	<1 mg/l	9	0.003±0.001 mg/l	NA	Yes
Sediment Pb	blank	<1 mg/l	9	0.017±0.008 mg/l	NA	Yes
Sediment B	blank	<1 mg/l	9	0.678±0.172 mg/l	NA	Yes
Sediment K	blank	<1 mg/l	8	0.09±0.00 mg/l	NA	Yes
Sediment Ba	blank	<1 mg/l	9	0.182±0.277 mg/l	NA	Yes
Sediment Fe	blank	<1 mg/l	9	0.09±0.10 mg/l	NA	Yes
Sediment Mg	blank	<1 mg/l	9	0.87±1.00 mg/l	NA	No
Sediment Ca	blank	<1 mg/l	8	0.00±0.00 mg/l	NA	Yes
Sediment Cu	spike recovery	15%	5	96.5±2.7 %	3.5±2.7%	Yes
Sediment Mn	spike recovery	15%	5	95.2±0.8 %	4.8±0.8%	Yes
Sediment Mo	spike recovery	15%	5	78.4±6.8 %	21.6±6.8%	No
Sediment Zn	spike recovery	15%	5	94.8±4.0 %	5.2±4.0%	Yes
Sediment V	spike recovery	15%	5	94.2±2.2 %	5.8±2.2%	Yes
Sediment P	spike recovery	15%	5	95.5±2.5%	4.5±2.5%	Yes
Sediment Pb	spike recovery	15%	5	90.1±9.9%	9.9±9.9%	No
Sediment B	spike recovery	15%	5	83.5±5.5%	16.5±5.5%	No
Sediment Ba	spike recovery	NA	5	93.5±9.4%	6.5±9.4%	No

Table 4.4 (*cont.*) Accuracy for marsh health indicator variables measured during the 1991 EMAP pilot study. Results are given for each indicator variable where accuracy was assessed by means of comparison to a standard. The measurement accuracy goal [(standard value and expected relative percent difference (RPD) between the standard and the measurement (as defined in the QAPP)], the number of measurements made (n), the mean value measured for the standard (±95% Confidence Interval), and the mean RPD of the measurements (± the 95% Confidence Interval) are listed. The last column states whether or not the measurement accuracy goal was met. Although not defined as a goal in the QAPP, the percent spike recovery for the sediment and leaf tissue analyses are also listed.

Indicator Variable	Accuracy Standard Used	Accuracy Goal (RPD)	n	Mean of Measurements ±95% C.I.	Mean RPD ±95% C.I.	Was Goal Met?
Tissue Al	10 mg/l Std	15%	5	10.8±0.5 mg/l	8.0±5%	Yes
Tissue Al	5 mg/l Std	15%	9	5.3±0.2 mg/l	6.0±4.0%	Yes
Tissue Cu	10 mg/l Std	15%	6	9.82±0.23 mg/l	1.8±2.3%	Yes
Tissue Cu	5 mg/l Std	15%	11	4.93±0.06 mg/l	1.4±1.2%	Yes
Tissue Mn	10 mg/l Std	15%	6	9.95±0.21 mg/l	0.5±2.1%	Yes
Tissue Mn	5 mg/l Std	15%	11	4.94±0.08 mg/l	1.2±1.6%	Yes
Tissue Mo	10 mg/l Std	15%	6	9.92±0.13 mg/l	0.8±1.3%	Yes
Tissue Mo	5 mg/l Std	15%	11	4.84±0.08 mg/l	1.2±1.6%	Yes
Tissue Zn	10 mg/l Std	15%	6	9.89±0.30 mg/l	1.1±3.0%	Yes
Tissue Zn	5 mg/l Std	15%	11	5.07±0.08 mg/l	1.4±1.6%	Yes
Tissue V	10 mg/l Std	15%	6	9.80±0.30 mg/l	2.0±3.0%	Yes
Tissue V	5 mg/l Std	15%	11	4.89±0.08 mg/l	2.2±1.6%	Yes
Tissue P	10 mg/l Std	15%	6	9.88±0.13 mg/l	1.2±1.3%	Yes
Tissue P	5 mg/l Std	15%	11	4.91±0.09 mg/l	1.8±1.8%	Yes
Tissue Pb	10 mg/l Std	15%	6	9.87±0.11 mg/l	1.3±1.1%	Yes
Tissue B	10 mg/l Std	15%	6	9.83±0.27 mg/l	1.7±2.7%	Yes
Tissue B	5 mg/l Std	15%	11	4.85±0.11 mg/l	3.0±2.2%	Yes
Tissue K	200 mg/l Std	15%	6	201.0±2.6 mg/l	0.5±1.3%	Yes
Tissue K	100 mg/l Std	15%	11	108.0±4.0 mg/l	8.0±4.0%	Yes
Tissue Ba	10 mg/l Std	15%	6	9.87±0.26 mg/l	1.3±2.6%	Yes
Tissue Ba	5 mg/l Std	15%	11	5.01±0.06 mg/l	0.2±1.2%	Yes
Tissue Fe	10 mg/l Std	15%	5	9.8±0.5 mg/l	2.0±0.5%	Yes
Tissue Fe	5 mg/l Std	15%	9	4.9±0.1 mg/l	2.0±2.0%	Yes
Tissue Mg	200 mg/l Std	15%	6	195.6±1.6 mg/l	2.2±0.8%	Yes
Tissue Mg	100 mg/l Std	15%	11	106.9±3.2 mg/l	6.9±3.2%	Yes

Table 4.4 (*cont.*) Accuracy for marsh health indicator variables measured during the 1991 EMAP pilot study. Results are given for each indicator variable where accuracy was assessed by means of comparison to a standard. The measurement accuracy goal [(standard value and expected relative percent difference (RPD) between the standard and the measurement (as defined in the QAPP)], the number of measurements made (n), the mean value measured for the standard (±95% Confidence Interval), and the mean RPD of the measurements (± the 95% Confidence Interval) are listed. The last column states whether or not the measurement accuracy goal was met. Although not defined as a goal in the QAPP, the percent spike recovery for the sediment and leaf tissue analyses are also listed.

Indicator Variable	Accuracy Standard Used	Accuracy Goal (RPD)	n	Mean of Measurements ±95% C.I.	Mean RPD ±95% C.I.	Was Goal Met?
Tissue Ca	200 mg/l Std	15%	6	198.6±2.3 mg/l	0.7±1.6%	Yes
Tissue Ca	100 mg/l Std	15%	11	110.0±3.5 mg/l	10.0±3.5%	Yes
Tissue Al	blank	<1 mg/l	9	0.01±3.5 mg/l	NA	Yes
Tissue Cu	blank	<1 mg/l	11	0.015±0.010 mg/l	NA	Yes
Tissue Mn	blank	<1 mg/l	11	0.000±0.000 mg/l	NA	Yes
Tissue Mo	blank	<1 mg/l	11	0.002±0.003 mg/l	NA	Yes
Tissue Zn	blank	<1 mg/l	11	0.002±0.004 mg/l	NA	Yes
Tissue V	blank	<1 mg/l	11	0.002±0.000 mg/l	NA	Yes
Tissue P	blank	<1 mg/l	11	0.897±1.328 mg/l	NA	No
Tissue Pb	blank	<1 mg/l	11	0.007±0.007 mg/l	NA	Yes
Tissue B	blank	<1 mg/l	11	0.022±0.027 mg/l	NA	Yes
Tissue K	blank	<1 mg/l	11	0.097±0.012 mg/l	NA	Yes
Tissue Ba	blank	<1 mg/l	11	0.001±0.000 mg/l	NA	Yes
Tissue Fe	blank	<1 mg/l	9	0.01±0.000 mg/l	NA	Yes
Tissue Mg	blank	<1 mg/l	11	0.00±0.00 mg/l	NA	Yes
Tissue Ca	blank	<1 mg/l	11	0.00±0.00 mg/l	NA	Yes
Tissue Al	spike recovery	15%	5	101.2±12.7%	1.2±12.7%	Yes
Tissue Cu	spike recovery	15%	5	92.9±6.5%	8.1±6.5	Yes
Tissue Mn	spike recovery	15%	5	93.8±4.4%	6.2±4.4%	Yes
Tissue Mo	spike recovery	15%	4	90.8±4.4%	9.2±4.4%	Yes
Tissue Zn	spike recovery	15%	6	89.0±8.6%	11.0±8.6%	No
Tissue V	spike recovery	15%	6	87.5±8.2%	12.5±8.2%	No
Tissue P	spike recovery	15%	6	90.0±6.3%	10.0±6.3%	No
Tissue Pb	spike recovery	15%	5	87.6±3.3%	12.4±3.3%	No
Tissue B	spike recovery	15%	4	88.5±4.5%	11.5±4.5	No
Tissue K	spike recovery	15%	5	108.4±8.1%	8.4±8.1%	No

Table 4.4 (*cont.*) Accuracy for marsh health indicator variables measured during the 1991 EMAP pilot study. Results are given for each indicator variable where accuracy was assessed by means of comparison to a standard. The measurement accuracy goal [(standard value and expected relative percent difference (RPD) between the standard and the measurement (as defined in the QAPP)], the number of measurements made (n), the mean value measured for the standard (±95% Confidence Interval), and the mean RPD of the measurements (± the 95% Confidence Interval) are listed. The last column states whether or not the measurement accuracy goal was met. Although not defined as a goal in the QAPP, the percent spike recovery for the sediment and leaf tissue analyses are also listed.

Indicator Variable	Precision Standard Used	Precision Goal (RPD)	n	Mean RPD ±95% C.I.	Was Goal Met?
Biomass	sample re-weighing	20%	76	1.11±0.04	Yes
Bulk Density	sample re-weighing	15%	37	0.351±0.06	Yes
Percent Organic	sample re-weighing	15%	14	0.10±0.18	Yes
Percent Organic	sample splits	15%	44	1.63±0.40	Yes
Percent Organic	batch differences	15%	7	2.0±0.42	Yes
Salinity	sample splits	15%	41	0.91±0.28	Yes
Stem Diameter	sample re-measure	20%	924	2.95±0.24	Yes
Stem Length	sample re-measure	20%	924	0.00±0.00	Yes
eH	probe re-measure	20%	618	7.30±2.20	Yes
pH	sample re-measure	20%	85	2.13±0.67	Yes
sulfide	replicate analysis	25%	174	9.63±2.23	Yes
Hydraulic Cond.	sample re-measure	30%	468	30.56±3.45	No
Water Level gage 1	standard re-measure	20%	6	0.00±0.00	Yes
Water Level gage 2	standard re-measure	20%	6	0.00±0.00	Yes
Water Level gage 3	standard re-measure	20%	6	0.00±0.00	Yes
Water Level gage 4	standard re-measure	20%	6	0.00±0.00	Yes
Water Level gage 5	standard re-measure	20%	6	0.00±0.00	Yes
Water Level gage 6	standard re-measure	20%	6	0.00±0.00	Yes
Water Level gage 7	standard re-measure	20%	6	0.00±0.00	Yes
Water Level gage 8	standard re-measure	20%	6	0.00±0.00	Yes
Sediment TKN	sample splits	15%	6	7.4±6.4	Yes
Sediment Al	sample splits	15%	6	20.5±15.4	No
Sediment Cu	sample splits	15%	6	17.0±18.1	No
Sediment Mn	sample splits	15%	6	3.3±3.1	Yes
Sediment Mo	sample splits	15%	6	33.3±85.7	No

Table 4.5 Estimated precision for marsh health indicator variables measured during the 1991 EMAP pilot study. Results are given for each indicator variable where precision was assessed by means of multiple measurements. The measurement precision goal [(standard value and expected relative percent difference (RPD) between measurements (as defined in the QAPP)], the number of measurements made (n), and the mean RPD of the measurements (± the 95% Confidence Interval) are listed. The last column states whether or not the measurement precision goal was met.

Indicator Variable	Accuracy Standard Used	Accuracy Goal (RPD)	n	Mean RPD ±95% C.I.	Was Goal Met?
Sediment Zn	sample splits	15%	6	6.2±4.4	Yes
Sediment V	sample splits	15%	6	11.1±10.6	Yes
Sediment P	sample splits	15%	6	3.2±1.9	Yes
Sediment Pb	sample splits	15%	6	26.8±24.5	No
Sediment B	sample splits	15%	5	35.5±40.3	No
Sediment K	sample splits	15%	6	9.8±8.8	Yes
Sediment Ba	sample splits	15%	6	15.6±28.5	No
Sediment Fe	sample splits	15%	6	8.2±6.0	Yes
Sediment Mg	sample splits	15%	6	5.3±3.3	Yes
Sediment Ca	sample splits	15%	6	26.0±33.7	No
Sediment S	sample splits	15%	6	5.4±4.3	Yes
Tissue TKN	sample splits	15%	6	10.5±9.4	Yes
Tissue Al	sample splits	15%	6	10.7±12.4	Yes
Tissue Cu	sample splits	15%	5	0.8±2.2	Yes
Tissue Mn	sample splits	15%	6	23.6±35.5	No
Tissue Mo	sample splits	15%	6	0.0±0.0	Yes
Tissue Zn	sample splits	15%	6	31.0±28.3	No
Tissue V	sample splits	15%	6	12.6±10.8	No
Tissue P	sample splits	15%	6	3.3±5.7	Yes
Tissue Pb	sample splits	15%	3	30.5±60.1	No
Tissue B	sample splits	15%	4	13.9±25.8	No
Tissue K	sample splits	15%	6	4.3±3.7	Yes
Tissue Ba	sample splits	15%	6	25.7±24.1	No
Tissue Fe	sample splits	15%	6	11.9±7.8	No
Tissue Mg	sample splits	15%	6	6.8±7.8	Yes
Tissue Ca	sample splits	15%	6	6.6±5.9	Yes
Tissue S	sample splits	15%	6	3.9±2.2	Yes

Table 4.5 (*cont.*) Estimated precision for marsh health indicator variables measured during the 1991 EMAP pilot study. Results are given for each indicator variable where precision was assessed by means of multiple measurements. The measurement precision goal [(standard value and expected relative percent difference (RPD) between measurements (as defined in the QAPP)], the number of measurements made (n), and the mean RPD of the measurements (± the 95% Confidence Interval) are listed. The last column states whether or not the measurement precision goal was met.

resulted in an RPD of 30.6±3.5%, while the quality goal was 30%. It is probable that the method can be refined somewhat, resulting in a lower RPD. In the case of sediment and tissue contaminants, 14 of 32 (44%) split samples did not meet the ±15% precision goal. In the case of the sediment constituents, 6 out of 51 tests (11%) did not meet the accuracy goal of 15% RPD. In the case of the leaf tissue constituents, 7 out of 51 tests (14%) did not meet the precision goal of 15% RPD. Most test failures (70%) were related to spike recoveries, and 10 of the 13 failures were within ±20% and the remaining 2 tests were within ±25%.

4.2 SITE CLASSIFICATION

The initial selection and classification of sites as either healthy or impaired were made based on a basin-scale habitat map, Chabreck (1978), that showed the extent of salt marsh habitats.

Healthy sites and impaired sites were selected, using aerial photography, from each of the three basins (Barataria, St. Bernard, Terrebonne) in the Louisiana coastal salt marshes. The judgment determining what was healthy and what was impaired was based upon: 1) the rate of recent land loss, 2) obvious internal marsh breakup, and 3) severe alteration of natural hydrology or impoundment by canals and spoil banks.

Candidate sites were evaluated using an inventory of the NASA overflights for various time periods within the Louisiana Coastal zone and using loss/accretion maps. We used the most recent overflight (1988-1989) and the USACOE land loss maps (i.e., showing land loss from ~1935 to 1978) to determine areas that have remained stable and areas that are breaking up. Defining whether a marsh is healthy or impaired is somewhat subjective and also complicated by the varying scales of the available photography. The 1988 aerial photography is high-altitude photography (scale approximately 1:24,000), while the U. S. Army Corps of Engineers land loss maps were at a coarser resolution (1:62,500). However, the ACOE map scale did not permit us to assess vegetation and open water in the same manner as they could be assessed from low altitude overflight or finer-scale photography.

The following steps were used to select field sampling sites:

1. Using most recent aerial photographs and vegetation maps, salt marsh areas were located that were characterized by <40% open water and those with >60-70% open water.

2. The recent photos were compared with the USACOE maps to determine if the site had changed during the time period.

3. If the site remained stable at <50% open water, it was classified as healthy. If the site showed an increase from <40% open water in 1978 to >60% open water in 1988, then it was classified as impaired.

4. Procedures 1 through 3 were repeated until 6 healthy and 6 impaired sites were identified within the salt marshes of each of the three basins.

5. The sites were checked to ensure that each could be considered a unique site and that no two sites of a given classification (healthy, impaired) were hydrologically controlled by the same local drainage network.

The intent was to select sites at the two ends of the marsh health continuum ("Healthy" and "Impaired"). The original classification procedure called for the sites to be flown over before sampling to confirm that the classification was reasonable. However, time constraints did not allow for the photos to be collected prior to the field sampling. As a result, some sites were misclassified. An incorrectly classified site was

defined as a site that was determined upon sampling to be (1) not salt marsh or (2) not meeting the classification criteria for healthy or impaired sites described above. A re-classification scheme was developed, based upon the Pilot Study sampling and the analysis of the aerial photos that were obtained after the sampling. [If the photos had been available before sampling, we believe that several sites would not have been sampled.]

A reclassification scheme was developed based upon the aerial photos and our field sampling experience. We reclassified the sites without looking at the indicator data to minimize any bias. The results of the reclassification are described in Table 4.6 which presents the justification used for the classification and reclassification for each of the sites sampled. The re-classification is summarized in Table 4.7. Of the initial classification for the Terrebonne basin, 75% were not changed. We had difficulty actually finding a healthy marsh in the Barataria basin. Only one site that we initially classified as healthy in Barataria turned out to be a healthy site, and two turned out to be impaired sites. The percentage of sites initially classified correctly for Barataria basin was 42%. In the St. Bernard marshes, one site initially classified as healthy was later reclassified as an impaired site, and one site originally classified as impaired was reclassified as healthy. The percentage of sites initially classified correctly for the St. Bernard basin was 75%. In summary, of the 45 sampled clusters, 15 were reclassified as healthy sites, 17 were reclassified as impaired sites, and 13 were reclassified as "in-between or undetermined" sites. Twelve of the 45 sites (27%) required a change in classification.

4.3 INDICATOR VARIABILITY WITHIN AND AMONG SAMPLE SITES, BASINS, AND HEALTH CLASSES

The environmental variability for all indicators is summarized in Tables 4.8 through 4.10. These tables present summaries of indicator variance [coefficient of variation (CV)] at different measurement scales (within-site, among sites, among basins, among marsh health classes and total). The ratio of scale-specific variance to total variance is shown in Table 4.8.

In general, most of the indicators show the minimum amount of variance at the within sample site level, with increasing variance as the spatial scale is increased from sample site to co-located site to basin or marsh health level. This increase in variance is small enough (<25% increase) for some indicators and thus is unimportant. Indicators that exhibit this behavior of essentially constant variance across all spatial scales are:

1. Total biomass
2. *Spartina alterniflora* biomass
3. Water cover
4. Number of stems
5. Mean stem length
6. Mean stem diameter
7. Wet bulk density
8. Dry bulk density
9. eH
10. Sulfide
11. Bottom salinity (>20 cm depth)
12. Depth to 1963 137Cs peak

These are indications that the replication within a site could be decreased in favor of greater spatial coverage.

BH1	Original Classification was healthy; the modified classification was healthy. Broken Marsh nearby but site is in unbroken area.
BH2	Original Classification was healthy; the modified classification was undetermined. Area showed break-up on project photos that was not visible on 1988-1989 photos.
BH3	Original Classification was healthy; the modified classification was undetermined. Area showed break-up on project photos that was not visible on 1988-1989 photos.
BH4	Original Classification was healthy; the modified classification was impaired. Only the area along the edge of the lake is not breaking up, the inland marsh where we sampled is breaking up based upon project photos.
BH5	Original Classification was healthy; the modified classification was undetermined. Area showed break-up on project photos that was not visible on 1988-1989 photos.
BH6	Original Classification was healthy; the modified classification was impaired. Only the area along the edge of the lake is not breaking up, the inland marsh where we sampled is breaking up based upon project photos.
BI1	Original Classification was impaired; the modified classification was healthy. An intact area of marsh in an area that is breaking up.
BI2	Original Classification was impaired; the modified classification was undetermined. An intact area of marsh in an area that is breaking up. The breaking up area is much further inland (>200 m).
BI3	Original Classification was impaired; the modified classification was impaired. The last surviving remnant of a former more extensive marsh. This site is now a small marsh island.
BI4	Original Classification was impaired; the modified classification was impaired. This site appears to be in the last stages of conversion to all open water.
BI5	Original Classification was impaired; the modified classification was impaired. This site is an area that has become open water, except near natural levees or spoil banks.
BI6	Original Classification was impaired; the modified classification was impaired. This site is in the process of becoming open water for areas near natural levees or spoil banks.
SH1	Original Classification was healthy; the modified classification was impaired. The random sampling placed this cluster in a large area of dead standing *S. alterniflora* and mud flats in an area that was mostly solid marsh. This was quite evident on the project photos but not on the 1978-1979 photos.
SH2	Original Classification was healthy; the modified classification was undetermined. Area showed break-up on project photos that was not visible on 1988-1989 photos.
SH3	Original Classification was healthy; the modified classification was healthy.
SH4	Original Classification was healthy; the modified classification was healthy.
SH5	Original Classification was healthy; the modified classification was healthy.
SH6	Original Classification was healthy; the modified classification was healthy.

Table 4.6 Description of the original, the modified site classification, and comments explaining the classification for sites sampled during the 1991 EMAP Wetlands Southeast Pilot Study. (xyz where x = Basin, y = class, z = site number; B = Barataria, S = St. Bernard, T = Terrebonne, H = healthy, and I = impaired).

SI1	Original Classification was impaired; the modified classification was healthy. Maps showed recent land loss in the general area, but this site fell into an area that was not breaking up. This was not visible on the 1978-1979 photos but was on the project photos.
SI2	Original Classification was impaired; the modified classification was impaired.
SI3	Site not sampled
SI4	Original Classification was impaired; the modified classification was undetermined. Maps showed recent land loss in the general area, but this site fell into an area that was not breaking up. This was not visible on the 1978-1979 photos but was on the project photos.
SI5	Site not sampled
SI6	Site not sampled
TH1	Original Classification was healthy; the modified classification was undetermined. Area showed break-up on project photos that was not visible on 1988-1989 photos.
TH2	Original Classification was healthy; the modified classification was undetermined. Area showed break-up (large interior pond) on project photos that was not visible on 1988-1989 photos.
TH3	Original Classification was healthy; the modified classification was healthy.
TH4	Original Classification was healthy; the modified classification was healthy.
TH5	Original Classification was healthy; the modified classification was healthy.
TH6	Original Classification was healthy; the modified classification was healthy.
TI1	Original Classification was healthy; the modified classification was impaired. Site is in area of vast conversion of marsh to open water.
TI2	Original Classification was impaired; the modified classification was impaired. Site is in area of vast conversion of marsh to open water, although part of this site included a densely-vegetated natural levee.
TI3	Original Classification was impaired; the modified classification was undetermined. Area showed recovery on project photos that was not visible on 1988-1989 photos.
TI4	Original Classification was impaired; the modified classification was impaired. Site may be an example of an impoundment with altered hydrology.
TI5	Original Classification was impaired; the modified classification was impaired. Site is in area that is deteriorating rapidly.
TI6	Original Classification was impaired; the modified classification was impaired. Site borders a large open water area that was marsh in the recent past.

Table 4.6 (*cont.*) Description of the original, the modified site classification, and comments explaining the classification for sites sampled during the 1991 EMAP Wetlands Southeast Pilot Study. (xyz where x = Basin, y = class, z = site number; B = Barataria, S = St. Bernard, T = Terrebonne, H = health, and I = impaired).

	ORIGINAL CLASSIFICATION		MODIFIED CLASSIFICATION	
BASIN	MARSH HEALTH	SITE ID	MARSH HEALTH	NEW SITE ID
BARATARIA	HEALTHY	BH1	HEALTHY	BH1-H
BARATARIA	HEALTHY	BH2	UNDETERMINED	BH2-U
BARATARIA	HEALTHY	BH3	UNDETERMINED	BH3-U
BARATARIA	HEALTHY	BH4	IMPAIRED	BH4-I
BARATARIA	HEALTHY	BH5	UNDETERMINED	BH5-U
BARATARIA	HEALTHY	BH6	IMPAIRED	BH6-I
BARATARIA	IMPAIRED	BI1	HEALTHY	BI1-H
BARATARIA	IMPAIRED	BI2	UNDETERMINED	BI2-U
BARATARIA	IMPAIRED	BI3	IMPAIRED	BI3-I
BARATARIA	IMPAIRED	BI4	IMPAIRED	BI4-I
BARATARIA	IMPAIRED	BI5	IMPAIRED	BI5-I
BARATARIA	IMPAIRED	BI6	IMPAIRED	BI6-I
ST BERNARD	HEALTHY	SH1	IMPAIRED	SH1-I
ST BERNARD	HEALTHY	SH2	UNDETERMINED	SH2-U
ST BERNARD	HEALTHY	SH3	HEALTHY	SH3-H
ST BERNARD	HEALTHY	SH4	HEALTHY	SH4-H
ST BERNARD	HEALTHY	SH5	HEALTHY	SH5-H
ST BERNARD	HEALTHY	SH6	HEALTHY	SH6-H
ST BERNARD	IMPAIRED	SI1	HEALTHY	SI1-H
ST BERNARD	IMPAIRED	SI2	IMPAIRED	SI2-I
ST BERNARD	IMPAIRED	SI4	UNDETERMINED	SI4-U
TERREBONNE	HEALTHY	TH1	UNDETERMINED	TH1-U
TERREBONNE	HEALTHY	TH2	UNDETERMINED	TH2-U
TERREBONNE	HEALTHY	TH3	HEALTHY	TH3-H
TERREBONNE	HEALTHY	TH4	HEALTHY	TH4-H
TERREBONNE	HEALTHY	TH5	HEALTHY	TH5-H
TERREBONNE	HEALTHY	TH6	HEALTHY	TH6-H
TERREBONNE	HEALTHY	TI1	IMPAIRED	TI1-I
TERREBONNE	IMPAIRED	TI2	IMPAIRED	TI2-I
TERREBONNE	IMPAIRED	TI3	UNDETERMINED	TI3-U
TERREBONNE	IMPAIRED	TI4	IMPAIRED	TI4-I
TERREBONNE	IMPAIRED	TI5	IMPAIRED	TI5-I
TERREBONNE	IMPAIRED	TI6	IMPAIRED	TI6-I

Table 4.7 Listing of the original site classification and the modified classification for sites sampled during the 1991 EMAP Wetlands Southeast Pilot Study.

Indicator Variable	Coefficient of Variation as a Percentage				
	Within Site	Among Sites	Among Basins	Among Health Class	All Data
Total biomass ($g\ m^{-2}$)	100.7	91.1	89.2	92.5	99.0
Spartina alterniflora biomass ($g\ m^{-2}$)	110.0	103.4	109.5	110.8	111.6
Spartina patens biomass ($g\ m^{-2}$)	233.6	258.0	533.6	536.7	589.4
Juncus roemerianus biomass ($g\ m^{-2}$)	180.5	219.4	486.2	367.3	290.3
Distichilis spicata biomass ($g\ m^{-2}$)	252.2	336.6	490.6	583.4	484.9
Spartina alterniflora cover (%)	125.8	56.1	155.9	157.2	155.0
Spartina patens cover (%)	237.7	71.0	612.7	560.2	621.5
Juncus roemerianus cover (%)	171.5	87.5	498.8	408.1	333.2
Distichilis spicata cover (%)	233.8	116.9	498.1	437.0	565.7
Water cover (%)	23.3	30.6	26.4	26.4	26.5
Number of stems ($cm\ m^{-2}$)	54.8	69.2	67.9	69.0	71.6
Mean stem length ($cm\ m^{-2}$)	18.9	21.0	25.6	27.3	27.2
Mean stem diameter ($cm\ m^{-2}$)	12.9	13.9	17.1	18.3	18.3
Total stem length ($cm\ m^{-2}$)	54.1	67.1	70.8	70.7	70.8
Total stem diameter ($cm\ m^{-2}$)	53.0	65.9	67.6	69.3	68.7
Number of tassels (m^{-2})	158.8	165.2	236.4	164.7	201.3
Wet bulk density ($g\ cc^{-1}$)	10.9	10.6	14.2	14.8	14.4
Dry bulk density ($g\ cc^{-1}$)	20.1	25.1	40.2	42.0	44.4
Percent organic	14.8	18.4	34.1	37.1	37.5
eH (mV)	-18.5	-40.7	-24.6	-25.3	-25.7
pH (pH units)	34.9	48.9	54.4	60.9	66.7
Sulfide (ppm)	30.9	30.4	55.6	54.9	58.6
Water depth in plot (cm)	61.6	97.0	103.5	96.1	104.7
Hydraulic conductivity ($s\ cm^{-1}$)	72.1	111.3	187.3	206.2	353.9
Surface (<20 cm depth) substrate salinity (ppt)	6.9	11.2	27.9	28.9	35.2
Bottom (>20 cm depth) substrate salinity (ppt)	12.3	18.4	29.5	29.6	31.3
Core compaction (%)	NA	28.4	59.3	67.3	63.2
Depth to 1963 (cm)	NA	19.8	36.1	39.5	42.0

Table 4.8 Summary of indicator variable variance for 1991 EMAP Wetlands Southeast Pilot Study. This table represents the coefficient of variation (CV) for each of the indicators measured for various measurement levels (within site, among sites, among basins, among marsh health class and total). Parentheses after each indicator list the measurement units.

	Coefficient of Variation as a Percentage			
Indicator Variable	**Among Triplicate Sites**	**Among Basins**	**Among Health Classes**	**Among Total**
Tissue TKN (mg l^{-1})	14.6	21.3	22.5	23.4
Tissue Al (mg kg^{-1})	66.2	151.1	129.3	157.7
Tissue Ba (mg kg^{-1})	31.4	48.7	56.6	59.8
Tissue Bo (mg kg^{-1})	89.3	144.5	150.8	135.8
Tissue Ca (mg kg^{-1})	18.1	21.8	20.6	21.9
Tissue Cu (mg kg^{-1})	106.0	179.7	186.1	257.5
Tissue Fe (mg kg^{-1})	47.8	62.4	69.6	75.3
Tissue Pb (mg kg^{-1})	107.0	140.7	128.9	135.5
Tissue Mg (mg kg^{-1})	14.4	20.6	21.6	23.5
Tissue Mn (mg kg^{-1})	31.8	59.6	60.8	59.3
Tissue Mo (mg kg^{-1})				
Tissue K (mg kg^{-1})	8.7	20.1	20.5	25.9
Tissue P (mg kg^{-1})	11.3	21.2	21.9	22.9
Tissue Na (mg kg^{-1})	4.8	16.2	24.8	24.0
Tissue V (mg kg^{-1})	15.7	20.6	23.5	23.9
Tissue Zn (mg kg^{-1})	30.4	67.2	61.9	82.6
Tissue S (mg kg^{-1})	19.1	30.3	34.3	35.5
Sediment TKN (mg kg^{-1})	13.2	37.2	41.3	40.1
Sediment Al (mg kg^{-1})	15.2	22.4	30.9	30.1
Sediment Ba (mg kg^{-1})	29.1	85.2	112.2	103.8
Sediment Bo (mg kg^{-1})	37.4	72.8	103.2	105.2
Sediment Ca (mg kg^{-1})	49.0	70.2	82.4	81.7
Sediment Cu (mg kg^{-1})	27.8	45.5	49.2	49.8
Sediment Fe (mg kg^{-1})	15.1	26.9	31.4	31.1
Sediment Pb (mg kg^{-1})	31.0	107.9	196.3	230.7
Sediment Mg (mg kg^{-1})	5.3	11.3	22.5	23.1
Sediment Mn (mg kg^{-1})	19.0	41.4	40.2	45.5
Sediment Mo (mg kg^{-1})		360.5	387.3	670.8
Sediment K (mg kg^{-1})	29.5	21.9	21.8	25.1
Sediment P (mg kg^{-1})	28.3	44.5	41.3	99.8
Sediment Na (mg kg^{-1})	13.4	31.3	49.5	51.3
Sediment V (mg kg^{-1})	6.0	12.7	13.8	16.1
Sediment Zn (mg kg^{-1})	17.7	22.7	28.5	26.7
Sediment S (mg kg^{-1})	11.5	16.8	23.1	22.5.7

Table 4.9 Summary of leaf tissue and sediment constituent indicator sample site variance for 1991 EMAP Wetlands, Southeast Pilot Study. This table presents the coefficient of variation (CV) for each of the indicators measured for various measurement levels (among sites, among basins, among marsh health class and total). Parentheses after each indicator list the measurement units.

Indicator Variable	Ratio of Total Variance to Variance			
	Within Site	Among Sites	Among Basins	Among Health
Total biomass (g m^{-2})	0.98	1.09	1.11	1.07
Spartina alterniflora biomass (g m^{-2})	1.01	1.08	1.02	1.01
Spartina patens biomass (g m^{-2})	2.52	2.28	1.10	1.12
Juncus roemerianus biomass (g m^{-2})	1.61	1.32	0.60	.079
Distichilis spicata biomass (g m^{-2})	1.92	1.44	0.99	0.83
Spartina alterniflora cover (%)	1.23	2.76	0.99	0.99
Spartina patens cover (%)	2.61	8.75	1.01	1.11
Juncus roemerianus cover (%)	1.94	3.81	0.67	0.82
Distichilis spicata cover (%)	2.42	4.84	1.14	1.29
Water cover (%)	1.14	0.87	1.00	1.00
Number of Stems (cm m^{-2})	1.31	1.03	1.05	1.04
Mean stem length (cm m^{-2})	1.44	1.30	1.06	1.00
Mean stem diameter (cm m^{-2})	1.42	1.32	1.07	1.00
Total stem length (cm m^{-2})	1.31	1.06	1.00	1.00
Total stem diameter (cm m^{-2})	1.30	1.04	1.02	0.99
Number of Tassels (m^{-2})	1.27	1.22	0.85	1.22
Wet bulk density (g m^{-2})	1.32	1.36	1.01	0.97
Dry bulk density (g m^{-2})	2.21	1.77	1.10	1.06
Percent organic	2.53	2.04	1.10	1.01
eH (mV)	1.39	0.63	1.04	1.02
pH (pH units)	1.91	1.36	1.23	1.10
Sulfide (ppm)	1.90	1.93	1.05	1.07
Water Depth in plot (cm)	1.70	1.08	1.01	1.09
Hydraulic Conductivity (s cm^{-1})	4.91	3.18	1.89	1.72
Surface (<20 cm) Substrate Salinity	5.10	3.14	1.26	1.22
Surface (>20 cm) Substrate Salinity	2.54	1.70	1.06	1.06
Core Compaction (%)	NA	2.23	1.07	0.94
Depth to 1963 layer (cm)	NA	2.12	1.16	1.06

Table 4.10 Comparison of the ratio of total variance to variance at the different sampling levels (within a sample site, among triplicate sites, among basins and among marsh health classes) for the vegetation and soil parameters measured for the EMAP 1991 Pilot Study. The ratio of the total CV to the CV at each of the levels is presented.

The coefficients of variation for the spectral reflectance indices generally ranged from 0 to 28%. Spectral indices that contained green minus red reflectance values exhibited the highest coefficients of variation. Generally, the indices became less variable with increasing altitude. For example, the infrared/red index stabilized at approximately 150-200 feet. The majority of the indices stabilized at 200 feet. The coefficients of variation at the 200 foot altitude were exceptionally small, ranging from 0.5 to 4.7 % for all indices except those containing the green minus red reflectance values. We assumed that the viewing area of the marsh surface that was scanned at 200 feet was relatively homogeneous; thus, variation in viewing area due to movement of the helicopter was minimal. These low coefficients of variation are probably near the minimum for helicopter-based measurements of spectral reflectance of Louisiana salt marshes.

Twelve sites were sampled for the marsh water-level study (using 8 gages). Four gages were deployed at sites in Terrebonne Basin for the entire field experiment (November 1991 through June 1992). The other eight gages were deployed at four sites in the Barataria Basin, then were moved to four new sites in the St. Bernard Basin. The water level data are summarized in Figure 4.1 which presents the percent of time the marsh was flooded for each of the water-level gage sites. The upper plot presents the percent of time the marsh was flooded above the top of the surface of the vegetation clumps. The lower plot presents the percent of time the marsh was flooded above the top of the surface of mud. These plots were made based upon all the data collected. The healthy:impaired comparison from Terrebonne should be the most reliable, because it was based upon the longest record. In general, however, the gages showed no consistent flooding difference between the healthy and the impaired sites.

4.4 RELATIONSHIPS AMONG INDICATORS

4.4.1 STEM MORPHOLOGY AND DENSITY

Non-destructive morphometric estimates of *Spartina alterniflora* standing biomass may be obtained using stem density, stem length and plant cover. The relationships among standing biomass of live *S. alterniflora* and total culm diameter and total stem diameter are shown in Figures 4.2 and 4.3, respectively. A multiple regression, including total stem diameter and the number of stems, predicts the biomass value with a coefficient of determination >0.8 as shown in Table 4.11. This relationship is quite good for both healthy and impaired sites (Table 4.12). Thus, non-destructive sampling can be used to estimate live biomass for this species.

There is variability in the relationships among morphometric measurements of culms and the total biomass. Healthy and impaired sites differ in the relationships among live plant biomass and both the total culm length and the total culm diameter in each sample plot (Figures 4.2 and 4.3). There is only one impaired sample that could be considered an outlier in these plots. This sample was reclassified from healthy to impaired during the study and has one of the highest biomass values of all sites. It is possible that this site was misclassified, but we have not adjusted the data following this analysis in an attempt to be objective.

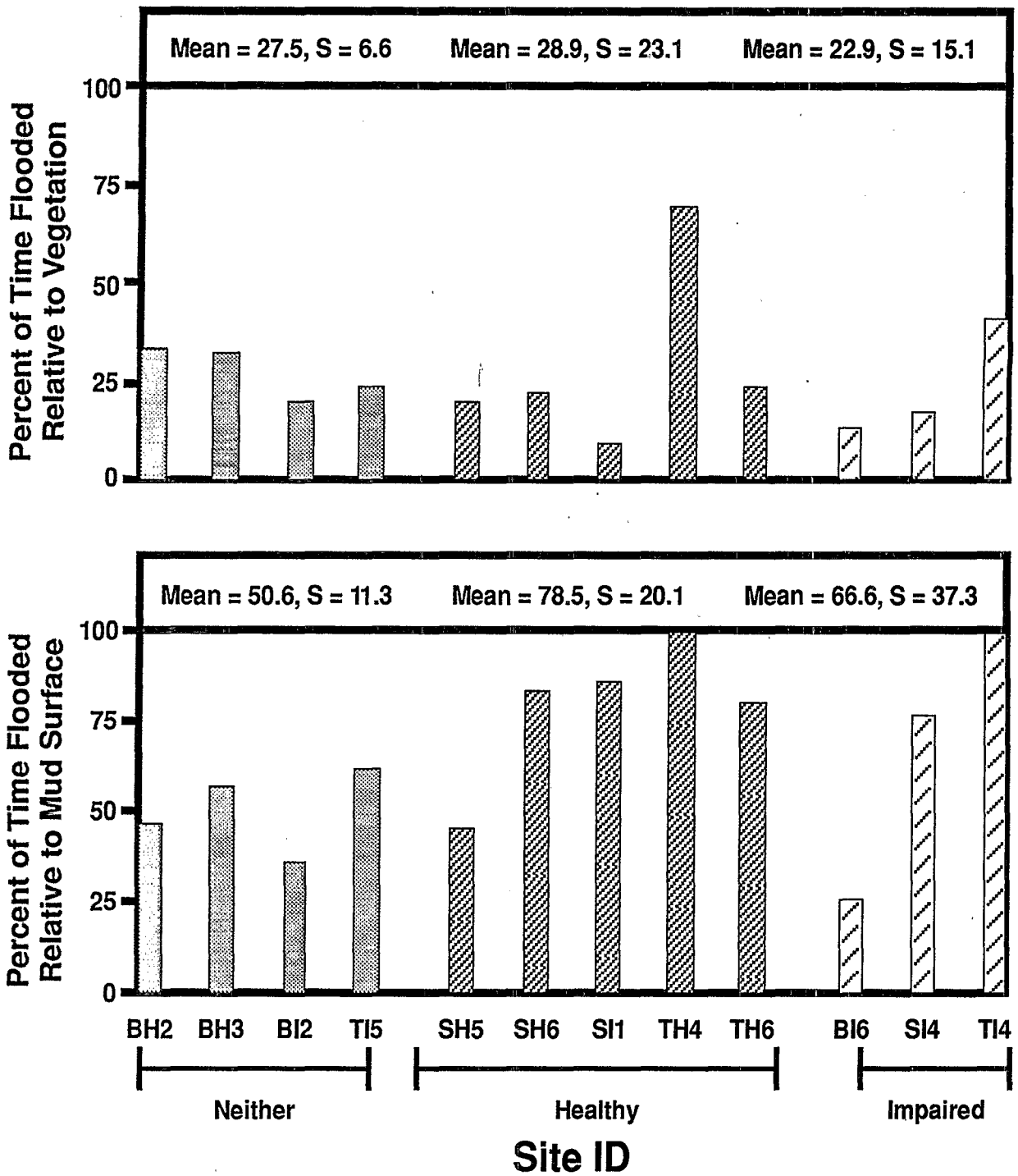

Figure 4.1 Summary of marsh flooding relative to the vegetation surface (top) and relative to the mud surface (bottom) for the 1991 EMAP Wetlands, Southeast Pilot Study. The horizontal axis is the original site ID, with the re-classification assignment indicated. The vertical axis is the percent of time the marsh was flooded during the gage deployment period. The mean and standard deviation for each marsh health class is indicated at the top of the plot.

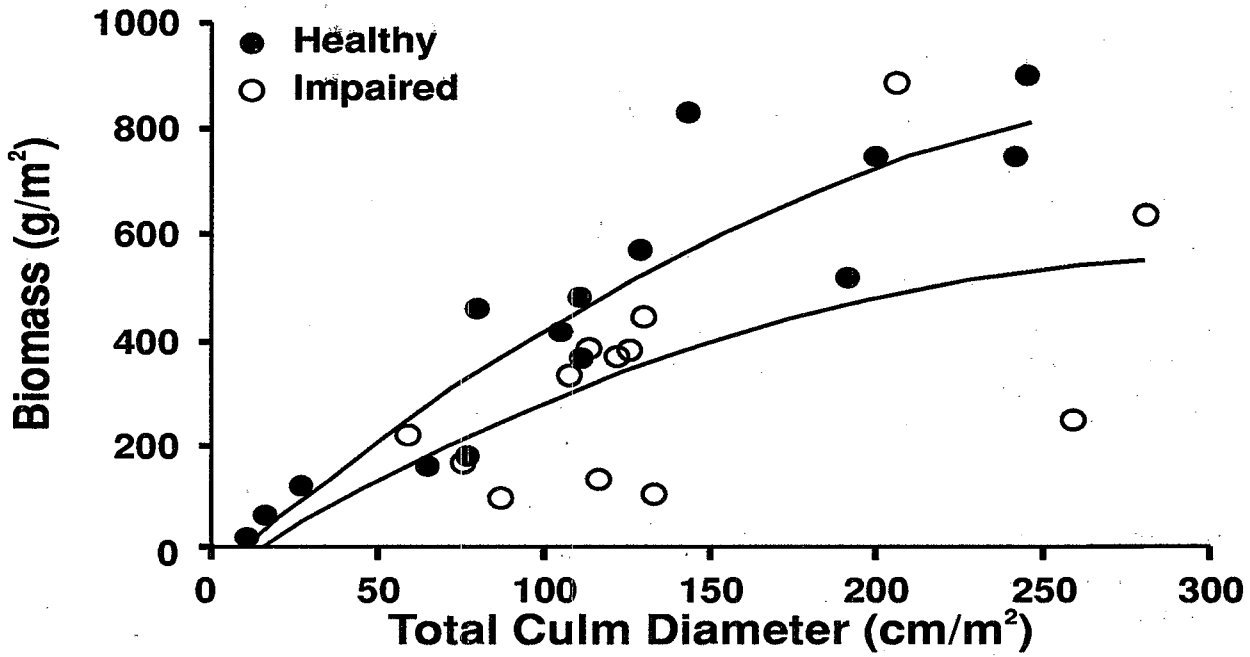

Figure 4.2 The relationship between standing biomass of live *S. alterniflora* and total stem diameter at the healthy and impaired sites sampled in 1991.

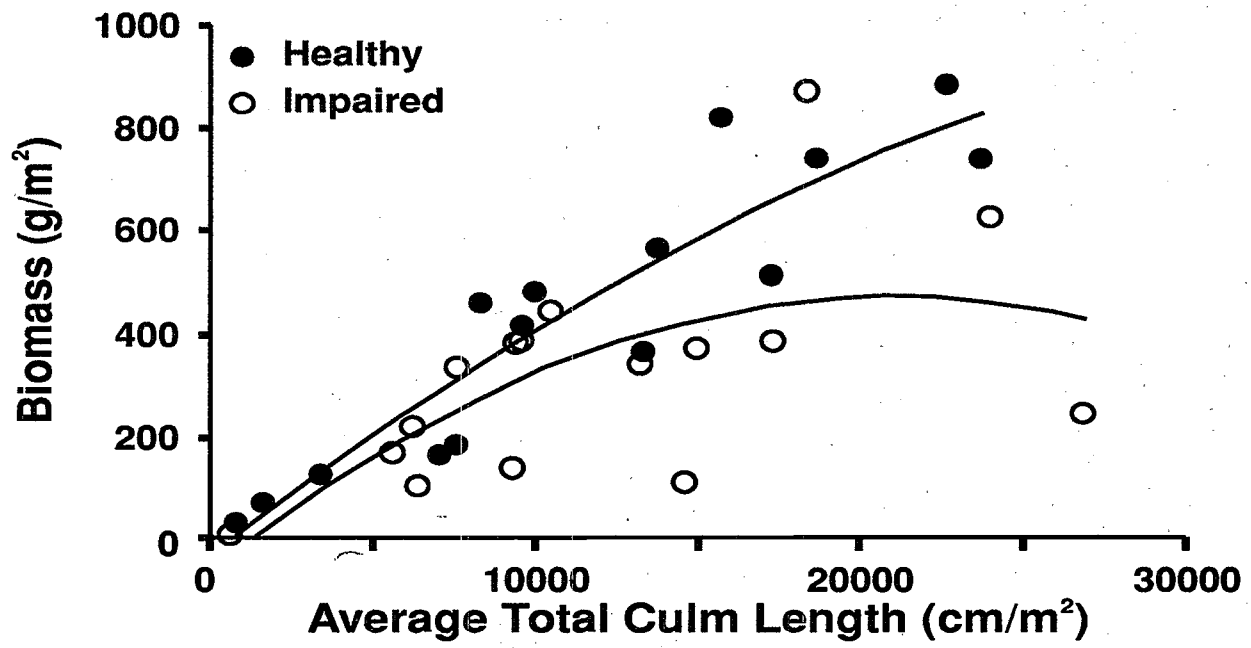

Figure 4.3 The relationship between standing biomass of live *S. alterniflora* and total culm length at the healthy and impaired sites sampled in 1991.

	% Cover	Live Biomass	Total Length	Total Diameter
% Cover	-	0.81	0.68	0.66
Live Biomass	0.81	-	0.79	0.74
Total Length	0.68	0.79	-	0.91
Total Diameter	0.66	0.74	0.91	-

Table 4.11 Correlation matrix of the adjusted coefficient of determination (R^2) for a polynomial regression of four morphometric measures of *S. alterniflora*.

		Adjusted R^2	
Data Set	n	2 variables	3 variables
All data	177	0.82	0.85
Healthy Sites	70	0.91	0.91
Impaired Sites	54	0.87	0.90
Neither Category of Sites	53	0.74	0.76

Table 4.12 Correlation matrix of the adjusted coefficient of determination (R^2) for a multiple linear regression of morphometric measures of *S. alterniflora* that may be used to predict standing live biomass. The 2 variable linear model uses total culm diameter and total culm length. The 3 variable linear model uses total culm diameter, total culm length and % cover.

Each of these plots shows a divergence in the impaired and healthy sites as the biomass increases. In effect, the density of stems is apparently decreased with length or diameter at the impaired sites. A likely reason for this is increased aerchyma tissue, because the concentration of N, P and other tissue elements showed no higher concentrations of elements that could explain these differences. There were no apparent differences in the relationships between percent cover and live biomass at healthy and impaired sites (Figure 4.4). We found no indices of stem density, number of stems or size frequency of stems to discriminate between healthy and impaired sites.

Discussion: There are reasonable relationships between the morphology of the plant and total biomass that may be used to non-destructively estimate standing live biomass for this species. In practice this procedure would, for example, result in measuring the morphological aspect on all samples and in bringing back some samples (25%) for biomass determinations. The empirical relationships can be established in the lab and compared with previous measurements. A significant increase in efficiency would result (i.e., less equipment and fewer samples in the field and fewer lab measurements).

It will be useful to investigate morphometric indices for other species (especially for *Juncus* sp.). Not all species are amenable to this approach.

Measurements of plant stem morphology may be used to distinguish healthy from impaired sites in this plant community at the sites sampled. It is a promising approach to non-destructively estimate plant condition and evaluate site condition.

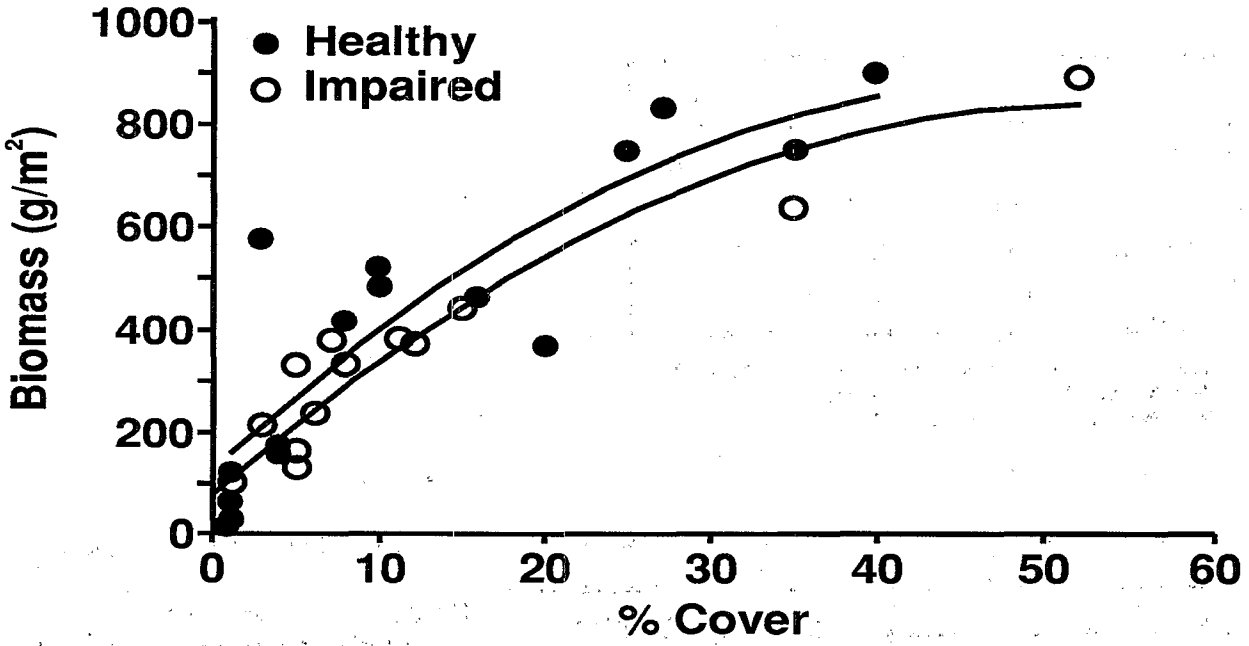

Figure 4.4 The relationship between standing biomass of live *S. alterniflora* and percent vegetation cover at the healthy and impaired sites sampled in 1991.

4.4.2 REPRODUCTIVE TISSUES

The reproductive tissues of *S. alterniflora* form over several weeks during the end of the growing season. The tall, elongated tassels bearing the flower head do not form on all plants. Plants would not be expected to form reproductive structures if carbohydrate reserves below ground were not available. Thus, the absence or presence of tassels may indicate recent metabolic changes affecting plant production.

There is an apparent relationship between the sulfide concentration in the soil at the time of sampling and the density of tassels (Figure 4.5). There are no tassels above a sulfide concentration of 30 ppm. This suggests that this plant has a minimal tolerance for sulfides that may not be exceeded. However, due to the small sample size, it is premature to construct a relationship between influorescences and sulfide concentration. The sulfide measurements are representative, perhaps, of soil conditions over the previous 0.5 to a few days. The tassel density is indicative of growing conditions for the previous several weeks.

Discussion: Decreased tassel density may indicate poor conditions due to elevated soil sulfur concentration or a covariate indicator.

4.4.3 SOIL CONDITIONS AND RELATIONSHIPS WITH OTHER FACTORS

Wetland flooding (data were collected at 11 sites using water level gages) was positively related to soil sulfide concentration and cumulative inorganic accumulation (Figures 4.6 and 4.7). Wetland flooding was inversely related to the total sulfur concentration in the soil (Figure 4.8).

Sulfides should form and accumulate during flooding, as soil reducing conditions develop under anaerobic conditions. The observed eH values were generally between -100 to -200 mV, that is, sufficiently low to suggest that sulfide formation could occur (observed, but not shown).

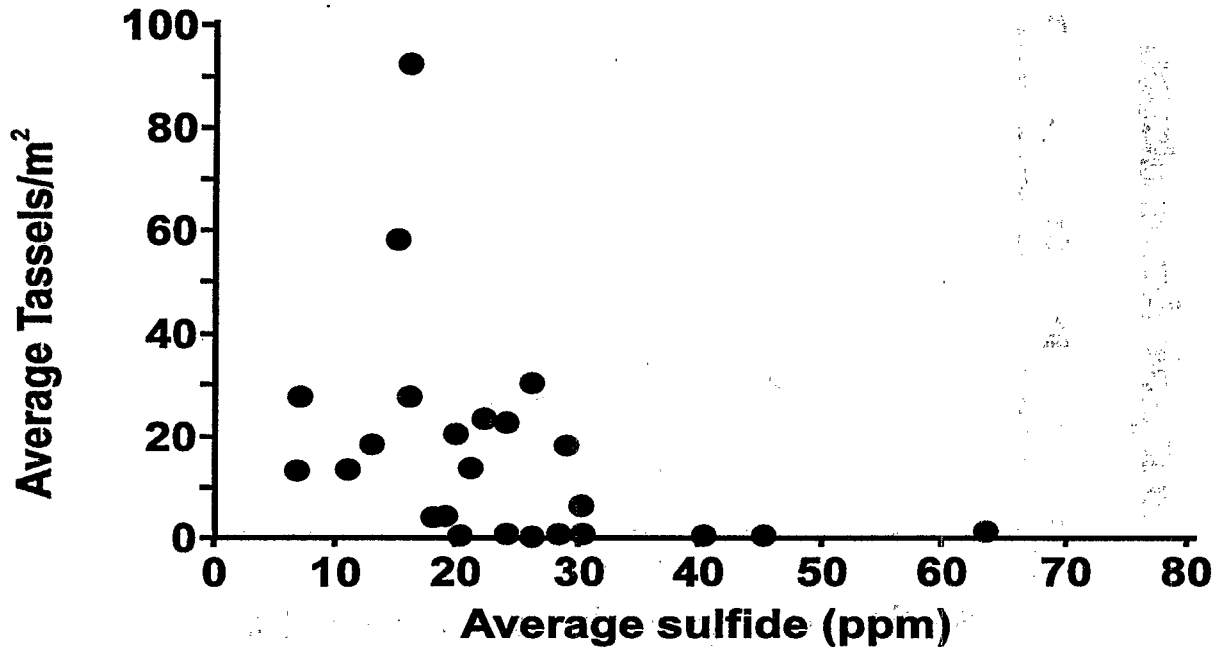

Figure 4.5 The average sulfide concentration in replicate plots and the average number of reproductive structures (tassels) of *Spartina alterniflora* in those plots.

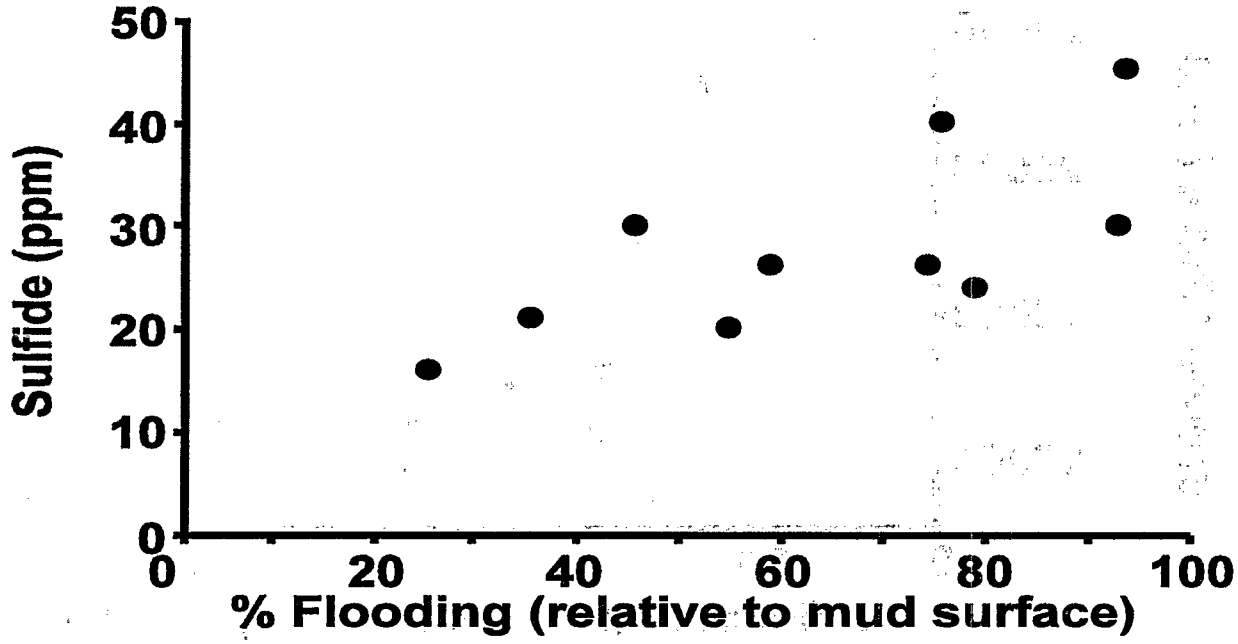

Figure 4.6 The relationship between the percent of time the site is flooded (from water level gage records) and sulfide concentrations at the sites at the time of sampling. Only sites that are dominated by *S. alterniflora* (cover>80%) are included.

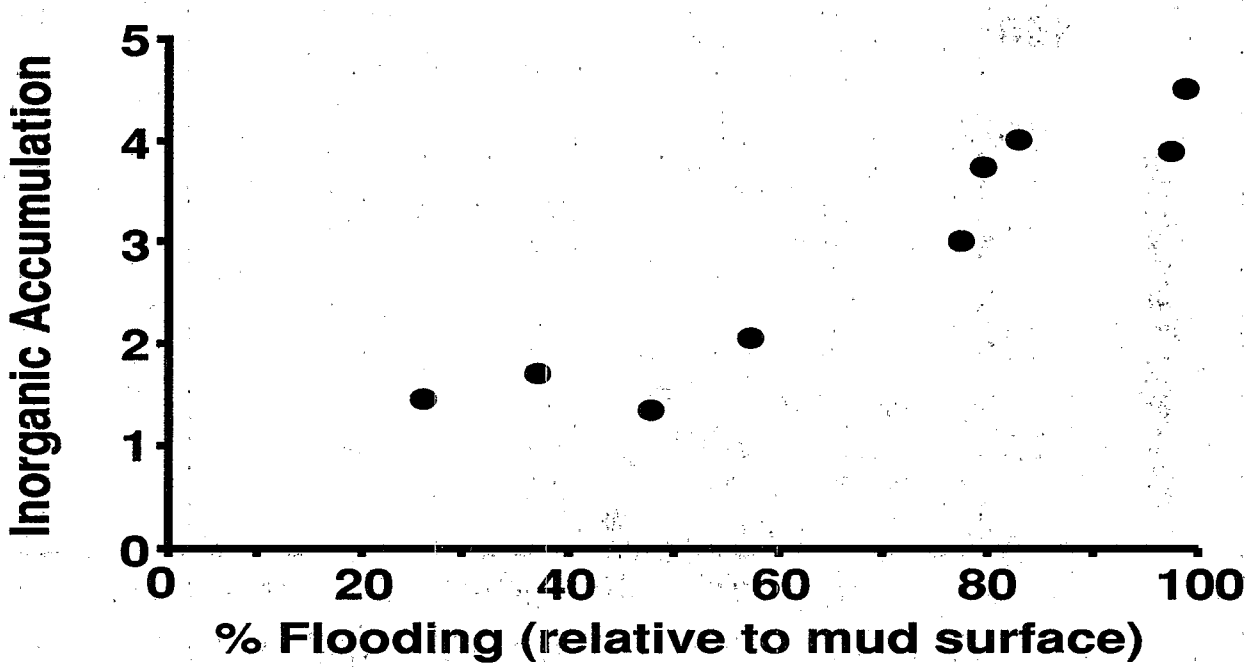

Figure 4.7 The relationship between the percent of time the site is flooded (from water level gage records) and the accumulation of inorganic matter at the sampling sites. Only sites dominated by *S. alterniflora* (cover>80%) are included and inorganic accumulation was determined by sediment cores with high-quality dating using ^{137}Cs.

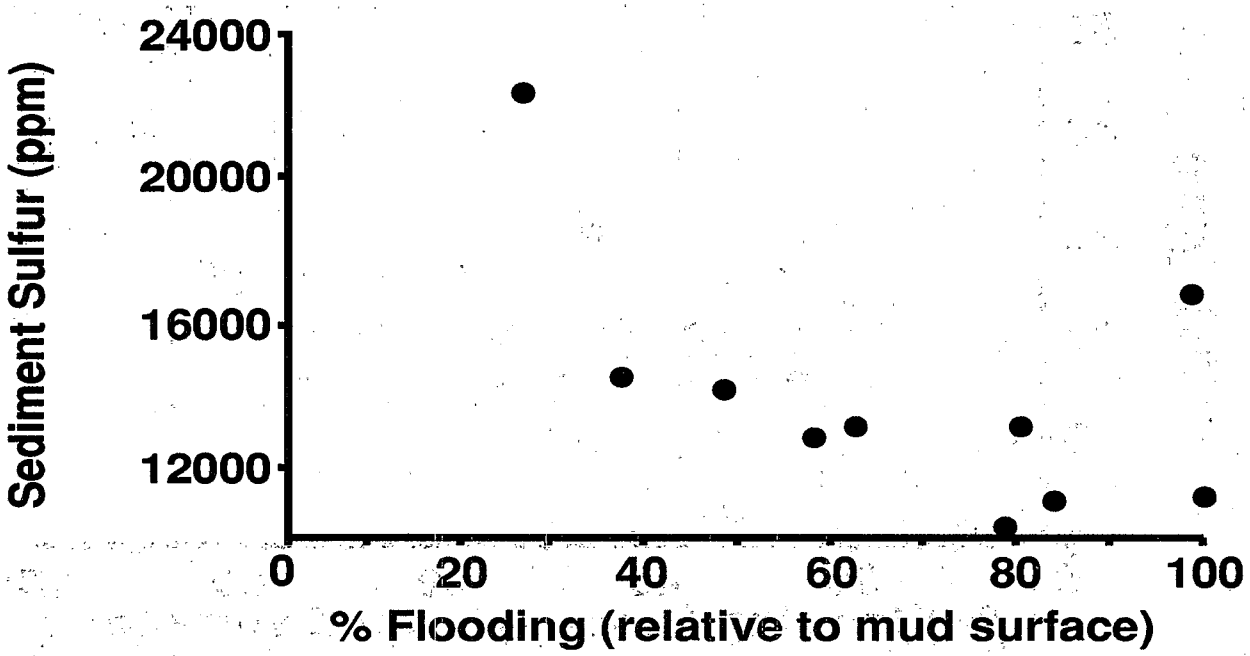

Figure 4.8 The relationship between the percent of time the site is flooded (from water level gage records) and the soil sulfur concentration at the sampling sites. Only sites that are dominated by *S. alterniflora* (cover>80%) are included.

Increased flooding could result in more fluctuations in water level, hence more sediment deposition events and therefore higher inorganic accumulation rates. If flooding frequency increases sedimentation rates (an observed relationship in other studies), then the soil matrix may become less permeable to oxygen when suspended particles, especially fine sediments, accumulate. The relative lack of organic matrix would decrease soil porosity under these circumstances. Alternatively, flooding may reduce soil oxidation (i.e., greater reducing conditions) and the organic particles may clog the pore spaces, instead of being decomposed to a gas.

The concentration of sulfides in soils and soil sulfur is inversely related and apparently different among healthy and impaired sites (Figure 4.9). The general decline in soil sulfur with increasing sulfide concentration may be related to mobilization of the soil S into gaseous form and release of the gas through the soil pore waters during tidal cycles or through the plant tissues. The reasons for differences between the healthy and impaired sites are not clear. The healthy sites have lower concentrations of soil sulfide per total sulfur in the soil than do the impaired sites. Alternatively, the impaired sites have greater concentration of total sulfur for the same concentration of soil sulfide. This result could be a consequence of higher rates of gas transport (of H^2S) from soil to vegetation at the healthy sites, or to greater retention of sulfur in the soils at the impaired sites. Retention could be favored, for example, by anaerobic conditions lower than -250 mV (e.g., under a long period of flooding). While cause-and-effect relationships remain to be uncovered, percent sulfur as sulfide appears to be a potential discriminating factor of site condition.

Discussion: Soil hydrologic conductivity, sulfide and total sulfur concentration may be useful indicators to distinguish between healthy and impaired *S. alterniflora* marshes. These measurements should be tested over a wider geographic area and expanded to examine other species dominance groups.

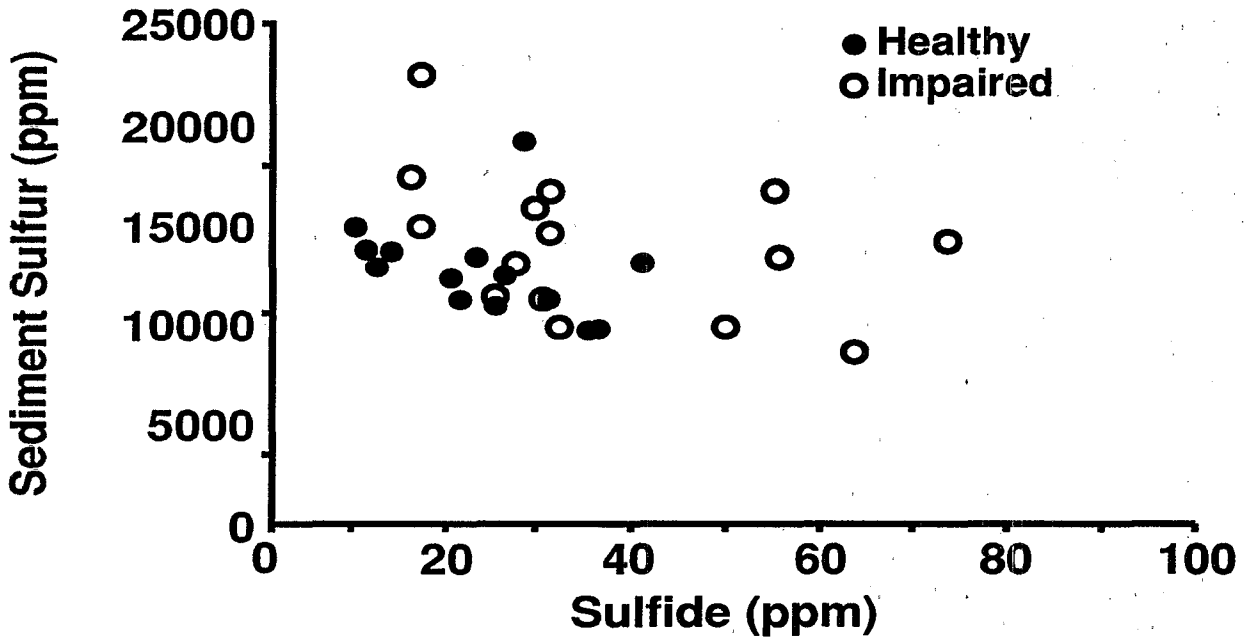

Figure 4.9 The relationship between sediment sulfur concentration and sulfide concentration at the healthy and impaired sites sampled in 1991.

4.4.4 BIOMASS AND SPECTRAL REFLECTANCE DIFFERENCES AMONG MARSH HEALTH CLASSES

No significant differences ($P>0.15$) in total live biomass or total cover among the three marsh health categories were observed when the marsh sites were reclassified into healthy, impaired and undetermined. However, statistical contrasts between only the healthy and impaired classes revealed significance differences. There was a consistent tendency ($P=0.20$) for mean total biomass to be greater in the healthy marshes (727 ± 170 g m2) compared with that of the impaired marshes (353 ± 112 g m2) with the undetermined marsh class being intermediate (581 ± 148 g m2). No spectral indices at the 100 ft altitude were significantly different among these marsh health classes. However, at 200 ft and 400 ft the following spectral indices showed significant ($P \leq 0.15$) differences among the marsh classes: 200 ft: Y3 ($P=0.07$), infrared ($P=0.12$), infrared/red ($P=0.06$), infrared minus red ($P=0.10$), green plus red/green minus red ($P=0.09$) (Figure 4.10); 400 ft: Y3 ($P=0.06$), infrared ($P=0.03$), infrared/red ($P=0.14$), infrared minus red ($P=0.04$), infrared plus red ($P=0.02$), infrared minus red/infrared plus red ($P=0.10$) (Figure 4.11).

Discussion: There appears to be some reasonable relationships between spectral reflectance (particularly at the 200 ft. and 400 ft. altitudes) and marsh health, the latter assessed from either empirical data on plant biomass (or plant cover) or more subjectively from aerial photographs and wetland loss records.

4.4.5 RELATIONSHIPS BETWEEN PLANT VIGOR AND SPECTRAL REFLECTANCE INDICATORS

In addition to analyzing differences in spectral indices between marsh health classes, live above-ground biomass and plant cover were correlated with the 20 spectral reflectance indices to determine if statistical relationships exist between plant vigor, as estimated by biomass and cover, and the spectral indices. At an altitude of 100 ft., neither total live above-ground biomass nor plant cover were significantly ($P \leq 0.05$) correlated with any of the spectral indices. However, at the 200 foot altitude, live above-ground biomass and plant cover were weakly associated ($P \leq 0.15$) with certain spectral indices i.e., biomass correlated with: infrared reflectance ($r=0.42$, $P=0.14$), infrared plus red ($r=0.43$, $P=0.12$), and infrared minus red ($r=0.40$, $P=0.16$); cover correlated with: infrared reflectance ($r=0.44$, $P=0.11$), infrared plus red ($r=0.49$, $P=0.07$), infrared minus red ($r=0.39$, $P=0.17$). At the 400 foot altitude, no correlations were significant even at the 15% level.

Discussion: Although the spectral indices were not well correlated with plant vigor, a weak relationship between plant vigor and some of the spectral indices was detected. These results suggest that a more in-depth investigation of the use of spectral reflectance in assessing marsh plant vigor might be warranted.

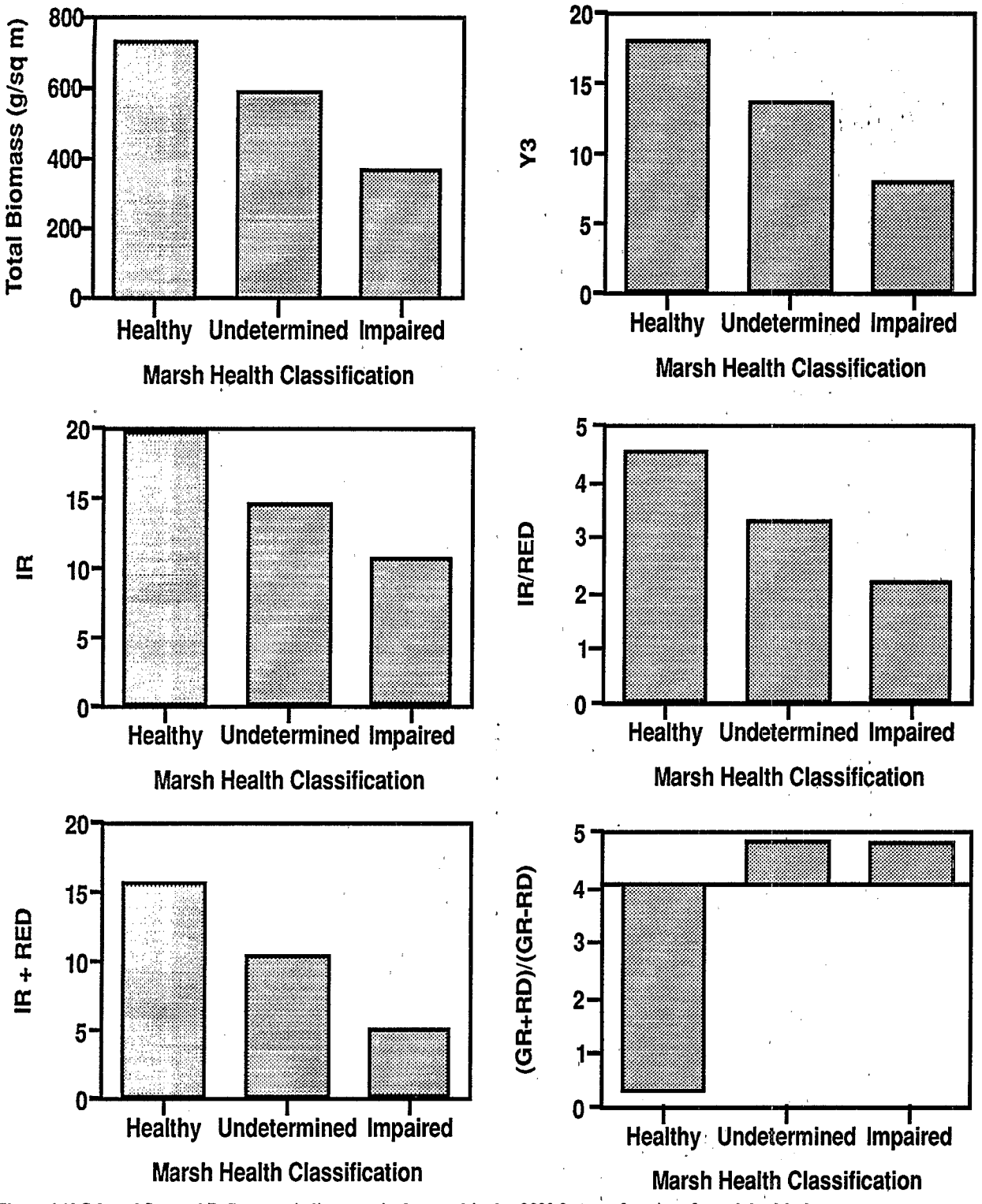

Figure 4.10 Selected Spectral Reflectance indices acquired at an altitude of 200 feet as a function of marsh health class.

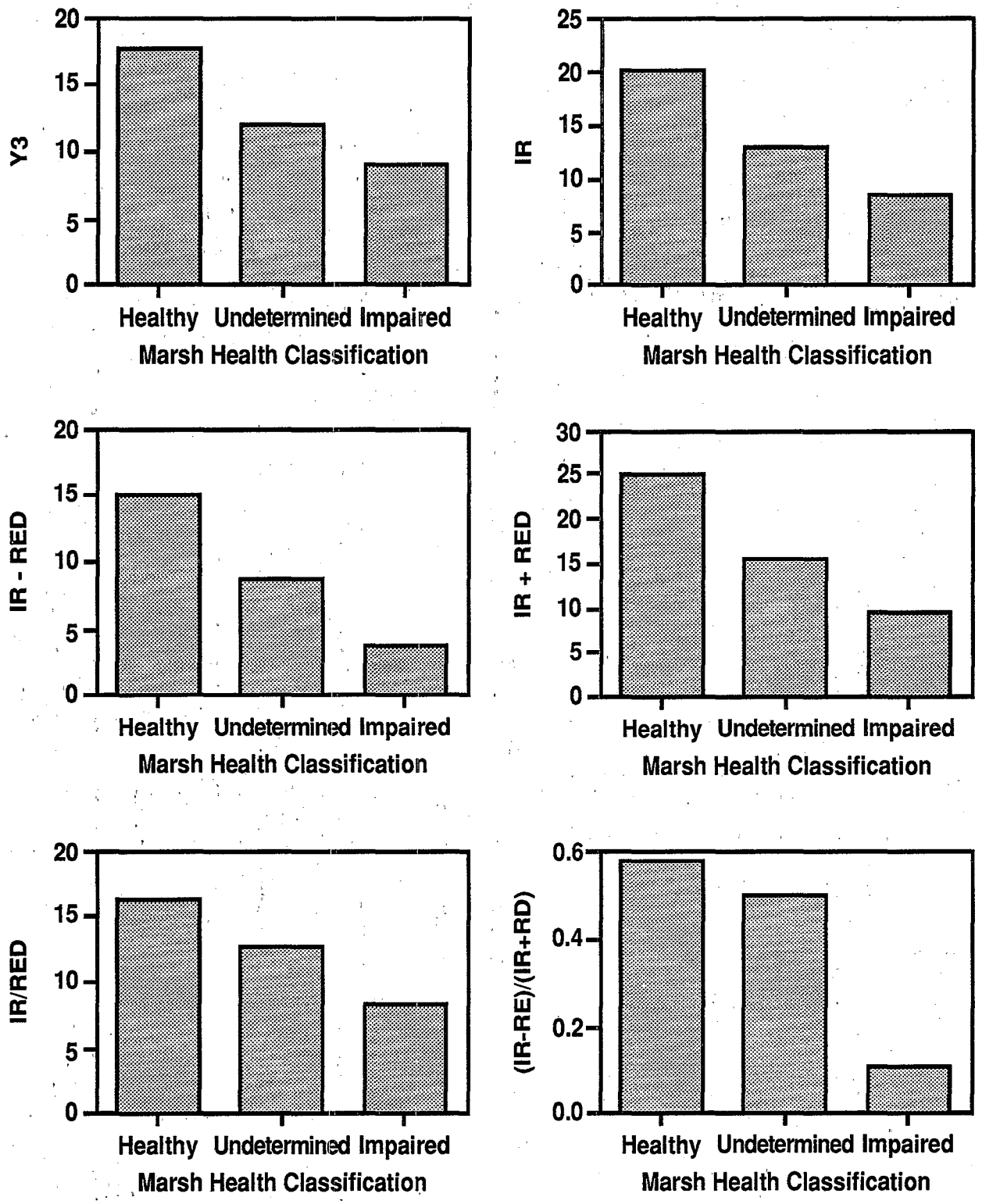

Figure 4.11 Selected Spectral Reflectance indices acquired at an altitude of 400 feet as a function of marsh health class.

4.5 ANOVA RESULTS

Table 4.13 presents the analysis of variance results for the vegetation and soil parameters, Table 4.14 presents the analysis of variance results for the leaf tissue and sediment constituents. The only indicators that showed statistical significance (at the 0.05 level) for Marsh Health effects were the following:

1. Total biomass
2. Water cover
3. Mean stem length
4. Surface substrate salinity
5. Bottom substrate salinity
6. Bulk density

ANOVA may not be the most appropriate analysis technique for these data. Discriminant analysis seems an appropriate technique because the Pilot Study was designed to classify observations into groups ("healthy" or "impaired") based upon quantitative measures collected from members within each group.

4.6 MULTIVARIATE RESULTS

We attempted to classify the sites into healthy and impaired by discriminant analysis (see Chapter 4 for discussion of methods). The table of results lists the variables used, the results of a test of the homogeneity within the covariance matrix, the re-substitution error rate summary and the cross-validation error rate summary. The results from the test for homogeneity of the covariance matrix determine which type of discriminant function will be used. If the matrix was not homogeneous (at the 0.10 level), a quadratic discriminant function was used. If the matrix was homogeneous (at the 0.10 level), a linear discriminant function was used. The re-substitution summary is a summary of the classification results. The cross-validation option that was used with the analytical procedure (PROC DISCRIM: SAS, 1990e) is a bias-reducing technique. In this process, n-1 of the observations is used to develop the classification. This classification is then used to classify the one observation left out. This procedure was repeated for the n observations, and the results were used to calculate the misclassification rate. Although this technique resulted in a nearly unbiased estimate, the variance was large. However, the cross-validation is a more accurate estimate of how the classification function will work on future data.

The first model run was to see how well the analysis could discriminate, using only water cover and total biomass. Because the sites were picked based upon land/water change over time (see project QAPP, Swenson et. al., 1992a and the project Data Report Swenson et. al., 1992b), cover and biomass essentially defined marsh health. This classification (see Section 3.2) was done on a macro- to meso-scale level, using aerial photographs. The discriminate analysis was run on data collected at a microscale (0.25 m2 plot) level. Thus, this discriminate analysis was an estimate (although crude) of the agreement between the indicators at two spatial scales. Table 4.15 presents the results of the analysis using only Total Biomass and Water Cover. The results of the cross-validation summary indicate that these two variables can classify the sites with an error of ~18% for the healthy sites and ~23% for the impaired sites. The results of the Canonical Discriminant analysis are shown in Figure 4.12. In this case, all three marsh health classes (Healthy, Impaired, Undetermined) were used to allow for the extraction of two canonical variables. In general, the healthy and impaired sites did separate, with the first canonical variable having the most discriminatory power. We then attempted to develop a model based upon other variables that would yield similar results. The analyses were performed using several combinations of variables. In general, most of the classifications were of moderate success, with classification errors about 50%.

	Variability Scale				
Indicator	**Basin**	**Health**	**Health*Basin**	**Site(Basin, Health)**	**Site Rep (Site Basin, Health)**
Total Biomass	0.4136	**0.0090**	0.3047	0.4057	**0.0454**
S. Alt. Biomass	0.5510	0.1043	0.9207	0.3093	**0.0125**
S. Pat. Biomass	0.5822	0.2825	0.4329	**0.0194**	0.9290
J. Rom. Biomass	**0.0478**	0.3342	0.3714	0.6240	**0.0019**
D. Spi. Biomass	0.8060	0.6298	0.9934	0.9749	**0.0066**
S. Alt. Cover	0.4547	0.3514	0.9705	**0.0089**	0.5528
S. Pat. Cover	0.9813	0.1465	0.9853	**0.0095**	0.9696
J. Rom. Cover	**0.0**	**0.0**	**0.0**	0.9994	**0.0001**
D. Spi. Cover	0.8059	0.1620	0.7686	**0.0427**	0.8849
Water Cover	0.8577	**0.0249**	0.3343	0.5357	**0.0404**
Stem Number	0.3058	0.7248	0.4996	0.1554	**0.0097**
Sum. Length	0.4409	0.5637	0.4626	0.2595	**0.0017**
Sum. Diameter	0.4523	0.7796	0.5741	0.1762	**0.0014**
Length Mean	**0.0373**	**0.0341**	0.0820	0.3252	**0.1017**
Diameter Mean	0.4516	0.4955	0.3367	0.3365	0.0659
Tassels	0.0565	0.1714	0.4750	0.0693	0.2404
Number 0-10	0.2659	0.7117	0.6926	**0.0002**	0.8386
Number 0-25	0.2165	0.8758	0.7737	**0.0074**	0.4892
Number 125-150	0.5210	0.8186	0.4262	0.8906	**0.0001**
Number >150	0.5918	0.5739	0.9525	0.9718	**0.0001**
Wet Density	0.6994	0.1746	0.3381	**0.0096**	0.3697
Dry Density	0.0671	**0.0428**	0.6082	**0.0091**	**0.0125**
Percent Organic	0.1449	0.2234	0.2165	**0.0257**	**0.0017**
eH	0.1732	0.3713	0.3380	**0.0414**	0.2380
pH	0.4942	0.8521	0.8339	**0.0086**	0.1143
Sulfide	0.5054	0.5222	0.5342	**0.0125**	**0.0023**
Water Depth	0.2199	0.9204	0.1313	0.5129	**0.0001**
Hydraulic Cond.	0.4783	0.2966	0.6036	**0.0001**	0.9981
Top Salinity	**0.0022**	**0.0002**	**0.0013**	**0.0006**	0.6213
Bottom Salinity	**0.0161**	**0.0014**	**0.0289**	**0.0084**	0.4841
Compaction	0.1997	0.2966	0.1904	0.1144	0.9933
Depth to 1963	0.0714	0.0965	0.2654	**0.0289**	0.9890
Cum. Organic	0.2469	0.0973	0.7001	0.2155	0.9785
Cum. Inorganic	0.4747	0.2762	0.7162	**0.0022**	0.8307
Organic Accum.	0.0809	0.2236	0.1403	**0.0332**	0.9929
Cesium Accum.	0.4645	0.1604	0.8762	0.0924	0.9710
Min. Acc.	0.1099	0.1298	0.3187	0.0674	0.9887
Max. Acc.	**0.0467**	0.4405	0.2937	0.2556	0.9959

Table 4-13. Summary of ANOVA on soil and vegetation indicator variables to look at scales of variability. The probability level is listed for each indicator for each of the variability scales (Basin, Marsh, etc.). Bold numbers indicate that the probability is significant at the 0.05 level. Results are based upon Type III sums of squares. Site and Site Rep are considered to be random effects, Basin and Marsh Health are considered to be fixed effects. The general model is: Indicator = Basin, Health, Basin*Health, Site(Basin Health), Site Rep(Site Basin Health). Parentheses indicate nesting; asterisk indicates interaction. Only Healthy and Impaired marsh health classes were used. These are the results from the General Linear Model Procedure [(PROC GLM) (SAS) 1988)].

Indicator	Variability Scale				
	Basin	Health	Health*Basin	Site(Basin, Health)	Site Rep (Site Basin, Health)
LEAF TISSUE					
TKN	0.2332	0.2358	0.4011	0.4297	0.3649
Al	0.8075	0.4050	0.4668	**0.0165**	0.9996
Ba	0.0980	0.1549	0.2749	0.8663	**0.0297**
Bo	0.1237	0.4678	0.9733	0.5244	0.9076
Ca	0.5980	0.4082	0.4384	0.8429	0.6527
Cu	.	.	.	.	.
Fe	**0.0180**	0.1088	0.1546	**0.0011**	0.9754
Pb	0.1430	0.9881	0.8725	0.4947	0.2546
Mg	**0.0488**	0.1276	0.8898	0.6210	0.4907
Mn	0.8041	0.9036	0.0740	0.0786	0.6467
Mo	.	.	.	.	.
K	**0.0254**	0.8466	0.4205	**0.0587**	0.8587
P	0.1963	0.3658	0.6137	**0.0148**	0.8170
N	**0.0001**	0.6579	0.8334	**0.0122**	0.9924
V	0.0556	0.1212	0.7620	0.8206	0.2001
Z	0.4275	0.3085	0.5478	**0.0018**	0.9955
S	**0.0155**	0.2842	0.7091	**0.0717**	0.6010
SEDIMENTS					
TKN	0.2124	0.3841	0.2570	**0.0294**	0.9978
Al	**0.0112**	0.3134	0.7006	0.1987	0.3691
Ba	0.1415	0.9464	0.5502	**0.0001**	0.9802
Bo	0.1661	0.8140	0.6932	0.3016	0.9997
Ca	0.1035	0.4848	0.8260	0.7399	0.4166
Cu	**0.0407**	0.5868	0.4870	0.2784	0.9452
Fe	0.0915	0.4342	0.1057	**0.0685**	0.5916
Pb	0.2359	0.2849	0.4162	**0.0001**	0.5332
Mg	**0.0001**	0.3029	0.9757	**0.0775**	0.9990
Mn	0.4120	0.1807	0.4727	**0.0046**	0.9551
Mo	.	.	.	.	.
K	0.2185	0.1803	0.4659	0.9355	0.0765
P	**0.0015**	0.1108	0.2058	0.6054	0.9867
Na	**0.0009**	0.2661	0.0903	0.2589	0.9476
V	0.1089	0.4336	0.4279	0.0666	0.5855
Zn	**0.0489**	0.5642	0.2550	0.2045	**0.0326**

Table 4-14. Summary of ANOVA on soil and vegetation trace constituent indicators to look at scales of variability. The probability level is listed for each indicator for each of the variability scales (Basin, Marsh, etc.). Bold numbers indicate that the probability is significant at the 0.05 level. Results are upon Type III sums of squares. Na = level not applicable (only one accretion core per site). Site and Site Rep are considered to be random effects; Basin and Marsh Health are considered to be fixed effects. The general model is: Indicator = Basin, Health, Basin*Health, Site(Basin Health), Site Rep(Site Basin Health). Parentheses indicate nesting; asterisk indicates interaction. These are the results from the General Linear Model Procedure [(PROC GLM), (SAS, 1988)].

I. Indicators Used:

1. Total Biomass
2. Water Cover

II. Test of Homogeneity of Within Covariance Matrices:

Chi-square value = 7.11 with 3

Chi-square significant at the 0.10 level, within matrices used

Classification based on Quadratic Discriminant Function

III. Re-substitution Summary:

		To	
		Healthy	Impaired
From	Healthy	81.8	18.2
	Impaired	0.0	100.0

Total Error Count=0.0833

IV. Cross-Validation Summary:

		To	
		Healthy	Impaired
From	Healthy	81.8	18.2
	Impaired	23.1	76.9

Total Error Count=0.2083

Table 4.15 Discriminant Analysis results, using total biomass and water cover. The results of the test of the homogeneity within the covariance matrices are listed under heading II, along with the method used, linear or quadratic. The classification results are shown under headings III and IV which present the percent of observations assigned to each class for (1) the re-substitution classification (Heading III) and (2) the cross-validation (Heading IV). The total error count rate is also indicated for each of the classifications.

The best classification model, without cover and biomass, is presented in Table 4.16. This discriminant model gives classification results that are comparable to using biomass and cover. The marshes can be classified into healthy or impaired with an error of ~29% for the healthy and 22% for the impaired using the following variables:

1. The sum of the stem diameters
2 The log of the number of tassels (stems with seed heads)
3. The log of the sulfide concentration
4 The log of the "hydraulic conductivity"
5. The log of the sediment sulfur concentration.

A log transform was used for those indicators that showed a log-type distribution, based upon inspection of the data distribution.

The results of the Canonical Discriminant Analysis for this model are shown in Figure 4.13. The healthy and impaired sites separated using the first two canonical variables, with the first canonical variable again having the most discriminatory power. Although this model seems reasonable, it still needs to be verified. This verification can be accomplished by either using part of the data to develop the model, then testing it with the remaining data, or by collecting a new data set. We feel that the latter approach should be used, because the data set is fairly small and to split it would not leave much data for the analysis. This verification can be accomplished by applying the model developed during this Pilot Study to the future data collection efforts.

4.7 HYDROLOGY

The hydrologic parameter of interest was marsh inundation. This was estimated based upon analysis of time-series water level data collected at 8 sites. Time-series measurements at the sample sites were used rather than spot measurements of water levels, based upon results from a previous study (Wisemann and Swenson, 1988). The results from this study which analyzed water levels measured in a brackish marsh system along a transect stretching from the bayou to 75 meters inland are shown in Table 4.17. The analyses indicated that the water levels within the internal marsh were highly correlated with each other ($R>0.94$) but had a weaker correlation ($R<0.80$) with the water levels in the bayou at the time scales used in the analysis (half-hour sampling intervals). A more detailed time-series analysis of the data indicated that, although there were weak coherences (~0.6) at short time scales (tidal period and shorter), there was also an indication of higher coherences at longer time scales (weeks); however, the time frame was too short (1 month) to assess this with any degree of confidence. Clearly, spot measurements of water levels over short time scales are not adequate to characterize the water level regimes in these marshes. We monitored water levels in the marsh and adjacent bayou for a longer time period (up to 8 months) to obtain a reliable estimate of marsh inundation.

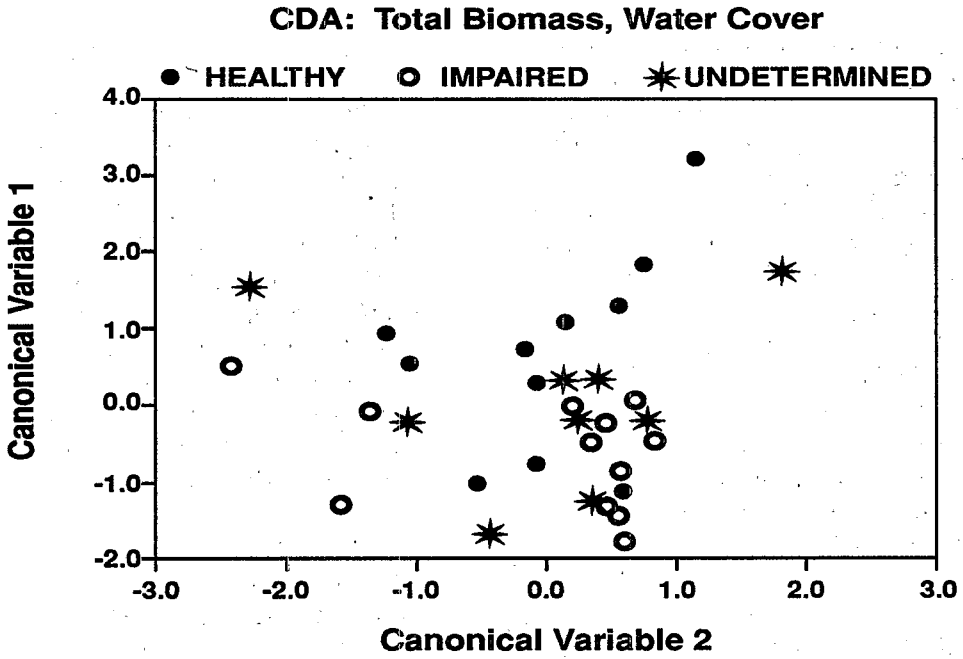

Figure 4.12 Results of Canonical Discriminant Analysis (CDA) on the 1991 EMAP Wetlands Southeast Pilot Study data. The plots show the distribution of the first two canonical variables as a function of marsh health class. The indicators used to derive the discriminant models are indicated at the top of the figure.

I. Indicators Used:

1. Log(Diameter)
2. Log(Tassels)
3. Log(sulfide)
4. Log(sediment sulfur)
5. Log(HC)

II. Test of Homogeneity of Within Covariance Matrices:

Chi-square value = 19.5 with 15 DF; Prob>Chi-square = 0.19

Chi-square not significant at the 0.10 level, pooled matrices used

Classification based on Linear Discriminant Function

III. Re-substitution Summary:

		To	
		Healthy	Impaired
From	Healthy	71.4	28.6
	Impaired	0.0	100.0

Total Error Count=0.125

IV. Cross-Validation Summary:

		To	
		Healthy	Impaired
From	Healthy	71.4	28.6
	Impaired	22.2	77.8

Total Error Count=0.2500

Table 4.16 Discriminant Analysis results, using a combination of vegetation and soil indicators. The indicators used in the models are listed under heading I. The results of the test of the homogeneity within the covariance matrices are listed under heading II, along with the method used, linear or quadratic. The classification results are shown under headings III and IV which present the percent of observations assigned into each class for (1) the re-substitution classification (Heading III) and (2) the cross-validation (Heading IV). The total error count rate is also indicated for each of the classifications.

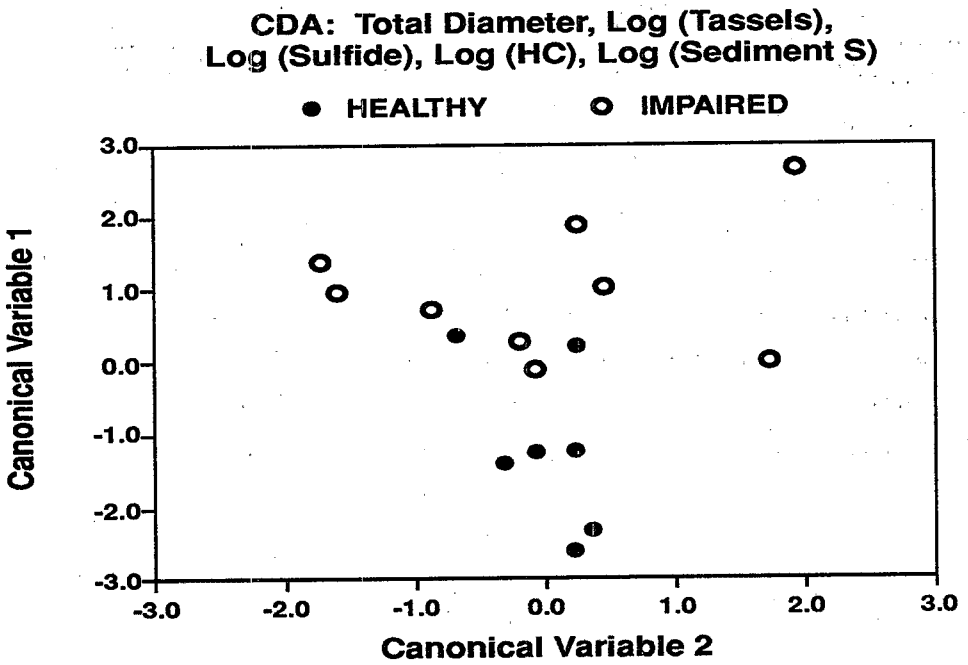

Figure 4.13 Results of Canonical Discriminant Analysis (CDA) on the 1991 EMAP Wetlands, Southeast Pilot Study data. The plots show the distribution of the first two canonical variables as a function of marsh health class. The indicators used to derive the discriminant model are indicated at the top of the figure.

	BAYOU	LEVEE	5 METERS	10 METERS	35 METERS
LEVEE	0.68				
	.nd				
5 METERS	0.69	0.80			
	0.41	.nd			
10 METERS	0.82	0.88	0.91		
	0.19	.nd	0.33		
35 METERS	0.80	0.88	0.94	0.99	
	0.38	.nd	0.47	0.13	
75 METERS	0.75	0.86	0.95	0.98	0.99
	0.48	.nd	0.72	0.29	0.68

Table 4.17 Correlation matrix of water level and salinity signals as a function of distance into the marsh. Indicated for each distance are the Pearson Correlation Coefficients for water levels (top number) and for salinity (bottom number). The data are from time series deployment in a Louisiana brackish marsh (Raccourci Bayou) from 08May87 thru 04June87. The sampling interval was 0.5 hours (Wiseman and Swenson, 1988).

5 CONCLUSIONS AND RECOMMENDATIONS

The evaluation of indicators and study design were successfully used for the first time in the 1991 field season. We exceeded the minimum sampling scheme in 1991, determined the indicator variability, the sampling error, and found several potential indicators of plant health for *S. alterniflora*. The intended low level of sample variance was achieved in almost all sampling. Most of the original indicators were justifiable choices, based on the literature and ongoing research results. A few indicators were inadequate or likely to be too difficult to implement with the framework of a regional sampling scheme.

A first-order goal of EMAP is to address questions of inventory, i.e., is the resource there? For wetlands, this includes an inventory of the areal extent and the biomass of the resources. To a certain extent, the presence or absence of biomass is a stress indicator. Plant cover, biomass and morphometric indicators can also be used in this effort. A second set of questions for EMAP involves the health of the biomass present. We have shown that there are additional indicators of change or stress that simple biomass parameters do not reveal. Soil conditions, stem morphology and the density of reproductive structures can be monitored to follow plant condition. To the extent that ecosystem health is important, these factors may themselves prove useful as indicators of faunal community health.

Soil reducing conditions have an important effect on plant health in laboratory and field experiments. We have uncovered some interesting relationships among plant conditions and both soil sulfide and total S concentration that are undoubtedly responsive to physical, biological and geological factors. It may be enough to find reasonable indicators of long-term changes, while understanding only some of these cause and-effect relationships. If long-term changes are identified through EMAP, then a more thorough investigation of the causal mechanisms of change may be warranted. Some new or additional indicators can be developed within the context of the emerging and evolving goals of this rather young EMAP program.

Below is a brief summary of key recommendations resulting from this first year's field sampling.

5.1 RESPONSE INDICATOR DEVELOPMENT

- Plant morphology and structure (e.g., stem width and reproductive structures) are potentially biomass-independent indicators of stress.

- Soil properties (e.g., eH, bulk density, carbon, hydraulic conductivity, sulfide and total S) are sources or consequences of stress that are easily measurable and probably essential properties to measure in EMAP. Interpreting the significance of variations in these properties requires additional measures that may eventually be reduced (e.g., accretion rates, water level, etc.).

- Accretion rates are important for evaluating controlling factors causing plant stress. These soil property data should be used to address questions about long-term marsh accretion and the relationship between biomass and accretion rates. These relationships remain prevalent issues for both indicator development and resource management.

- Pre-sampling aerial surveys (photography) should be made available for site selection and logistical support, and a 2 or 3 segment historical comparison of the sites is very informative for determination of whether the sites are healthy or impaired.

- Installation of water-level gages may be too costly and time-intensive to continue for all sites, but water level is an essential measurement to continue in some fashion, if only to determine important relationships among stressors and plant responses. It may be informative to examine the tide gage records of nearby field sites or to choose field sites for indicator development on the basis of their proximity to good tide gage records.

- It is very cost-effective to collect some soil samples for archival purposes. The toxic effects of pollutants are frequently a threat, and this data could be integrated with the other EMAP studies (e.g., EMAP Estuarine). It may be good to include a screening for some organic pollutants for the same reason. Furthermore, the constituents might provide a direct signal concerning marsh health and/or a basis for interpretive indicator responses.

- This study was initiated as a preliminary attempt at identifying whether spectral reflectance measurements of the marsh surface from a helicopter platform could be used to assess marsh health and would, thus, warrant continued investigation. The results presented above indicate that differences in marsh vigor may be definable with this technique. However, the sources of variation in the data must be identified and a larger number of sampling stations must be employed.

- pH measurements appear to have little use in the program. The variability among sites of contrasting conditions was low.

5.2 SAMPLING EFFICACY

- Sampling efficacy may be improved by investigating the relationship between sample frequency and variability. For example, there are two ways to improve upon the previous sampling efforts estimating plant biomass. One is to sample fewer plots, and the other is to further develop morphometric measures for non-destructive sampling. Modification of sampling scheme will reduce effort with a small loss of replicability. Specifically, the number of replicates for biomass harvest can be reduced from 6 to 5 plots. This should be examined further and may have a potentially long-term consequence for field sampling efficiency.

5.3 ADDITIONAL INDICATORS

- EMAP-Wetlands has expanded its scope beyond monocultural coastal wetlands to include ecosystem health and general resource condition of more diversified coastal wetlands. In practice, this may mean that indicators of fish habitat quality (for example) are appropriate areas for indicator development.

- Non-destructive sampling techniques are desirable, especially in light of the desirability of long-term landowner cooperation.

- Below-ground biomass is a potentially important parameter to measure in subsequent studies.

5.4 EXPANSION TO OTHER REGIONS

- Indicator development for individual species of homogenous macrophyte cover will be easier to expand than it will be for heterogeneous plant cover. There is a drastic change in species dominance going from salt to freshwater marshes. The difficulties involved in sampling the brackish marshes are much greater than those involved in monotypic salt marshes. Caution is urged in expecting too much too soon when expanding the vegetation types analyzed from salt marsh to other plant communities. The end-members conditions (healthy and impaired) for *S. alterniflora* may not be estimated by the same parameters for all species. In fact, it is unlikely that is the case.

- The Louisiana province is not necessarily representative of all salt marsh sites. This means that coastal wetland monitoring activities in other Gulf states are likely to present different geophysical conditions affecting plant community health.

- The response of plants to a stressor is not necessarily linear. There may be a threshold effect (e.g., to tidal energy or submergence) or an optimum response level (e.g., to a pollutant, sulfide or salinity). The range of conditions found in the Louisiana field trials may not represent all ranges of factors affecting the status of plant health. For these reasons and others, it is prudent to continue investigation of any indicators showing even minimal likelihood of success.

- Soil salinity was never an important component of any of the statistical cluster or discriminant analyses. However, it may be an especially important parameter to include in Gulf of Mexico-wide sampling, in view of the hypersaline conditions anticipated in Texas estuaries.

5.5 SUMMARY TABLE

A summary of the utility of the indicators selected to reflect wetland condition is shown in Table 5.1.

SALT MARSH INDICATOR DEVELOPMENT RESULTS				
	Indicators of Condition	Useful for Interpretation	Probable Community Change Indicator	New Direction Possible
1. Soil Parameters				
a. Salinity	?(s. Tx.)	X	X	
b. Bulk density		X	X	
c. Percent organic	X	X	X	
d. Sulfide	X	X	X	
e. pH				
f. eH	?	X	?	
g. Hydraulic conductivity	X	X	X	refine method?
h. Water levels		X	X	
i. Chemical constituents - trace metals	?		X	S fractions
j. Chemical constituents - nutrients	X	X	X	
k. Sediment/organic accumulation	?	X	X	
2. Vegetation Parameters				
a. Cover	X	X	X	light wand
b. Biomass	X	X	X	light wand
c. Stem density	X	X	X	
d. Stem length	X	X	X	
e. Stem diameter	X	X	X	weight/x-sec.
f. Chemical constituents - trace metals	?	?	?	
g. Chemical constituents - nutrients	?	?	?	
h. Species presence	?	X	XX	
3. Other, new approaches				macrobenthos dendritic network fish PRES./ABS. below ground biomass grain size

Table 5.1 Summary of indicator evaluations.

SALT MARSH INDICATOR DEVELOPMENT RESULTS				
	Non-destructive sampling Method	Not recommended for Regional Stage II	Archive for Possible Use	New Direction Possible
1. Soil Parameters				
a. Salinity	?(s. Tx.)	X	X	
b. Bulk density		X	X	
c. Percent organic	X	X	X	
d. Sulfide	X	X	X	
e. pH				
f. eH	?	X	?	
g. Hydraulic conductivity	X	X	X	refine method?
h. Water levels		X	X	
i. Chemical constituents - trace metals	?		X	S fractions
j. Chemical constituents - nutrients	X	X	X	
k. Sediment/organic accumulation	?	X	X	
2. Vegetation Parameters				
a. Cover	X	X	X	light wand
b. Biomass	X	X	X	light wand
c. Stem density	X	X	X	
d. Stem length	X	X	X	
e. Stem diameter	X	X	X	weight/x-sec.
f. Chemical constituents - trace metals	?	?	?	
g. Chemical constituents - nutrients	?	?	?	
h. Species presence	?	X	XX	

Table 5.1 (*cont.*) Summary of indicator evaluations.

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