TEXAS SEAGRASS MONITORING PROGRAM

STRATEGIC PLAN

Prepared

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For

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EXECUTIVE SUMMARY

The Texas Seagrass Monitoring Program was proposed at a Workshop held in Corpus Christi, Texas, in August 2000 that was attended by some eighty resource managers, estuarine scientists, and environmental representatives dedicated to seagrass conservation and protection. As an outgrowth of this workshop, a Seagrass Monitoring Steering Committee (Workgroup) was formed to guide and coordinate the development of a coastwide Seagrass Monitoring Plan for Texas. This document, the Strategic Monitoring Plan, was produced through consensus of the Workgroup and recommends the conceptual design of the monitoring program that will be sponsored by Texas Parks & Wildlife Department (TPWD), Texas Commission on Environmental Quality (TCEQ), and Texas General Land Office (TGLO) in accordance with Texas' Coastal Management process.

After a review of background information on the need for coastwide seagrass monitoring, the document clarifies appropriate Goals and Objectives for the Texas Program. A thorough understanding of the applications of monitoring data is important for selecting seagrass parameters and for designing a robust sampling scheme for Texas unique bay systems. These applications range from general status and trends information, to specific management programs where water quality degradation or structural habitat disturbance must be assessed.

Two technical sections in the plan offer guidance on potential seagrass health indicators and tentative field methods for their sampling; this includes both ground survey stations and large area landscape analysis by aerial photography. The health indicators thus determined must be based on defined conceptual models of seagrass ecosystem dynamics. The exact indicator parameters will be specifically selected at a later date during the implementation of the Plan by the three State agencies above. At the current time, field studies and data analysis are being performed by researchers to test various techniques and statistical validity; and the final evaluation of protocols must await until complete results are available.

The data collected by aerial monitoring or field surveys will be compiled in specific seagrass-related databases maintained by the three State agencies (TPWD, TCEQ, TGLO) with coastal resource management responsibility. Since these 3 agencies already collect substantial amounts of coastal data, seagrass monitoring is expected to primarily expand on their existing data acquisition programs. A major new component involves development of a data management system, which will consist of a web-based data distribution network using Arc-IMS to link the relevant seagrass and coastal datasets between the 3 agencies and other certified sites. The monitoring program will be initiated under an MOU which will allow the three state agencies to proactively implement the recommendations in this document. Key groups in the three agencies will be designated to work on evaluating and selecting seagrass health indicators upon completion of the R-EMAP study, establishing the distributed web-based seagrass data management system, organizing and funding seagrass sampling surveys, and establishing water quality criteria to protect seagrass propagation (aquatic life use) based on seagrass monitoring data.

SECTION 1: INTRODUCTION AND BACKGROUND

Many anthropogenic factors are putting stress on Texas coastal zone resources, in particular seagrass areas.

- Coastal Texas population is growing by 2-3% per year. Affluent commuters prefer to live outside cities near the water or bay front, increasing the amount of shoreline development. Many urban Texas residents also own second homes on the coast.
- Impacts from popular water-oriented recreation activities (e.g. boating and fishing) are rapidly increasing.
- Maintenance dredging of the Gulf Intracoastal Waterway (GIWW), and other ship channels along the Texas coast that are essential to water-borne transportation and the business economy, has major impacts on water quality of seagrass areas.
- Unincorporated areas have less stringent water quality protective regulations e.g. use of septic systems for wastewater treatment can lead to nutrients leaching into surrounding bay water. Nonpoint source (NPS) runoff from agricultural lands or city storm drains may be significant [see Coastal Bend Bays and Estuary Program plan (CBBEP 1998) and Galveston Bay Estuary Program plan (GBEP 1995)].

The magnitude of seagrass changes reflects moderate seagrass degradation in Texas waters.

- Seagrass loss and habitat changes have been well documented in Texas estuaries. “Hot spots” exist, mostly near major urban centers (Galveston and Corpus Christi) or ship channels (Lower Laguna Madre).
- All seagrass beds in West Galveston Bay disappeared by 1982. Only 437 acres remained in the Christmas Bay system (Pulich 2000, personal observation), although recovery has started in a protected part of mid-West Galveston Bay (Ikenson 2002).
- Between the mid 1970’s and 1988, approximately 35,000 acres of shoalgrass (*Halodule*) were lost in the lower Laguna Madre due to GIWW dredging. Over that same time, *Syringodium filiforme* and *Thalassia testudinum* increased also by 15,000 and 10,000 acres, respectively, displacing *Halodule* to some extent (Quammen and Onuf 1993, Onuf 1994).
- About 3.8% of seagrass in upper Laguna Madre (about 2300 acres) were lost between 1990 and 1996 due to the brown tide algal bloom (Onuf 2000).
- While about 2100 acres of shoalgrass have been gained overall in the Corpus Christi Bay area since 1975, there has been a concomitant, localized decrease

of 815 acres of mostly turtlegrass in the Redfish Bay system (Pulich et al. 1997).

- Propeller scarring has affected from 33% to 98% of the seagrass beds in the Corpus Christi and Redfish Bays area according to a 1998 study (Dunton and Schoenberg 2002).

Seagrass monitoring has been recommended to assess and provide a basis to manage these problems. "Monitoring," as defined for this planning document, refers to assessing the environmental conditions and ecological health of seagrass beds. It is not simply seagrass mapping to determine the presence or absence of seagrass. Physical, hydrographic, and other ecological data are required to fully describe the health and productivity potential of Texas seagrass beds.

- The goal of developing a Seagrass Monitoring Program was a major recommendation of the Seagrass Conservation Plan for Texas, adopted in 1998 by Texas Parks and Wildlife Department (TPWD), Texas Commission on Environmental Quality (TCEQ) (formerly Texas Natural Resource Conservation Commission), and, and the Texas General Land Office (TGLO).

- The Texas Surface Water Quality Standards (TSWQS) were revised by TCEQ in July 2000 to include "Seagrass propagation" as a new aquatic life use. This designation requires that saltwater with significant stands of submerged seagrass be protected. It is necessary as a long-term goal to define quantitative water quality and related seagrass habitat criteria in order to apply the new standards to environmental assessment and protection activities in seagrass areas. TCEQ, TGLO and TPWD recognized that a formal seagrass monitoring program is necessary in order to obtain the quantitative data to establish numeric criteria for seagrass protection.

- Monitoring data are also routinely needed to assess impacts to seagrass in other coastal regulatory or management actions involving:
  - Nutrient enrichment from nonpoint source pollution and watershed loadings (e.g. agriculture, mariculture, septic tanks or storm drains)
  - Dredging (especially the GIWW channel) that produces high levels of suspended solids and turbidity
  - Shallow-draft boating activities that cause propeller scarring
  - Shoreline and marina developments, especially near seagrasses
  - National Estuary Program projects
  - Restoration and mitigation projects
  - State Scientific Areas and Estuarine Reserves, such as Redfish Bay.

Process for Developing the Texas Seagrass Monitoring Program

- At an August 2000 workshop in Corpus Christi, a Monitoring Planning Workgroup was assembled consisting of TPWD, TCEQ (TNRCC), TGLO, Texas Estuary Programs, USGS, USFWS, EPA, NMFS, university researchers and non-governmental groups interested in conserving seagrasses.

- Goals, objectives and strategies for a Texas seagrass monitoring program were identified. Technical issues associated with a coastwide sampling design and selection of accurate seagrass health indicators were discussed. The necessary organizational framework was created to guide the subsequent program development process.

- Under direction of a Steering Committee (i.e. Workgroup), and with funding from the EPA Gulf of Mexico Program and TPWD, a strategic planning document was envisioned. This plan would contain the conceptual design details and recommendations for the statewide seagrass monitoring program. The focus of the plan would be to identify conceptual ecosystem models, to propose potential indicators, and to evaluate monitoring protocols for key field and landscape parameters reflecting seagrass bed health and quality.

- The need for a data management system and organized network of data custodians was recognized in order to maintain the monitoring data and provide for its access and distribution to resource agency managers, research scientists and concerned non-governmental organizations.

- Research projects would be undertaken to test sampling scheme(s) designs and potential indicators, and to evaluate field and landscape monitoring protocols applicable on a coastwide scale.

- After final acceptance of the strategic plan by the appropriate state agencies and other partnering entities, program implementation would begin by seeking funding for coordinated monitoring projects in specific target areas.

Planning Objectives

This strategic planning document lays out the strategies and conceptual design of the **Texas Seagrass Monitoring Program.** The major sections will address:

1. <u>Major Goals, Objectives, and Strategies of seagrass monitoring</u>, which addresses the question: Why is it important to monitor seagrasses?
2. <u>Field Monitoring Sampling Design</u>, which addresses the questions: How will seagrass health be monitored? What field parameters will be measured and what field survey protocols will be followed?
3. <u>Landscape Monitoring Sampling Design</u>, which addresses the questions: What landscape parameters will be measured and what mapping protocols will be used?

4. Monitoring Data Management System, which addresses the questions: How will monitoring data be compiled, maintained, quality-controlled and distributed for review and analysis?
5. Implementation of Monitoring Program, which addresses the practical questions: Who will coordinate and fund the seagrass monitoring program? Who would participate in monitoring? Who will use monitoring data to set standards?

SECTION 2: MONITORING GOALS AND OBJECTIVES

The Texas Seagrass Monitoring Program will focus on two primary goals:

1. Protection and propagation of seagrass through water quality management programs.
2. Conservation and restoration of seagrasses through estuarine habitat management programs.

Goal 1: In order to effectively protect seagrasses through water quality or dredging regulations, seagrass monitoring can be utilized in three different regulatory situations . These three situations underscore the broad regulatory context for seagrass monitoring: performing assessments, validating permit decisions, and establishing water quality standards. Each application also represents a facet of specific state or federal regulatory programs, with differing statutory jurisdictions. These regulatory programs are identified as follows:

Assessments: Clean Water Act activities such as “305(b)” Reports, “303(d)” Assessments, Total Maximum Daily Loads (TMDL’s), and Watershed Restoration.
Clean Water Act Permit Decisions: Wastewater (NPDES) and Army Corps of Engineers (Sec. 404/401) permits; Consistency review of Sec. 404 permits under Texas Coastal Management Program (CMP).
Texas Surface Water Quality Standards: Aquatic life use designation and quantitative criteria Development.

Goal 2: In order to evaluate the effectiveness of coastal habitat management programs, seagrass monitoring can provide data for evaluating the results of state or local estuarine management policies. Several monitoring objectives address non-regulatory management programs such as Coastal Preserves, State Scientific Areas, Estuarine Reserves, State Estuary programs, and non-governmental organization projects. A variety of strategies, many are also common to first goal above, comprise the specific actions to accomplish seagrass management and conservation objectives.

The following monitoring objectives and strategies are identified:

Objective 1: Monitor status and trends of seagrass distribution

Strategy 1: Perform coastwide seagrass status and trends inventories at 5-year intervals. Map distribution and coverage from 1:24,000 scale, true color (not color infrared) aerial photography. The resulting baseline maps will be the primary basis for designating seagrass use in coastal waterbody segments.

Strategy 2. If possible, perform seagrass mapping (both aerial and ground reconnaissance) after hurricanes or other natural catastrophic events.

Strategy 3. Perform seagrass surveys and mapping in conjunction with estuary program implementation projects. (e.g. GBEP and CBBEP)

Objective 2: Monitor ecological health of seagrass by assessing environmental criteria for seagrass beds

Strategy 1: Determine seagrass ecological health in coastal waterbody segments by field surveys. Define the threshold of impairment with ecological health tools, such as indices of biological integrity. From this analytical strategy, determine the threshold of seagrass change that equals impairment.

Strategy 2: Document ambient conditions of constituents that support seagrass propagation and determine loadings that prevent seagrass use.

Strategy 3: Develop health indicators for compliance monitoring and as possible biomonitoring assessment tools.

Objective 3: Monitor ecological health of seagrass by assessing spatial or landscape criteria for seagrass beds

Strategy 1: Acquire high resolution remote sensing/aerial photography data at a landscape scale (1:9,600 or greater). Develop high resolution (large-scale) maps with standardized methodology. Quantify seagrass acreage and species composition, and other relevant landscape features, such as propeller scarring, for water-body segments.

Strategy 2: Develop large scale maps of appropriate detail at project sites and delineate zones of influence (e.g. for discharges). Compile detailed base maps in areas of high human activity and population growth.

Strategy 3: Determine seagrass ecological health in coastal waterbody segments at landscape scale. Define the threshold of impairment with ecological health tools, such as indices of biological integrity. From this analytical strategy, determine the threshold of seagrass change that equals impairment.

Objective 4: Monitor ecological health of seagrass by assessing conditions necessary to maintain seagrass use and propagation

Strategy 1: For site assessments, document constituents of concern that impact seagrasses such as light, nutrients, total suspended solids, toxics, etc. Although it is assumed that existing toxic criteria are adequate, additional information on toxicity to seagrass may need to be developed.

Strategy 2. Perform assessments of seagrass health indicators (as identified in Strategy 1) and develop indices of biological integrity.

Strategy 3: For developing numeric water quality standards, determine related seagrass plant stress criteria. The long-term goal is to have seagrass-specific quanititative criteria, with associated threshold data (i.e. What is the effect threshold for various parameters? That is, what concentrations, conditions, and/or loadings result in a plant effect?)

Strategy 4: In order to determine limits for permit compliance, develop health indicators for compliance monitoring and as possible biomonitoring assessment tools.

Objective 5. Monitor to support seagrass mitigation and restoration programs.

Strategy 1: In support of seagrass restoration and creation projects, identify conditions to enhance, restore, or create seagrass habitat.

Strategy 2: In order to establish effective seagrass mitigation ratios, monitor selected restoration sites, planting methods, important habitat variables, success criteria, and health indicators.

Strategy 3: Document constituents of concern that impact seagrasses such as light, nutrients, total suspended solids, etc. TCEQ assumes existing toxic criteria are adequate. Is there specific information on toxicity to seagrass that needs consideration?

Strategy 4: Use seagrass monitoring data to develop and assess effectiveness of Best Management Practice's (BMP's) for the Army Corps of Engineers Dredged Material Placement Plan (DMMP).

Objective 6. Develop a seagrass monitoring Data Management System (DMS) .

Strategy 1: Design the DMS to handle compilation and formatting of seagrass monitoring data, custodial quality assurance/quality control (QA/QC) issues, and data archiving.

Strategy 2: As part of the DMS, establish a data clearinghouse for access and distribution of data through a web-based server application.

SECTION 3: FIELD SAMPLING DESIGN FOR SEAGRASS MONITORING

I. Intensive Field Surveys

The Seagrass Monitoring Workgroup recognized the fundamental need for establishing a rigorous, statistically sound field sampling and survey program. The development of such a program must first address questions concerning field sampling design and the seagrass ecosystem parameters or indicators to be measured. In addition, field sampling must be based on a clearly defined conceptual model that identifies the appropriate seagrass ecosystem parameters for measurement. While constraints on such a program are recognized (namely manpower and costs), monitoring objectives require a reasonable balance between operational constraints and the need for scientifically accurate indicator data, at a sufficient density of coverage.

Seagrass Health and Environmental Indicators. Many indicators of seagrass plant health and environmental quality have been identified in previous monitoring planning studies and workshops. Several published references in particular deal with proposed seagrass indicators and field survey protocols. Neckles (ed) (1994) summarized the proceedings of a monitoring workshop on Gulf of Mexico seagrasses sponsored by EPA –Office of Research and Development (Environmental Monitoring and Assessment Program) and USGS (formerly National Biological Survey) National Wetlands Research Center. This document provides a basic foundation for seagrass monitoring programs, and provides many recommendations for seagrass indicators and ecosystem health parameters, field survey and mapping techniques, as well as related research needs. The Chesapeake Bay Program had earlier identified submerged vegetation monitoring parameters and procedures for temperate eelgrass (*Zostera*) under its renowned estuarine management system (Batiuk et al. 1995). Washington State's Department of Natural Resources (Norris et al. 2000) has also recently designed a seagrass monitoring model for Puget Sound eelgrass which is based on rigorous statistical criteria. While each of these plans contains pertinent, generic information, none is directed specifically towards Texas subtropical seagrass communities. Geographic differences, in particular, can dictate the modifications required to customize the monitoring procedures to Texas seagrasses.

Seagrass parameters can be divided generally into biotic (seagrass abundance, morphology, physiology, and tissue composition) and habitat condition (physicochemical, hydrographic, and habitat) indicators. Most are standard plant ecology and estuarine environmental parameters derived from published seagrass productivity and growth models (Dennison et al. 1993, Dunton et al. 2002). Such models are powerful tools for understanding the complex ecological and biogeochemical relationships between seagrasses and their environment. The exact suite of parameters monitored can depend on the specific conceptual model chosen. Since the efficacy of many parameters has not yet been rigorously substantiated for the Texas monitoring program, this planning document treats parameters as potential indicators until results from the Texas R-EMAP study described below are available.

Seagrass Plant Growth Conceptual Model

This section briefly describes the seagrass plant model that forms the basis for potential monitoring parameters indicative of Texas' seagrass health. A conceptual model to predict trends in biomass when seagrasses are exposed to different environmental conditions was previously developed to assess plant responses to dredging events in Laguna Madre (Dunton et al. 2002). This model was formulated to have both above- and below-ground components and to be applicable to the three dominant seagrass species in the Laguna, turtlegrass (*Thalassia testudinum)*, shoal grass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme)*. The model is driven by incident light and incorporates carbon transport from above- to below-ground tissue. A comprehensive sediment diagenesis model is coupled to the seagrass biomass model allowing the incorporation of important sediment toxicity effects (Fig. 1).

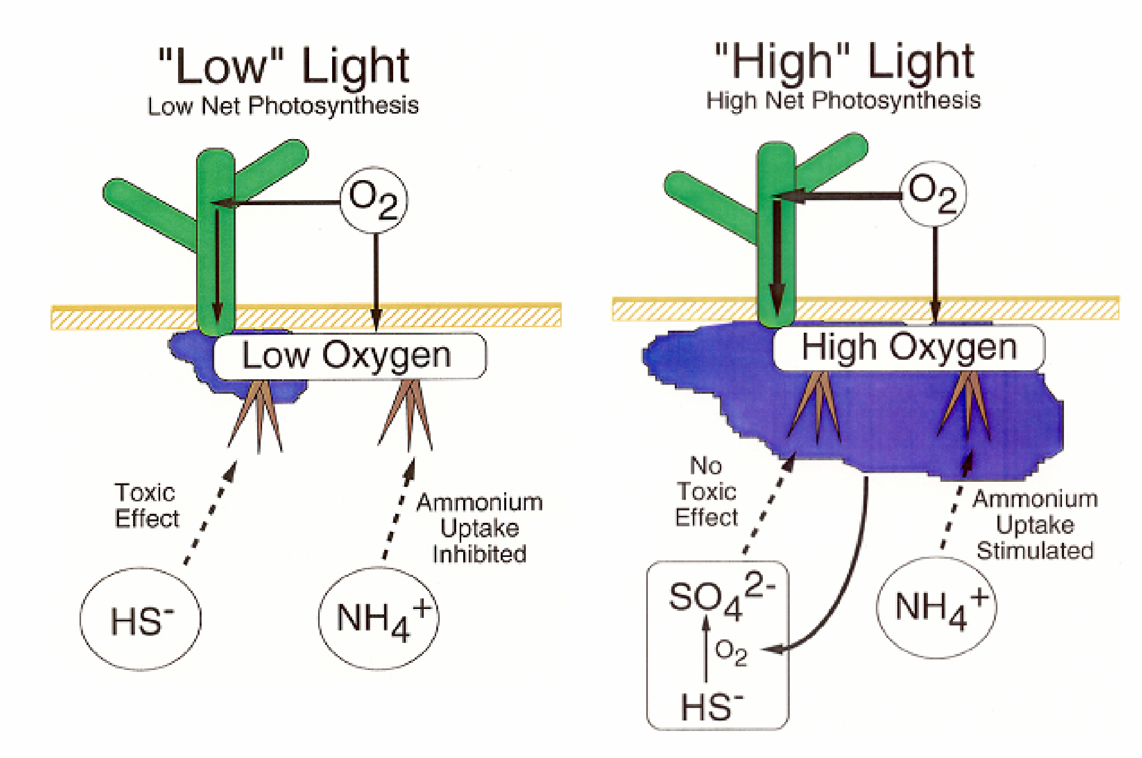


Figure 1. The components of the seagrass model incorporate both the above- and below-ground portions of plant biomass and the changes in sediment geochemistry that occur in relation to underwater light fields.

More sophisticated seagrass models have been developed to examine the flow of carbon and nitrogen in plant tissues. Carbon flow represents energy flow while nitrogen

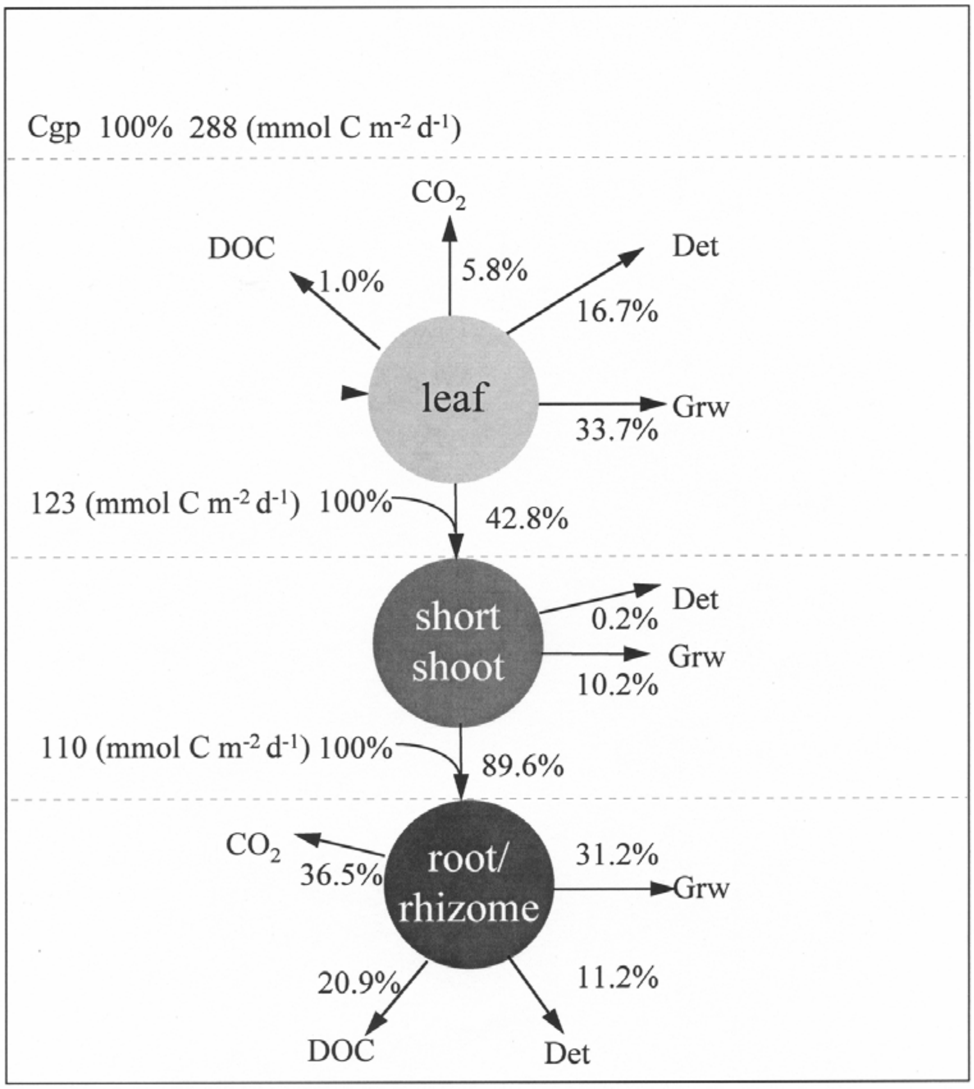


Figure 2. *Thalassia* carbon flow diagram. Arrows indicate direction and numbers (in bold) show the amount of the flow (mmol C m^{-2} d^{-1}) to other seagrass components, such as respiration (CO_2), excretion (DOC), detritus (Det), and growth (Grw) based on a net carbon input from gross primary production (Cgp) of 288 mmol C m^{-2} d^{-1}.

flow is a surrogate for the nutritional state of the plant. Dunton et al. (2002) used field measurements and literature values of production, growth and turnover rates to develop the data and constraint systems. Model results for *Thalassia testudinum* indicate that assimilated carbon was equally partitioned between leaves and below-ground tissues and that the flow was unidirectional during the summer months (Fig. 2). Losses to dissolved organic carbon (DOC) from the root/rhizome module were substantial and may contribute to the high DOC concentrations measured in the sediments. Lee and Dunton (2000) noted that nitrogen assimilation occurred in the below-ground module and model results indicate that internal recycling, particularly from the leaves, was important.

Losses of dissolved organic nitrogen (DON) were minimal, indicating that *Thalassia* uses nitrogen efficiently.

II. Field Sampling Design and R-EMAP Project

Field survey sampling design for Texas areas is currently being evaluated in a R-EMAP pilot project conducted by University of Texas Marine Science Institute, funded by EPA, Region 6, and its Office of Research and Development. Indicators and sampling design are being evaluated by researchers at the University of Texas by applying geostatistical data analysis methods to randomly selected seagrass sampling sites consistent with the recommended EPA-REMAP approach. Results from this project will form the basis for establishing a coastwide field monitoring grid tailored to Texas seagrass beds. Indicator measurements and sampling protocols will be recommended after data from their study have been subjected to rigorous statistical analyses.

The Region 6 REMAP study will identify the indicators that provide the most critical information on water quality criteria and are relevant to successful maintenance and growth of seagrasses. This study will generate data to assess the relative value of various indicators with respect to cost, inherent variability on spatial and temporal scales, and field effort. The study focuses on two estuarine systems, the Mission-Aransas and lower Laguna Madre. The two systems are distinctly different in terms of salinity, nutrient loadings, and freshwater inflows. Yet both support extensive seagrass meadows that contain all five species of seagrasses common to the Texas coast (*Halodule wrightii, Ruppia maritima, Thalassia testudinum, Syringodium filiforme,* and *Halophila engelmanii*). Consequently, a monitoring program that proves successful in accounting for seagrass changes in this pilot investigation will be robust in application to other systems. In both systems, a large amount of baseline data collected in conjunction with previous seagrass studies will be utilized for indicator development through geostatistical analysis.

This study addresses the following questions:

- What key indicators (biotic and abiotic) are most sensitive to causative changes in water quality and best reflect the health of submerged seagrass beds?
- Which seagrass indicators provide the most critical information over spatial and/or temporal time scales? Are some more cost-effective than others?
- Which suite of indicators would be most appropriate, based on their statistical strength, for inclusion into an Index of Biological Integrity (IBI)?
- What monitoring design should be established in Texas seagrass beds for probabilistic sampling that allows for rigorous statistical geospatial analysis? What are some of the options?
- Over what time scales (from every sixty days to annual) is sampling most appropriate on a cost-benefit basis? What temporal scales provide the most sensitivity to environmental change?

- How concentrated should sampling efforts become? What spatial sampling density is sufficient to capture the inherent variability in the system? What is the trade-off between replication, the number of stations, and cost?

This project involves sampling 30 sites within each of two estuarine systems, the Mission-Aransas and the lower Laguna Madre. Within each of the two study areas, core EMAP seagrass indicators are measured along with additional parameters that have been identified based on recent research activities (Table 1). This effort will require the development of a detailed bathymetric base map in digital form using Geographic Information System (GIS) software.

Table 1. Core EMAP coastal indicators considered at each permanent sampling site.

Water Quality	**Sediment Quality**	**Seagrass Light Response Indicators**	**Plant Nutrient Response Indicators**
Dissolved oxygen	grain size	biomass (above- & below-ground)	C:N:P blade ratios
Conductivity, salinity, and temperature	total organic carbon	root:shoot ratio	epiphytic algal species composition and biomass
Nutrients (NH_4^+, NO_3^-, NO_2^-, PO_4^{-3})	pore water NH_4^+	leaf area index; blade width	drift macroalgal abundance/composition
Chlorophyll *a*	Redox?	shoot density	
total suspended solids (TSS)	Depth to reducing layer?	chlorophyll fluorescence	
light attenuation (*k*)	Sulphide?	species composition	
Surface irradiance (%SI)		maximum depth limit	

All sixty sites will be sampled every six months from July 2002 through February 2004. At each site, a rapid visual assessment technique developed early in the twentieth century by plant sociologist Braun-Blanquet (Braun-Blanquet 1972) is used to assess the abundance of seagrass and macroalgae. This method is used in the EPA sponsored seagrass status and trends monitoring project in the Florida Keys National Marine Sanctuary (FKNMS). It is very quick, requiring only minutes at each sampling site, yet is robust and highly repeatable, thereby minimizing among-observer differences, and has recently been applied to seagrass research. At each site, a 50-m-long transect is established by driving steel rods into the substratum at both ends of the transect. Each time a site is visited, the transect is marked with a 50-m rope from the site marker towards the south. During each sampling period, ten quadrats (0.25 m^2) are placed along each transect at pre-determined random distances from one of the marker rods. A new set of random sampling positions are chosen before each visit to a site. Each quadrat is examined using SCUBA or snorkeling equipment. All seagrass species occurring in the quadrat are listed, and a score based on the cover of the species in that quadrat is assigned (see Table 2). Cover is defined as the fraction of the total quadrat area that is obscured by a particular species when viewed from directly above. From the observations of cover in each quadrat at a site, three statistics will be computed for each species: density, abundance and frequency following the detailed procedures of Fourqurean et al. (2001).

Table 2. Braun-Blanquet abundance scores (S). Each seagrass species will be scored in each quadrat according to this scale (from Fourqurean et al., 2001). (Shoot density applies to *Thalassia* only).

S	**Interpretation**
0	Species absent from quadrat
0.1	Species represented by a solitary short shoot, < 5 % cover
0.5	Species represented by a few (< 5%) short shoots, < 5% cover
1	Species represented by a many (> 5%) short shoots, < 5% cover
2	Species represented by many (> 5%) short shoots 5%-25% cover
3	Species represented by many (> 5) short shoots, 25%-50% cover
4	Species represented by many (> 5) short shoots, 50%-75% cover
5	Species represented by many (> 5) short shoots, 75%-100% cover

Data collected during the 18-month field effort will be incorporated into a geospatial database in various GIS layers for assessment and statistical analysis. These data layers will include seagrass distribution and measurements from a variety of indicators. Since indicators are clearly linked to an underlying ecological process, geostatistical analyses can be used effectively to evaluate the power and reliability of a given indicator.

The expected benefits of these activities include:

- Evaluation of the relative importance of various seagrass indicators for a state-wide seagrass monitoring program.
- Demonstration of a seagrass monitoring program in two distinctly different Texas estuaries characterized by widespread cover and diversity of seagrasses.
- Creation of a website linked to the EMAP website to provide other individuals and programs access to data on seagrass health and distribution.

Beginning in 2003, data will be analyzed and interpolated using Geostatistical Analyst, an ArcInfo 8.1 extension. Geostatistical techniques, which involve kriging or cokriging methods (for multivariate cases), can be used to create prediction surfaces. Several methods are available in the Geostatistical Analyst extension. Understanding the combination of spatial and temporal trends in data requires a combination of techniques from geospatial analysis using GIS and time series analysis. Some of the issues are the following:

- A given indicator at a particular location may vary seasonally (e.g. dissolved oxygen) or have a value that shows little seasonal variation (e.g. total suspended solids).
- There may be consistent differences from one year to the next in the level of an indicator.
- The indicators are linked by physical, chemical and biological relationships.

The techniques proposed for use in this study to clarify these relationships are:

- Geostatistical analysis of point information to generate spatial maps of expected concentrations of variables and their standard error of estimate. The Geostatistical Analyst extension of ArcInfo 8.1 will be used for this purpose. This technique has been successfully employed in a study of the benthic community in the Western Arctic ocean (Jonsdottir, et al., 2000).
- Fourier analysis of indicators showing seasonal variations. This is fairly easy to accomplish using regular regression methods, which can be combined with annual variables to examine combinations of year-to-year trends and seasonal variations within a year.
- Regression or other mathematical or physical models to describe the interrelationships of the indicator variables. This analysis will likely be programmed in Visual Basic to operate on data in ArcInfo 8.1 or a combination of ArcInfo 8.1 and Excel.

One goal of this study is to identify an indicator variable or combined set of variables that reliably identifies the health of seagrass beds. One method of doing this is an Index of Biological Integrity (IBI), which is a weighted set of indicator values that provide a score. Gradations of the score from high to low are then used to characterize regions of health of the seagrass population. Such indicators need to be:

- Statistically sound in the sense that they discriminate between sampled conditions in a statistically significant manner.
- Scientifically sound in the sense that the variables included in the IBI are rational.
- Reasonable in the sense that they may be used by resource staff to determine an IBI value following a standardized protocol within a reasonable amount of time with limited resources. Statistical summarization techniques are helpful in forming such indices but common sense selection of reasonable variables should always take precedence.

Incorporating Study Results into the Seagrass Monitoring Plan

After the Steering Committee Workgroup reviews and analyzes results from the R-EMAP study, decisions will be made to select the most definitive, cost-effective indicators for routine, coastwide monitoring surveys. These surveys will be designed for each bay system to cover all areas where seagrass occurs or potentially could occur; thus primarily shallow subtidal areas will be monitored. While a minimum suite of environmental parameters and bioindicators can be established for routine monitoring based on cost considerations, special studies will warrant more sophisticated measurements in certain cases.

A robust sampling grid will be applied to each bay based on evaluation of sample numbers needed to provide statistically valid results. The Steering Committee tentatively anticipates that some form of an EMAP global spatial grid developed according to the generalized random tessellation stratified (GRTS) design will be employed as the basic random sampling strategy (EPA/ORD/NHEERL 2002). The equal area sampling grid cells from GRTS satisfy probabilistic sampling requirements, but also support other critical options for monitoring seagrass target populations in coastal waters. Statistical issues such as uneven seagrass sample distributions, stratified or nested subsampling, and monitoring over time at special study areas, can be accommodated under this design. EPA-National Coastal Assessment Program staff and Texas research scientists will officially certify the sampling scheme at this final stage.

SECTION 4: SEAGRASS MAPPING AND LANDSCAPE ANALYSIS MONITORING DESIGN

I. Mapping to Determine Seagrass Status and Trends

The current standard methods for determination of seagrass status and trends involve mapping from 1:24,000 scale true color, not color infrared, aerial photography (NOAA-CSC 2001). Analysis of this scale color photography for seagrass distribution has traditionally been performed by photointerpretation of 9” x 9” positive phototransparencies, followed by digitization of seagrass polygons from map overlays and compilation of digital data into a spatial database (i.e. normally GIS). Details of these seagrass photointerpretation and computer mapping methods are thoroughly described in Dobson et al. (1996), Pulich et al. (1997) and most recently by NOAA-CSC (2001). For seagrass mapping projects using aerial photography of all scales, these techniques would generally be utilized, although some technological modifications have greatly streamlined the delineation and digitization steps (e.g. optical transfer - georegistration instrumentation, and digital scanners are now available). Rigorous standards and specifications apply in all phases of the work; and all required procedures must be followed to ensure accuracy and quality of status and trends seagrass data derived from the aerial photography.

The main disadvantage of 1:24,000 scale photography is that the minimum mapping unit detectable is approximately 1/8-acre or a 75ft by 75ft ground feature. This means that ground features smaller than this size will generally be missed. Some aspects of seagrass health cannot be definitively assessed at this scale of photography (e.g. marginal, recovering seagrass beds currently in Galveston Bay or damage to beds in Redfish Bay from propeller scarring). Indeed, this “1:24,000 scale mapping” should be distinguished from landscape monitoring (below) despite the common data source from remotely sensed aerial imagery. The mapping technique would be used primarily to establish the presence or absence of seagrass beds above a minimum size of 1/8-acre on a coastwide basis. Mapping also implies a static condition, whereas monitoring in this case implies the capability of detecting dynamic changes over short time periods, such as over a single growing season (3-4 months perhaps). For detection of spatial changes and landscape patterns indicative of sublethal stress, the resolution required for landscape analysis is a photographic scale of at least 1:9,600.

II. Landscape Monitoring of Seagrass Health

Landscape Model for Seagrass Impacts

Landscape dynamics indicators are recommended as essential components of seagrass monitoring programs, although such indicators should be integrated where possible with microscale processes and field survey data (Neckles 1994, Dobson et al. 1995). An ecosystem model for Texas seagrass dynamics is proposed that explains macroscale changes in seagrass bed morphology and spatial patterns as responses to environmental stressors, just as individual plants show responses to stressors (i.e. processes) on a microscale (Pulich et al. 2003). These spatial features and landscape patterns are considered to reflect large-scale habitat responses integrated over time. Such responses would be considered indicative of sublethal stress, perhaps presaging changes in or disappearance of an entire seagrass bed. Observation of landscape change or spatial impacts over a large seagrass area indicates that stress processes are at work affecting the entire seagrass plant community, and conversely, that stress is not localized in one area (Robbins and Bell 1994' Fonseca 1996). Such parameters as seagrass species succession, the abundance of macroalgae (seaweeds), spatial distribution of vegetation in deep or light-limited water, overall bed patterns (patchiness or fragmentation features indicating disturbance processes), and temporal variations in plant cover (change or trend dynamics), represent examples of these types of holistic landscape seagrass bed indicators.

In other coastal states, seagrass monitoring protocols are based on a similar model of remote sensing coverage closely integrated with intensive ground surveys. These intensive monitoring surveys range from establishing preselected (fixed) field transects, to conducting probabilistic, random sampling of seagrass bed stations in photographed areas. Florida has proposed monitoring of "sentinel" target seagrass sites that are of major concern for conservation. (see Greening 2002.) The Florida Seagrass Working Group has identified a number of "target" or problem sites where seagrass loss is occurring, as well as "reference sites where seagrasses have remained stable or are increasing." Field monitoring in the Indian River Lagoon of Florida relies on fixed transects for target sites (Morris et al. 2000). Scanning and archiving electronic photoimages of historic and existing seagrass beds is recommended. Washington State (Norris et al. 2000) combines both underwater video surveys and diver transects to monitor eelgrass (*Zostera*) beds. This program is particularly concerned with dynamics of deepwater eelgrass and impacts to eelgrass from dredging and other shallow water disturbance. For Chesapeake Bay Estuary Program projects, submerged aquatic vegetation (SAV) has been monitored aerially for many years, but at the 1:24,000 scale to determine status and trends (Orth and Moore 1983).

Remote Sensing Data Sources and Scale Issues

Aerial remote-sensing media (e.g. color aerial photography or multispectral imagery) can readily provide the data to detect these macroscale (i.e. landscape) responses if the resolution and temporal frequency are sufficient. Recent evaluation of sampling scale (Robbins 1997, McEachron et al. 2001, Dunton et al. 1998) indicates that seagrass sites may be photographed with 9" x 9" film at 1:9,600 or larger scale, capable of detecting 1 ft. minimum ground feature changes in seagrass landscapes. This includes bed fragmentation features, species discrimination, or seagrass bed changes along the shallow- to deep-water gradient.

In the case of seagrass monitoring using 1:9600 scale or larger photography, computer processing techniques now allow for image analysis of spatial (i.e. landscape) features from digital imagery. The resolution, contrast, and color signatures ultimately determine the most effective aerial remote sensing data. Recently, high-resolution airborne digital imagery (multispectral and hyperspectral scanner data) has become available (Mumby and Harborne 1999), but acquisition costs and area of coverage are still prohibitive for routine monitoring projects. However, with today's advances in digital scanning and color processing technology, true color aerial photography is most affordable and produces more than sufficient data, based on TPWD's experience with test projects (see Figure 4-1). The key requirement is still the basic need for high quality, clear aerial photography obtained under almost ideal weather and calm water conditions (Ferguson et al. 1993). Once available, this type of photography can be scanned using a high-resolution digital scanner to provide the 1-2 ft. feature resolution. The scanned photography or digital imagery can then be processed to identify and delineate various features. These features are then subjected to spatial analysis using image processing or GIS/geostatistical software programs (Robbins 1997). In special regulatory cases or as part of experimental studies, the need for hyperspectral imaging data may justify the increased costs of this technology.

Landscape Sampling Grid Design for Texas Estuaries

The design of a landscape sampling scheme requires foremost consideration of monitoring objectives to select critical target sites. Strictly random sampling of seagrass landscapes does not lend itself to most desired monitoring applications. Trend analysis, for example, requires fixed phototargets so that aerial photos can be taken at the same seagrass sites at different points in time. As discussed earlier, in Section 2, a number of priority monitoring objectives focus on detecting seagrass stress or impacts to seagrass health from factors such as:

- Water quality degradation
- Physical/mechanical destruction by dredging or prop scarring
- Natural (storms, climatic) events vs. anthropogenic impacts
- Disease

Evaluating these disturbance factors along the Texas coast leads to the question of how to monitor the landscape so as to best detect the resulting seagrass impacts.

Water quality stressors often produce effects along a gradient, emanating from the suspected source of a discharge or runoff of materials. Often, the gradient may consist of nutrients (dissolved or particulate organics), light attenuating matter (suspended solids like dredged sediments, color material, phytoplankton blooms, etc.), or discharges of toxic/pollutant compounds. This geographic gradient lends itself to targeted landscape sampling monitoring; discrete sites can be chosen based on a scientific rationale for the gradient. In some cases, the source of the impact would serve as the focal point for designing the gradient of seagrass landscape sampling. In other cases, the depth gradient may serve as the guiding factor for sampling locations.

Using the Florida and Washington programs as a guide, there is considerable merit in establishing key "target" sites in Texas estuaries for landscape monitoring using high resolution aerial photography. A number of potential seagrass areas along the Texas coast are currently considered susceptible to large scale, incipient impacts from water quality degradation and nutrient loading. From earlier studies, sites have been identified in West Galveston/Christmas Bays, Aransas/Redfish Bays, Corpus Christi/Redfish Bays, and Upper and Lower Laguna Madre which may be experiencing such impact (Pulich et al. 1997, Dunton et al. 1998, Onuf 1994). By considering the known location of seagrass beds in these bays, it is reasonable to select "target" sites for landscape monitoring in proximity to suspected sources of runoff materials, or along a gradient of anthropogenic stress (e.g. extending from developed mainland areas toward the less-developed barrier islands, or following along water circulation and flow patterns in the bays). Corresponding reference sites for these "target" sites must also be selected where no impacts are expected; and then landscape indicator differences can then be compared and evaluated among the sites using high resolution aerial photography. Statistical analysis of landscape patterns is achieved based on random subsampled areas, nested within the original "target photograph" area.

As part of our current strategic planning exercise, two bay systems have been identified for establishing landscape sampling "phototarget sites" focused on the objective of water quality impact assessment. The Seagrass Monitoring Workgroup has proposed a landscape sampling design for two problematic estuaries on the middle and lower Texas coast: the Coastal Bend bays near Corpus Christi and the lower Laguna Madre (Figures 4-2 and 4-3). The hypothesis for locating these phototarget sampling sites is based on suspected gradients of nutrient loading from anthropogenic sources and subsequent impacts to seagrass areas. Phototarget sites were selected from a grid corresponding to the "footprint" of 9" x 9" 1:9,600 scale aerial photos, each of which covers a ground area of 2.2 km x 2.2 km or 4.84 sq. kms. When this photogrid was overlaid onto the known distribution of seagrass in the Coastal Bend bays or Laguna Madre systems, 17 potential phototargets of this size were located in each system. While these targets are fixed monitoring sites, they do in fact provide coverage of a large fraction (approximately 20% to 33%) of the entire seagrass acreage in each bay system.

As shown in Fig. 4-2 of the Coastal Bend area, six seagrass photosites in Redfish Bay may contrast with reference sites in Harbor Island and Aransas Bay because of the proximity of Redfish Bay to anthropogenic disturbances from mainland urbanization. Recent studies have suggested substantial fragmentation of seagrass beds, and changes in species composition in these beds, along the mainland; but these areas need regular monitoring to determine the temporal trends and longevity of changes. Sites in Corpus Christi Bay along Mustang Island are also expected to show increasing impact over time from shoreline development along this resort barrier island. Similarly, several sites in upper Laguna Madre are especially close to resort development on North Padre Island. Discharges from the channelfront developments may impact seagrass in this part of the upper Laguna Madre.

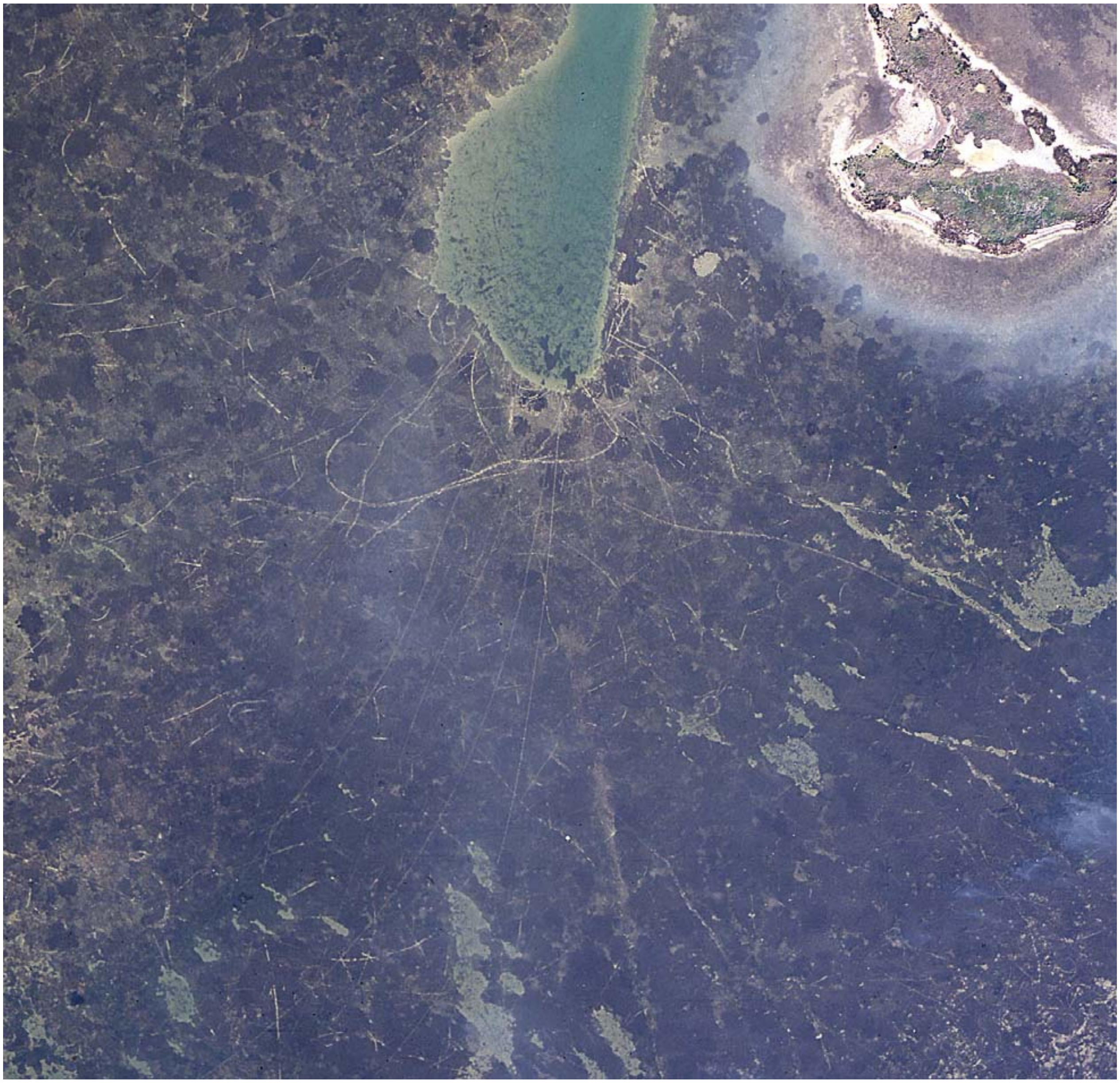


Figure 4-1a. Photograph of Terminal Flats, Redfish Bay, Texas, taken December 8, 2000. Scale 1:4800. Identifiable features are: turtlegrass areas, shoalgrass areas, bare bottom patches, propeller scars, deepwater channels, and patches of drift algae.

Figure 4-1b. Photograph of Terminal Flats, Redfish Bay, Texas, taken December 20, 2001. Scale 1:4800. Compared to Fig. 4-1a, this photograph taken a year later shows an increase in bare bottom patches corresponding to a decrease in shoalgrass and turtlegrass.

Fig. 4-2. Coastal Bend Region 1:9,600 Photo Monitoring Sites

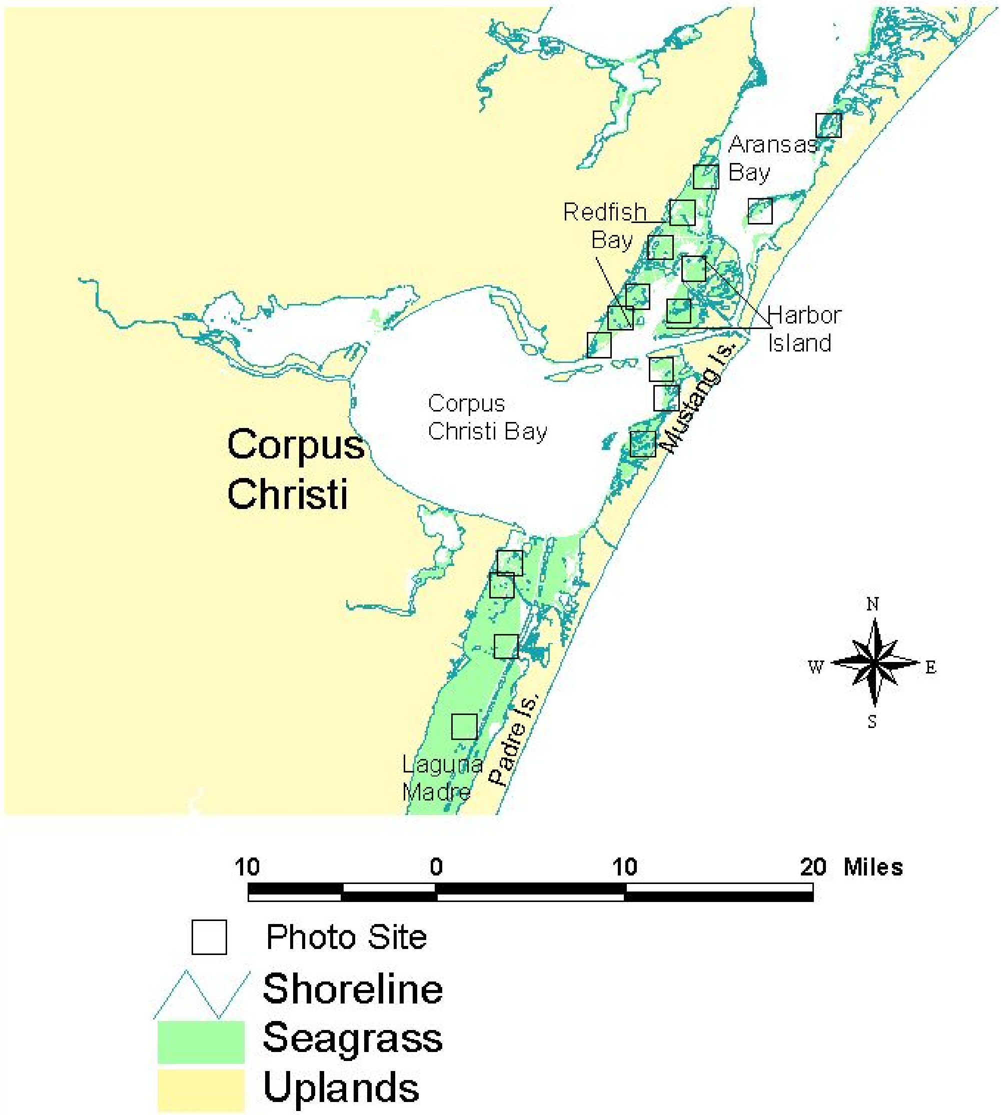
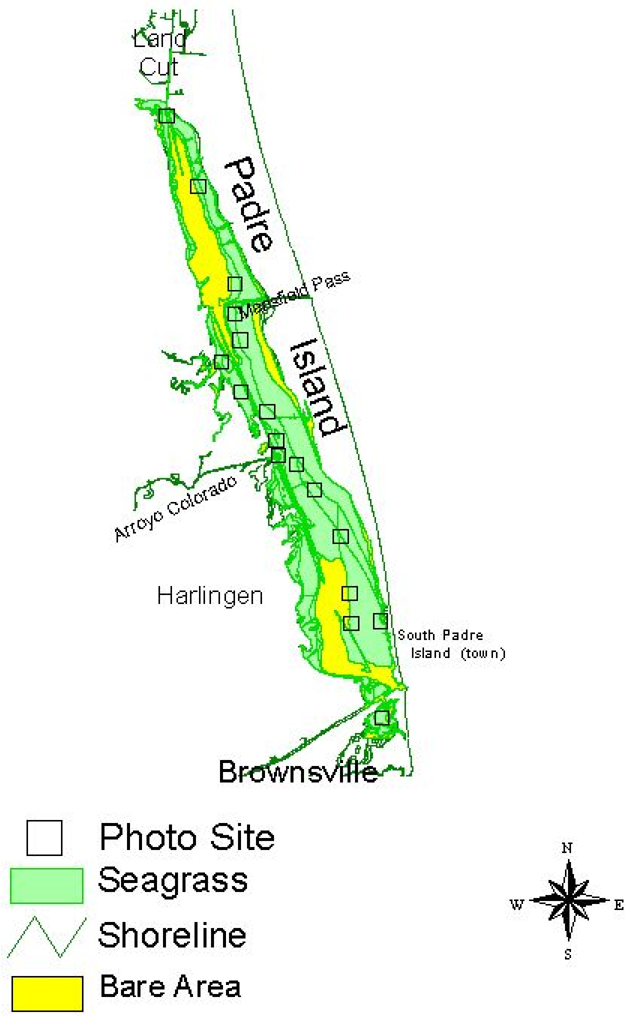


Figure 4-3. Lower Laguna Madre 1:9,600 Photo Monitoring Sites



As shown in Fig. 4-3 for the lower Laguna Madre, sixteen photomonitoring target sites are situated along the northward gradient of urban development and water quality discharges in this lower coast system. Several photosites near residential areas on South Padre Island and around Port Isabel may reveal localized seagrass impacts from wastewater treatment discharges, septic systems, and shrimp farms. These types of environmental stresses have been increasing greatly in the southern portion of the lower Laguna over the last 20 years. A reference photosite placed in South Bay near Brazos Santiago Pass should reflect pristine conditions of this protected Coastal Preserve. Other Laguna sites in the vicinity of the Arroyo Colorado (in the middle portion of the lower Laguna) may show seagrass impacts correlated with the water quality gradient produced by this drainage. A measurable nutrient discharge gradient is expected to extend northward from the Arroyo towards Port Mansfield, but should then disappear to the north of Mansfield Channel. This is due to the water circulation pattern in the lower Laguna, which is restricted from Port Mansfield towards the Land Cut, and predominantly flows out into the Gulf through Mansfield Pass. A decreasing gradient of impacted seagrass sites may extend north from the mouth of the Arroyo towards Port Mansfield. Several sites found north of Mansfield Channel are selected for monitoring as reference sites and predicted to be less impacted.

Landscape Indicators of Seagrass Ecosystem Health

The derivation of landscape monitoring criteria for assessing seagrass health is proposed using remote sensing classification procedures specialized for seagrass communities and spatial data analysis techniques (Pulich et al. 2003). Under proper conditions, digital color imagery has been shown to be amenable to the application of image processing techniques to accomplish classification analyses on emergent vegetation and marine habitats, including coastal plant identification (Everitt et al. 1999) and seagrass/coral reef associations (Mumby and Harborne 1999, Maeder et al. 2002). When similar spectral analysis procedures are applied to seagrass ecosystems, discrimination of landscape features such as seagrass species composition, macroalgae accumulations, and bare patch distributions (spatial bed patterns) within seagrass beds is also achievable. By linking intensive ground survey data based on high precision GPS points to such classified seagrass landscape coverages, landscape indices (analogous to bioindicators) which describe ecosystem health will be developed with geospatial analysis software (eg. ArcInfo, Landstats, ERDAS and ESRI Geospatial Analyst).

TPWD staff have collaborated with the US Department of Agriculture (USDA), Remote Sensing Research unit, at Weslaco, Texas to develop image processing techniques for classifying these simple landscape features in seagrass beds from color aerial photography (W. Pulich, R. Fletcher and B. Hardegree, manuscript in preparation). Figs. 4-1a and 4-1b provide examples of the type of feature discrimination that is possible when this technique is applied to properly enhanced, digital photography. The preliminary image analysis work has tentatively resolved a variety of seagrass meadow classes using ISODATA maximum-likelihood clustering algorithms and manual masking techniques. Feature classes separable in these two large scale photos include two dominant seagrass species (*Thalassia* and *Halodule*), macroalgae accumulations, bare bottom patches, and linear features in the grassbeds (prop scars and pipe lines). Photography taken in year 2002 from two sites in Redfish Bay is currently being analyzed to verify the accuracy of classification techniques developed on the photographs from the previous 2 years. This requires checking 20-30 GPS points (at +/- 1 m spatial accuracy) per feature class to conduct a statistical accuracy assessment. Qualitative results thus far indicate the protocol developed is close to meeting the desired 85% accuracy goal specified for such standard image classification procedures (NOAA-CSC 2001), and only minor refinements in protocol appear necessary.

Further investigations need to be conducted to assess patterns in the seagrass landscape, either of seagrass patches or bare areas within the grassbeds. Other studies have demonstrated statistical relationships between changes in seagrass landscape structure and biomass and various environmental factors such as siltation, currents, or competition from other species (Terrados et al. 1997, Vidondo et al. 1997). Extrapolating from these spatial landscape patterns, calculation of patch statistics, edge metrics or other landscape bioindices (species distribution patterns) should be attempted (Heggem et al. 1999; Robbins and Bell 1994). Specialized GIS software techniques (e.g. kriging) are also available to perform data manipulation and spatial statistical analysis of environmental parameters collected at discrete sampling points, for example water quality or light depth zones produced by contouring point sample data (Lathrop et al. 2001). When such polygon data derived from point samples of environmental parameters are overlaid onto spatial seagrass coverages (distribution) or classified features, spatial correlations may be determined. An urgent research objective is to derive quantitative relationships between environmental quality parameters associated with degrading seagrass landscape patterns. In this way, landscape indices (i.e. metrics) are anticipated that reflect seagrass habitat impacts due to water quality stressors, physical disturbances, or natural environmental factors (Dan Heggem, EPA-ORD, Landscape Ecology Branch, personal communication).

SECTION 5: DATA MANAGEMENT SYSTEM

This section discusses essential data management system elements of the coastwide seagrass monitoring program including:

1. Collection and compilation of the major datasets
   a. Habitat distribution and landscape features of beds.
   b. Species occurrence.
   c. Vegetation abundance and phenology parameters.
   d. Physiological parameters, tissue composition, etc.
   e. Abiotic site parameters (water, sediment, climatic, etc.)
   f. Non-seagrass biotic measurements (epiphytes, macroalgae).
2. Custodial responsibility for databases
   (Storage and QA/QC maintenance of monitoring data; designated custodial agencies)
3. Data clearinghouse and web-based linkage of databases
   (How datasets are distributed/accessed on a network or the Internet)
4. Database format and software considerations (GIS, database programs, data standards, etc.)

Basic to this Plan is the design and establishment of a multifunctional data management system (DMS) for compiling, storing, maintenance and distribution of seagrass monitoring datasets. As described in the previous section, the datasets include seagrass distribution maps and landscape data (mainly vegetation patterns and areal coverage), quantitative vegetative and habitat ecological parameters, water and sediment quality data, and other ancillary coastal and hydrographic data. A basic prerequisite is that all monitoring data must be spatially referenced (georegistered) when collected, thus making it amenable to storage or analysis in a GIS database. Differential GPS should be the main method used if possible; otherwise sites must be located precisely on a USGS 7.5' map.

The environmental and biological data collected through surveys, monitoring programs, or by special studies need to be compiled into an information management system for ready access and analysis of data using a clearinghouse approach. In order to accomplish this, a specially maintained DMS will be developed and established by the three State resource agencies (TPWD, TGLO, TCEQ). Although monitoring data may be sampled and collected by other groups, particularly research scientists, these State entities are identified as the appropriate custodians for coordinating storage of the identified coastal monitoring information. This arrangement can best assure quality control and upkeep of relevant datasets. A clearinghouse system should be designed specifically to provide convenient access and integration of the data by state or federal agency managers and regulators, and research scientists.

Data Management Issues for the Seagrass Monitoring Program:

1. The Monitoring Workgroup agreed that management of seagrass monitoring data is an appropriate function of the three state agencies with coastal resource management and conservation responsibilities: TPWD, TGLO, and TCEQ. While other entities such as university researchers, contractors for agencies (state or federal), estuary programs or nongovernmental organizations might collect such data, the function of compiling, storing, and distribution of such data should be centralized under the three state agencies to assure format, consistency, quality control, and certification of the datasets. This ultimately meets the management objectives of these agencies for monitoring seagrass, and also provides the public and other government agencies access to the datasets.

2. The three agencies serve as custodians for specific types of datasets based on their respective missions. TPWD will continue compiling and maintaining seagrass distribution maps and landscape data, including digital photography and imagery. To the extent possible, it will maintain the necessary biological database containing ancillary information on seagrass vegetation parameters, other ecosystem flora and fauna, and estuarine biological processes. GLO will continue to maintain coastal infrastructure and base map datasets as used for Coastal Management and Oil Spill Response Programs. GLO and TPWD will leverage State resources and coordinate in obtaining future coastal aerial photgraphy datasets to monitor seagrass distribution. TCEQ will maintain coastal water and sediment quality monitoring data, as part of their Surface Water Quality Monitoring Program. USGS water data and various NOAA datasets could also be included. Although not previously mentioned, TWDB maintains hydrologic and tide datasets for bays and estuaries.

3. All datasets will be in a georegistered format, such that they can be easily manipulated and analyzed with GIS software (assume ESRI/ArcInfo compatible). Other general guidelines may be developed concerning database format to be followed, parameter fields, etc. The question of QA/QC requirements for compilation and maintenance of water quality/chemical parameters or seagrass biological datasets must be addressed. What criteria must be met for such data to be certified for inclusion in the TNRCC or TPWD databases? In the case of monitoring data collected by research scientists, a standardized quality assurance system must be followed prior to conducting sampling surveys. TPWD and TCEQ will define criteria that must be met in order for data to be included in their databases, irrespective of source.

4. An efficient, user-friendly distributed clearinghouse system will be developed to allow remote access to these custodial datasets. This could necessitate one agency assuming major responsibility for the server system development, with Internet links to other sites (at a minimum TPWD, TGLO, TCEQ and TWDB) where data resides for downloading.

Development of Prototype DMS and Clearinghouse

Under this plan, the TGLO, TPWD, and TCEQ support developing an integrated clearinghouse and DMS. TPWD GIS staff have already begun preliminary evaluation of a coastal monitoring data clearinghouse to perform seagrass assessments, and linkage of databases through a web-based server system. The relevant seagrass databases are actually seen as parts of major existing databases in the two agencies, TPWD and TCEQ. The TCEQ already maintains the TRACS Database for surface water quality monitoring (SWQM), and TPWD is organizing its seagrass distribution maps and imagery datasets into a departmental Resource Information System (RIS).

The Steering Committee proposes the following distributed data model system to access seagrass monitoring data. In this model, water quality data housed at TCEQ, seagrass data from TPWD, and other coastal data from TGLO, will be combined at the application level. For such a system to be successful, data providers must agree on data formats, access protocols, documentation and quality. Implementation of technologies such as ESRI's ArcIMS will require that participants coordinate closely to insure maximum interoperability and compatibility of the data at the application level. Additionally the data management system will be multi-tiered, supporting a wide range of end user applications from desktop GIS and statistical analysis packages to Web browser based data query tools. It is anticipated that most users will access data through the Internet as well as local ESRI trusted clients. Database access may be provided via ArcIMS map services, data extraction applications, FTP access, data mirroring, or through ODBC access.

Following from above, how should specific datasets be housed and shared? For example, it may be best to provide seagrass coverages through ArcIMS map services rather than through FTP access. Alternatively, if users require raw data for spatial analysis, shape files or coverages could be provided through FTP or through data streaming (feature map services) or ArcIMS extract servers. Water quality data may require replication or access through proprietary TCEQ applications and-or ArcIMS map services.

Data providers will be required to provide FGDC compliant (Federal Geographic Data Commission) metadata for all included data sets (FGDC 2003). Such metadata must also be easily accessible. Accordingly, data custodians will consider providing metadata through establishment of metadata servers or by providing metadata to a central repository, such as a seagrass-specific metadata server hosted by TPWD or another data custodian.

As a proof of concept, TPWD GIS staff have developed a web-based implementation of a distributed data-sharing tool using ESRI's ArcIMS technology. A map service was created for internal use that combines TPWD's seagrass data with SPOT 10m imagery and digital orthoquad maps (DOQs) served from TNRIS, as well as a water quality map service from TCEQ. The application allows the user to create dynamic maps of seagrass while accessing water quality data from TCEQ that may be relevant to specific seagrass areas of interest. This pilot project clearly demonstrates both the strengths and weaknesses of such a data distribution approach. Further discussion of operations development will be required by agency staff to address issues pertaining to data quality, security, and data access or downloading.

Future application development will focus on facilitating assessment and monitoring of actual or potential environmental impacts to seagrass. Accordingly, access to water quality information, both current and historical, will be critical to this effort. Specific end user needs must be addressed, as well as opportunities to leverage existing web-based applications such as TCEQ's Texas Surface Water Quality Viewer. Consideration of the end user needs will greatly determine the conceptualization, application development, and implementation of logical and physical data models for this project.

SECTION 6: IMPLEMENTATION OF MONITORING

For seagrass monitoring to effectively achieve these proposed resource protection objectives, long-term commitment to an organized field sampling and data collection program is necessary at the state management level. Field and landscape sampling designs have been briefly described in this document, but now a formal coordinated program must be set up to begin monitoring on a regular coastwide scale. Potential participants have been identified and contacted as part of this planning process; and they have indicated willingness to assist in conducting seagrass monitoring in an organized, standardized approach. If the commitment is made by the three resource agencies to dedicate appropriate staff and infrastructure (technology and equipment), the program can be initiated at a modest level. Long-term funding for data collection can then be sought within departmental budgets or through outside grants from other coastal management programs (especially the NOAA Coastal Zone Management Program).

As discussed earlier, the details of field sampling design and seagrass health indicators are tentative, since a definitive final monitoring protocol is still under research and development. Evaluation of study results must be performed upon completion of R-EMAP and other projects, in this way accurate, feasible indicators and protocols will be selected for sampling, consistent with the requirements of both, robust statistical data, and cost effectiveness. The field indicator data must also be properly integrated with aerial photography (landscape) data to enhance the efficiency and scale of monitoring coverage with limited resources. This process for evaluating and selecting seagrass health indicators will need to balance the science and management needs of the program. In addition, merely collecting the field data or aerial imagery on seagrass ecosystems will be insufficient without a proper data management structure for accessing, analyzing, and utilizing the data in state management and conservation programs. Thus an immediate action of the program is to establish a database system to compile, maintain and distribute the existing and anticipated, quality-assured seagrass data for use by resource managers.

Recommendations

These tasks especially, represent critical steps in the implementation of the monitoring program. The following recommendations offer a practical approach for implementation which is envisioned to occur in stages.

The first stage in plan implementation is to develop an MOU between the three agencies (TPWD, TCEQ, and TGLO) that proceeds to formally initiate the Seagrass Monitoring Program according to this Strategic Monitoring document. Initial priority actions that the MOU would address are:

1. Set up a formal 3-agency work group responsible for coordination of the Program that will oversee the actual seagrass and environmental monitoring as outlined under this document. Designate the functional

programs in the agencies whose participation is necessary to deal with primary implementation issues.

2. Establish an integrated data management system.
   This involves identifying custodial agency databases and the responsibilities for data compilation, ranging from the criteria for data standards and formats, QA/QC requirements, and database maintenance procedures. Coordination between TCEQ and TPWD will need to take place with appropriate data management and programmatic staff, to decide integration issues for SWQM and seagrass GIS databases. It also includes developing a web-based server application, for accessing and analyzing the seagrass data.

3. Evaluate technical data on seagrass health indicators upon completion of R-EMAP and other studies. In collaboration with Seagrass Monitoring Steering Committee, finalize the field sampling design and seagrass indicators to be used for coastwide monitoring. This design work will focus initially on coastal water quality and other environmental assessment applications dealt with by the three state resource agencies.

4. Start planning for the incorporation of seagrass monitoring data into the water quality assessment process. This task will focus on the eventual application of monitoring data in the management process which leads to establishing water quality criteria that protect seagrass propagation as an aquatic life use.

Under this MOU, the three agencies can then proceed as soon as practicable to a second stage. Actions will include:

1. Identify or seek funding to set up and establish the coastwide field sampling scheme.

2. Develop an organized sampling program to acquire high resolution aerial photography for lower Laguna Madre and the Coastal Bend based on the landscape sampling scheme proposed herein.

3. Solicit or develop proposals from identified program participants (see listing below) for intensive field survey projects (actual monitoring and **a**ssessment, as well as research projects).

Potential Participants in Monitoring Program and Area of Expertise (based on Attendee List from August 2000 Workshop)

- *US Geological Survey (National Wetlands Research Center) and TPWD (map seagrass distributions and conduct status and trends studies)*
- *University of Texas Marine Science Institute (monitor environmental effects on seagrass vegetation based on productivity and growth models; evaluate statistical field sampling design; determine impacts to seagrass community ecosystem)*
- *TPWD (coordinate remote sensing monitoring; maintain GIS database of seagrass landscape data; initiate a web-based data distribution system for linking seagrass databases)*
- *TCEQ (Surface Water Quality Monitoring Program and Water Quality Assessments Program) (modify TRACS database and oversee storage of official seagrass water quality and environmental data for coastal areas)*
- *TGLO (Coastal Division) (provide monitoring support for data acquisition in coastal areas as part of coastal management programs)*
- *USFWS (support monitoring of seagrass restoration and habitat conservation projects through Coastal Ecosystems Program)*
- *Texas A & M University (develop models to support monitoring of effects from light reduction or other stressors on seagrass productivity and growth).*
- *National Marine Fisheries Service (perform and evaluate seagrass restoration projects through long-term monitoring)*
- *Coastal Bend Bays and Estuary Program; Galveston Bay Estuary Program (coordinate and fund regional seagrass monitoring)*
- *USEPA – Region 6 (Office of Wetlands Protection and Water Quality Assessment)(provide technical support and facilitate monitoring projects through regional environmental programs)*

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