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INDICATOR DEVELOPMENT: SEAGRASS MONITORING AND RESEARCH IN THE GULF OF MEXICO. REPORT OF A WORKSHOP. HELD IN SARASOTA, FLORIDA ON JANUARY 28-29, 1992

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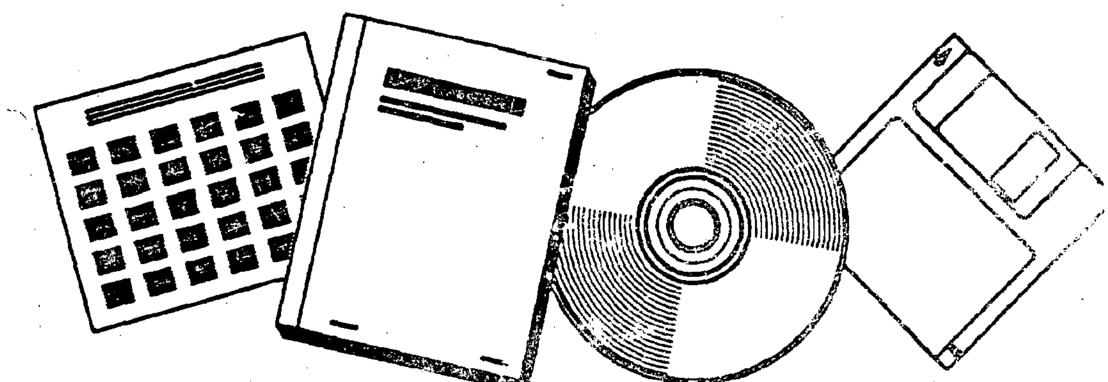

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16. ABSTRACT

Seagrass habitats in the Gulf of Mexico have declined precipitously during the past 50 years. Most habitat losses can be attributed to effects of coastal population growth and accompanying municipal, industrial, and agricultural development. Although proximate causes of local declines can sometimes be identified, the majority of habitat loss has resulted from widespread deterioration of water quality. Restoration and preservation of these important habitats depend foremost on improving scientific understanding of the complex causal relationships between anthropogenic stress and seagrass ecosystem persistence, and on developing scientifically based management programs for seagrass conservation.

On January 28-29, 1992, approximately 60 researchers, State and Federal regulators, and environmental managers met at Mote Marine Laboratory in Sarasota, Florida, to address monitoring strategies, research programs and mapping of submerged aquatic vegetation resources in the Gulf of Mexico. This report summarizes the results of the workshops, emphasizing the recommendations of participants in an attempt to guide development of a comprehensive seagrass conservation program in the Gulf of Mexico.

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Indicator Development:

Seagrass Monitoring and Research in the Gulf of Mexico

Report of a Workshop Held
at
Mote Marine Laboratory
in
Sarasota, FL

January 28-29, 1992

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PREFACE

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INTRODUCTION

Seagrass habitats in the Gulf of Mexico have declined precipitously during the past 50 years. Most habitat losses can be attributed to effects of coastal population growth and accompanying municipal, industrial, and agricultural development. Although proximate causes of local declines can sometimes be identified, the majority of habitat loss has resulted from widespread deterioration of water quality. Restoration and preservation of these important habitats depend foremost on improving scientific understanding of the complex causal relationships between anthropogenic stress and seagrass ecosystem persistence, and on developing scientifically based management programs for seagrass conservation.

On January 28-29, 1992, approximately 60 researchers, State and Federal regulators, and environmental managers met at Mote Marine Laboratory in Sarasota, Florida, to discuss strategies for monitoring the environmental status of seagrass habitats and to determine the research needed to increase our knowledge of seagrass responses to anthropogenic stress. The workshop was sponsored by the U.S. Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service, and the National Oceanic and Atmospheric Administration. The goals of the workshop were to provide technical guidance on monitoring requirements to the EPA's Environmental Monitoring and Assessment Program-Estuaries and to assist in the development of a coastal wetlands research program at the EPA's Environmental Research Laboratory-Gulf Breeze. In addition, the workshop provided a forum for coordinating research and monitoring activities among government agencies, universities, and private organizations with interest and mandates in the protection of submerged aquatic vegetation (SAV) resources in the Gulf of Mexico.

EMAP-Estuaries is designed to characterize the ecological condition of the nation's estuarine and coastal resources over broad geographic regions and long time periods. The program is intended to provide quantitative information on the extent and potential causes of adverse environmental changes. In an effort to provide one indicator of nearshore environmental quality, EMAP-Estuaries is mapping the location and extent of SAV in the coastal region of the Gulf of Mexico. All maps are scheduled to be completed in 1995. Baseline information on the distribution and abundance of SAV will then be used to develop a monitoring program to assess the status and trends of these habitats. This assessment will be based on measurement of defined parameters that serve as indicators of SAV habitat quality. The workshop developed recommendations for SAV mapping, classification, and monitoring in the Gulf of Mexico, and identified a set of ecological indicators for accurate assessment of SAV habitat condition.

The EPA Wetlands Research Program included funding in 1992 for the initiation of coastal wetlands research. The EPA Science Advisory Board recommended that initial research be conducted on the effects of cumulative impacts within watersheds on coastal SAV communities. The workshop identified and prioritized research needs to develop a pilot project and a future EPA Coastal Wetlands Research Initiative on a national scale. As a result of this workshop a study of seagrass responses to long-term light limitation was initiated at three field sites in the Gulf of Mexico.

Following introductory presentations on EMAP, the Wetlands Research Program, and the state of current knowledge of seagrass environmental requirements, workshop participants divided into three working groups to address the workshop objectives: seagrass mapping, ecological indicators, and research needs. At the end of the workshop, participants reorganized into four working groups, each charged with developing a list of the highest priority actions for preservation and restoration of seagrass systems. The working groups reconvened periodically in plenary sessions to report conclusions, solicit input from other workshop participants, and to integrate and synthesize recommendations. This report summarizes results of the workshop, emphasizing the recommendations of participants in an attempt to guide development of a comprehensive seagrass conservation program in the Gulf of Mexico.

RECOMMENDATIONS

Knowledge of seagrass systems and our ability to preserve and restore these important habitats will be advanced most effectively through the integration of mapping, monitoring, and research across a range of spatial and temporal scales (Fig. 1). Specific recommendations within each of these components of a comprehensive seagrass conservation program are listed below.

MAPPING

All maps should be produced at a scale of 1:24,000 to conform to the standard of U.S. Geological Survey topographic quadrangles.

Maps should be developed from aerial photographs combined with extensive concurrent field ground-truthing. A minimum list of ground data to verify photointerpretation includes submerged aquatic vegetation (SAV) species present, confirmation of the signature identification, nonvegetated features, and location. Other data that can be collected during ground truthing yet are not critical to map verification may either assist in photointerpretation or make the map more useful. These data include SAV density, water depth, presence or abundance of epiphytes and macroalgae, evidence of prop scars, sediment type, turbidity, and salinity.

Global Positioning System technology should be used whenever possible during routine collection of SAV field data to provide true locations for correlation with historical, present, and future maps.

SAV beds should be stratified for Environmental Monitoring and Assessment Program (EMAP) sampling based on geomorphic type: hypersaline lagoons, estuaries, open coastal, and deltaic formations. To ensure equal representation within geomorphic strata a second tier of sampling stratification should be introduced, based on bed size, water depth, and surficial sediment type.

Mapping of the Louisianan Province should be repeated every four years to assist other SAV monitoring, to ensure the repeatability of sample locations, and to establish long-term trends in SAV distribution and abundance.

ECOLOGICAL INDICATORS

Various parameters reflecting SAV responses to environmental stressors can be measured to quantify the ecological condition of the habitat. Response indicators fall into three classes, according to their readiness for incorporation into a long-term monitoring program:

- Parameters that are ready for implementation - macrophyte depth limit, shoot density, aboveground and belowground biomass, species composition of SAV and macroalgae;
- Parameters for which field evaluations are necessary to define temporal and spatial variability and to further characterize relationships to multiple environmental stressors - algal biomass, leaf width, plant constituents, stress proteins, grazer densities;
- Parameters dependent on newly available technologies that with, significant additional development, might be important future ecological response indicators - leaf area index measured with an automatic meter and genetic diversity using DNA fingerprinting.

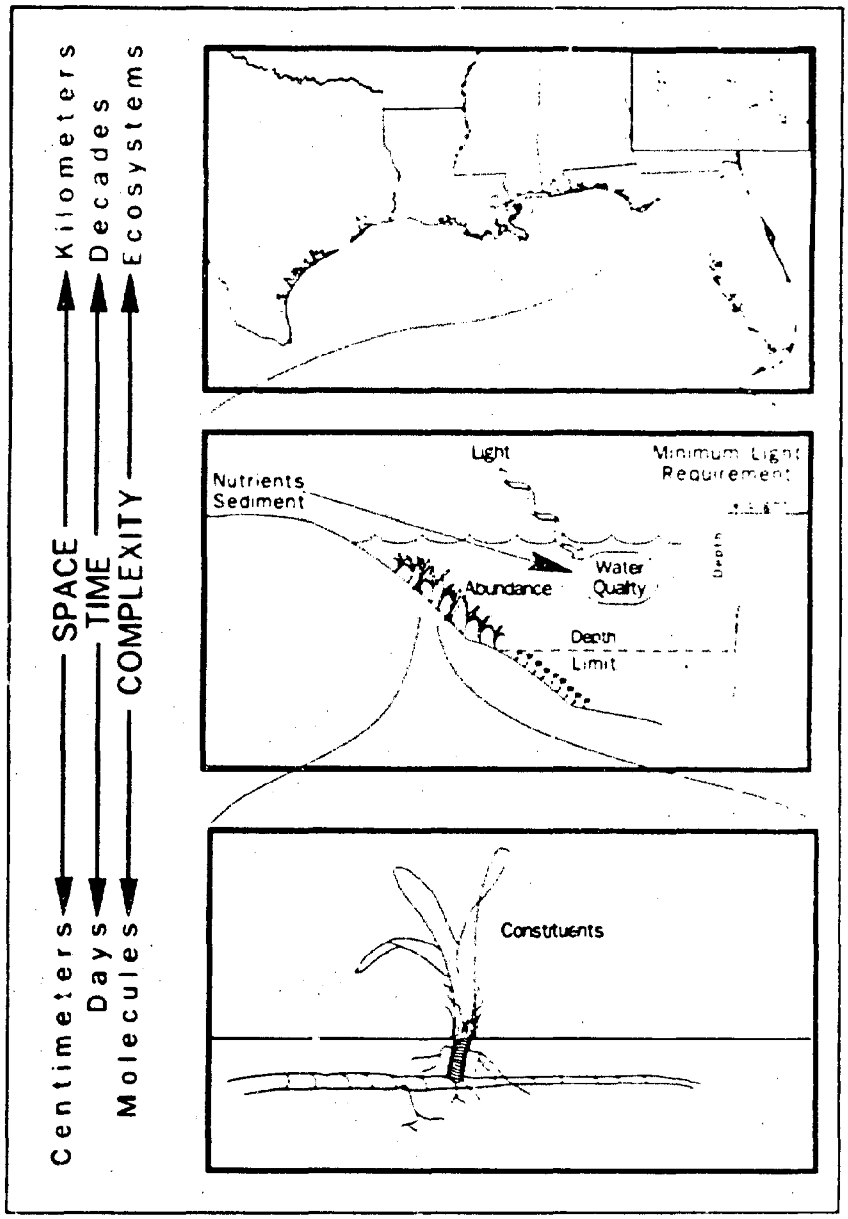

Figure 1. Integration of mapping, monitoring, and research into a comprehensive program for seagrass conservation in the Gulf of Mexico. Each component must consider scales in space, time, and ecological complexity.

None of the proposed response indicators have been tested at the regional and decadal scales used by EMAP. Seagrass beds are dynamic, complex systems, and many of the parameters used to characterize habitat condition, therefore, exhibit considerable temporal and spatial variability. We recommend strongly that the EMAP network be supplemented with increased sample density at selected sites. The ability to detect change from widely spaced samples taken annually must be validated before meaningful statistical confidence can be placed in the use of the proposed indicators to assess regional long-term trends in seagrass ecosystem health.

The most important parameters to measure as indicators of the extent of pollutant exposure or habitat degradation present in Gulf of Mexico seagrass systems are water column light attenuation, turbidity, chlorophyll concentrations, dissolved nutrient concentrations, and diel fluctuation in dissolved oxygen concentrations. All of these exposure indicators exhibit extreme temporal variability, so that single, annual samples would yield no useful information. To provide the needed data, exposure indicators must be evaluated either from frequent sampling or from continuous monitoring at permanent stations.

Although the proposed indicators exhibit general relationships with habitat quality, threshold values separating desirable conditions from undesirable ones cannot be identified for any of the variables. Research is needed to better define and validate criteria for interpreting specific values of candidate response and exposure indicators in terms of ecosystem health.

RESEARCH NEEDS

Research is needed to determine the species-specific minimum light requirements for long-term persistence and restoration of subtropical seagrasses.

Assessment of the responses of seagrass communities to environmental stresses (e.g., light quantity and quality, nutrients, sediment loading, salinity, temperature) is needed to better project the effects of environmental management strategies. This area of research should examine potential changes in seagrass species, productivity, genetic diversity, and reproductive success in response to these parameters. The roles of macroalgae and epiphytes in these changes and the potential complicating effects of plant-animal interactions should be evaluated.

Available maps should be used as a research tool rather than simply as an assessment method. Information on seagrass distribution and abundance should be used in correlative and other analyses to generate specific hypotheses on interrelationships among seagrass condition, depth, and other key forcing variables.

Very little is known about the environmental requirements of deepwater *Halophila* spp. communities. This seagrass community requires significant general research to understand its role and importance in marine ecosystems.

CONSERVATION OBJECTIVES

No permitted losses of existing seagrass communities should be tolerated. This is particularly important in the case of *Thalassia* beds, for which few examples of successful replacement have been documented.

Restoration of seagrasses to historical levels in the Gulf of Mexico will require widespread water quality improvements. This requires foremost that anthropogenic nutrient and sediment loading be reduced.

Legislative initiatives to protect and restore Gulf of Mexico seagrass communities depend ultimately on strong public support. Public education programs should be developed to increase awareness of, and appreciation for, the ecological and economic values of seagrass habitats.

A seagrass working group including research scientists, Federal, State, and local resource managers, and representatives of user groups should be formed to coordinate seagrass conservation efforts in the Gulf of Mexico.

BACKGROUND FOR RECOMMENDATIONS:

Workshop Presentations and Deliberations

CONSERVATION AND RESTORATION OF THE SEAGRASSES OF THE GULF OF MEXICO THROUGH A BETTER UNDERSTANDING OF THEIR MINIMUM LIGHT REQUIREMENTS AND FACTORS CONTROLLING WATER TRANSPARENCY

by

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INTRODUCTION

Spanning nearly 5 degrees of latitude and 15 degrees of longitude, the Gulf of Mexico is the ninth largest body of water in the world. The shallow coastal waters of the gulf consist of an assortment of physicochemical environments including extensive barrier island lagoons, 33 major river systems, and 207 estuaries. These range from the clear subtropical carbonate sediment-based systems of the Florida Keys to the temperate hypersaline Laguna Madre in Texas. The physical and chemical diversity provided by these environments supports extensive and highly productive plant communities that are valuable habitats for resident and migratory species of fish and wildlife. The Gulf of Mexico has the largest and most valuable shrimp fishery in the United States as well as numerous other important commercial and recreational fisheries, many of which depend on the shallow vegetated ecosystems fringing the gulf.

The Gulf of Mexico is experiencing the second fastest rate of growth of the five coastal regions of the United States. Most growth and development are occurring within a few miles of the shoreline or along the watersheds draining into the gulf. Two-thirds of the land area of the contiguous United States eventually drains into the Gulf of Mexico, delivering organic matter, inorganic nutrients, and fresh water. Unless growth and water quality are properly managed, the consequences are a predictable environmental degradation and a serious threat to the health and well-being of the coastal living marine resources.

Seagrasses are an important component of the coastal plant communities in the Gulf of Mexico (Durako et al. 1987, Zieman and Zieman 1989). Four genera, including five of the six tropical western hemisphere species, grow in the gulf: *Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii*, *Halophila decipiens*, and *Halophila engelmanni* (Fig. 2). Almost always found growing completely submerged, seagrasses stabilize unconsolidated sediments and recycle nutrients while providing food, shelter, and substrate for hundreds of species of flora and fauna (Durako et al. 1987, Zieman and Zieman 1989). Despite the low diversity of species, seagrasses occupy a wide variety of habitats including, but not restricted to, sand shoals, shallow muddy and sheltered lagoons, high-energy tidal channels, and relatively deep open-water continental shelves (Continental Shelf Associates Inc. and Martel Laboratories Inc. 1985, Iverson and Bittaker 1986, Durako et al. 1987, Zieman et al. 1989, Zieman and Zieman 1989). Their ability to grow in these very different environments results from their phenotypic plasticity and the wide diversity of morphology and life history strategies provided by a remarkably few species. Size alone illustrates the heterogeneity furnished by the limited species pool. Fully mature seagrass communities in the Gulf of Mexico span two orders of magnitude in canopy height and belowground structure and three orders of magnitude in weight, from the small low-relief meadows of *Halophila decipiens* and *Halophila engelmanni* up to the robust and dense beds of *T. testudinum* (Zieman and Wetzel 1980). In between these extremes are two conspicuous plants, *Halodule wrightii* and *S. filiforme*, which are intermediate in size and reproduce vegetatively at a moderately high rate (Eleuterius 1987, Fonseca et al. 1987).

Our understanding of the role seagrasses have in supporting the living marine resources of the Gulf of Mexico, and our ability to predict what the effects of altered water quality will have on these functions, depend on a comprehensive understanding of the mechanisms controlling their distribution and abundance. Light, temperature, substrate, nutrients, and water motion constitute the major environmental

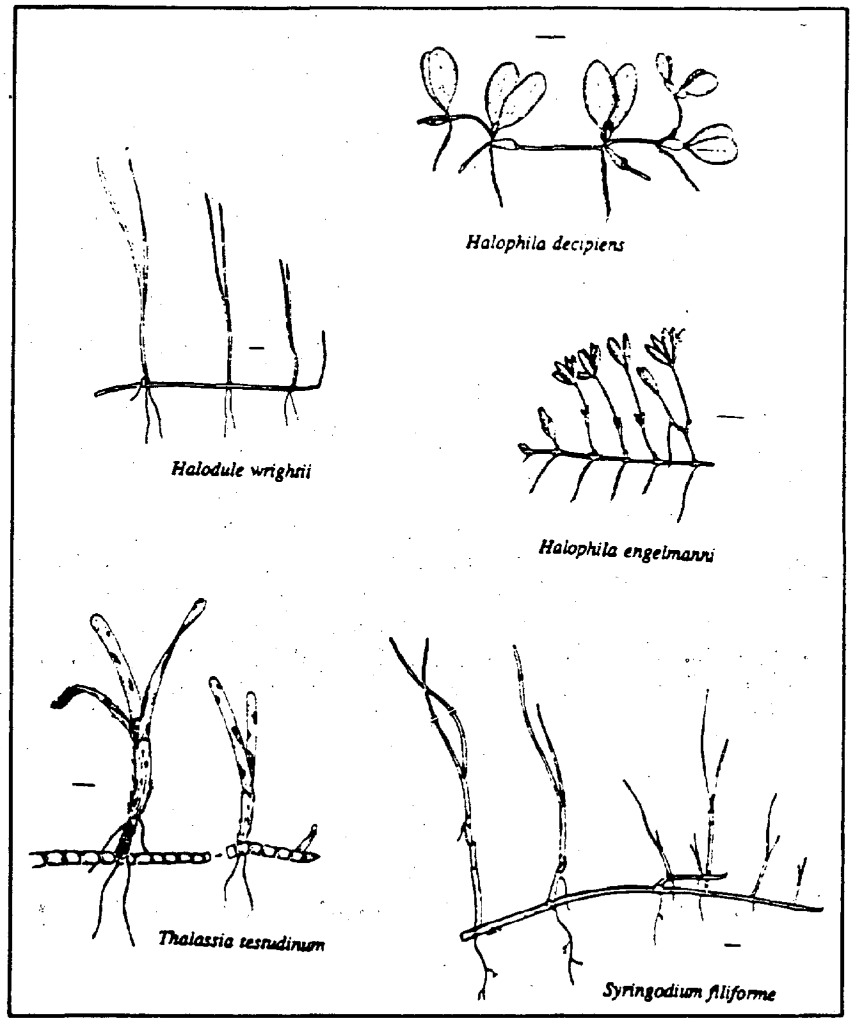

Figure 2. Illustration of the five species of sub-tropical and tropical seagrasses found growing in the Gulf of Mexico (from Fonseca, 1993). Horizontal bars = 1 cm scale.

factors controlling seagrass growth. Of these five parameters, light is the most important. The quality and quantity of available photosynthetically active radiation (PAR; 400-700 nm) drive the photosynthetic processes to fix carbon and produce oxygen, two metabolic processes critical for the survival and growth of seagrasses. Ultimately, the amount of light reaching seagrasses depends on water transparency, which is a function of the water quality parameters that influence light attenuation in the water column and on the surfaces of the leaves (Neckles 1991, Morris and Tomasko 1993).

In general, it is difficult to assign overall dominance or abundance to any one of the five species in the Gulf of Mexico. Areal distribution is patchy and, depending on the location, relative abundance of species will shift within a few meters. In spite of this variability, consistent patterns of depth distribution provide evidence for the interrelationships between seagrasses and water quality, particularly water transparency (Iverson and Bittaker 1986, Dennison 1987, Durako et al. 1987, Zieman and Zieman 1989, Duarte 1991, Kenworthy and Haunert 1991, Morris and Tomasko 1993). The observed patterns suggest that the five species can be collapsed into three groups with different minimum light requirements. In descending order from highest to lowest light requirements they are 1) *T. testudinum*, 2) *Halodule wrightii/S. filiforme*, and 3) *Halophila decipiens/Halophila englemanni*.

SEAGRASS MINIMUM LIGHT REQUIREMENTS

Two by-products of photosynthesis, carbohydrates and oxygen, form the basis of two working hypotheses seeking to explain the mechanisms controlling the distribution of seagrasses (Dennison and Alberte 1986, Marsh et al. 1986, Dennison 1987, Smith et al. 1988, Zimmerman et al. 1989, Zimmerman et al. 1991, Morris and Tomasko 1993). Carbon fixed in photosynthesis is used to build nonstructural carbohydrates, which support maintenance respiration, and structural carbohydrates, which support new growth (carbon balance; Zimmerman et al. 1989). Oxygen produced in photosynthesis is critical to the metabolic needs of the roots and rhizomes of seagrasses, which often grow in chronically anoxic sediments and are exposed to the potentially toxic effects of reduced sulfur compounds (Penhale and Wetzel 1983, Smith et al. 1984, Smith et al. 1988). Carbon balance and oxygen production are not necessarily competing hypotheses, yet they may operate to different degrees in affecting seagrass distribution, depending on the available species pool and the prevailing submarine light regime.

Recent studies have indicated that the minimum light requirements of seagrasses growing in the Gulf of Mexico are much higher than originally suggested by physiological studies of leaf photosynthesis alone (Vincente and Rivera 1982, Onuf 1991, Fourqurean 1991, Fourqurean and Zieman 1991, Kenworthy and Haunert 1991, Kenworthy 1992, Morris and Tomasko 1993). The traditional definition of the light compensation point (I_c), which historically has been 1-5% of the surface incident light, may be appropriate for phytoplankton, macroalgae, and charophytes, but it underestimates the requirements of many seagrasses, including those residing in the Gulf of Mexico (Dennison 1987, 1991, Duarte 1991, Kenworthy and Haunert, 1991).

Whole plant minimum light requirements, rather than the requirement of leaves alone, define an ecological light compensation point (*sensu* Goldsborough and Kemp 1988) estimated to be approximately 15-20% of the average annual surface incident light for *Halodule wrightii* and *S. filiforme* (Onuf 1991, Kenworthy et al. 1991, Morris and Tomasko 1993). Because of the extensive belowground storage mass of *T. testudinum* (Dawes 1987, Fourqurean and

Zieman 1991), this species may be capable of withstanding periods of reduced light (Hall et al. 1991). During periods of low light, carbohydrate reserves may be diverted from the rhizomes to support whole plant carbon balance (Tomasko and Dawes 1989). The ability to utilize reserves may depend on the previous light history of the plant. During periods of light stress, carbon reserves may become depleted more rapidly in species like *Halodule wrightii* and *S. filiforme* that have less belowground storage capability than does *T. testudinum*. *Thalassia testudinum* may be better adapted to avoid short-term deficiencies in carbon balance; however, observations of depth distribution suggest that its long-term light requirements are as high or perhaps even higher than those of *Halodule wrightii* and *S. filiforme* (Vincente and Rivera 1982, Phillips and Lewis 1983, Iverson and Bittaker 1986, Kenworthy and Haunert 1991). Reported patterns of depth distribution almost always indicate that *Halodule wrightii* and *S. filiforme* grow deeper than *T. testudinum*, reinforcing the hypothesis that factors other than carbon balance alone are important in determining light requirements and depth distribution (Zimmerman et al. 1991).

The larger reservoir of belowground tissues in *T. testudinum* meadows may be vulnerable to the phytotoxic effects of reduced sulfur compounds at the lower light levels in relatively deeper water, or during temporary and seasonal periods of poor water transparency. The primary mechanism controlling *T. testudinum* light requirements may be phytotoxicity rather than carbon balance, whereas *Halodule wrightii* is better adapted to minimize both problems. *Halodule wrightii* can avoid phytotoxicity and maximize carbon balance by having greater oxygen production at low light levels (high alpha), a higher maximum photosynthetic rate (high P_{max}; Williams and McRoy 1982, Fourqurean 1991, Kenworthy 1992), a shallower rooting depth, and lower root-rhizome to shoot ratios (Fourqurean and Zieman 1991, Fourqurean 1991, Kenworthy 1992). Therefore, *Halodule wrightii* can sustain growth at lower light levels for longer periods of time than can *T. testudinum* and will survive in deeper water as well as water with lower overall transparency (a lower minimum light requirement).

This comparison, and the emerging general understanding of the minimum light requirements of seagrasses, suggest that we may be able to predict what species should be growing under different conditions of water transparency as well as the maximum depth and overall areal coverage we should expect in a particular water body. This predictive capability would be a powerful tool for resource managers to use in water management programs designed for the protection and restoration of seagrasses (Kenworthy and Haunert 1991, Zimmerman et al. 1991, Morris and Tomasko 1993). The adequacy of this prediction will depend on the assumptions that an average annual attenuation coefficient or some other relevant variable is a reliable predictor of seagrass condition and that the factors responsible for light attenuation can be isolated for management attention. Currently, these are two areas of active research interest and should draw the attention of scientists and managers during development of the U.S. Environmental Protection Agency's Coastal Submerged Aquatic Vegetation Initiative (see, for example, Morris and Tomasko 1993).

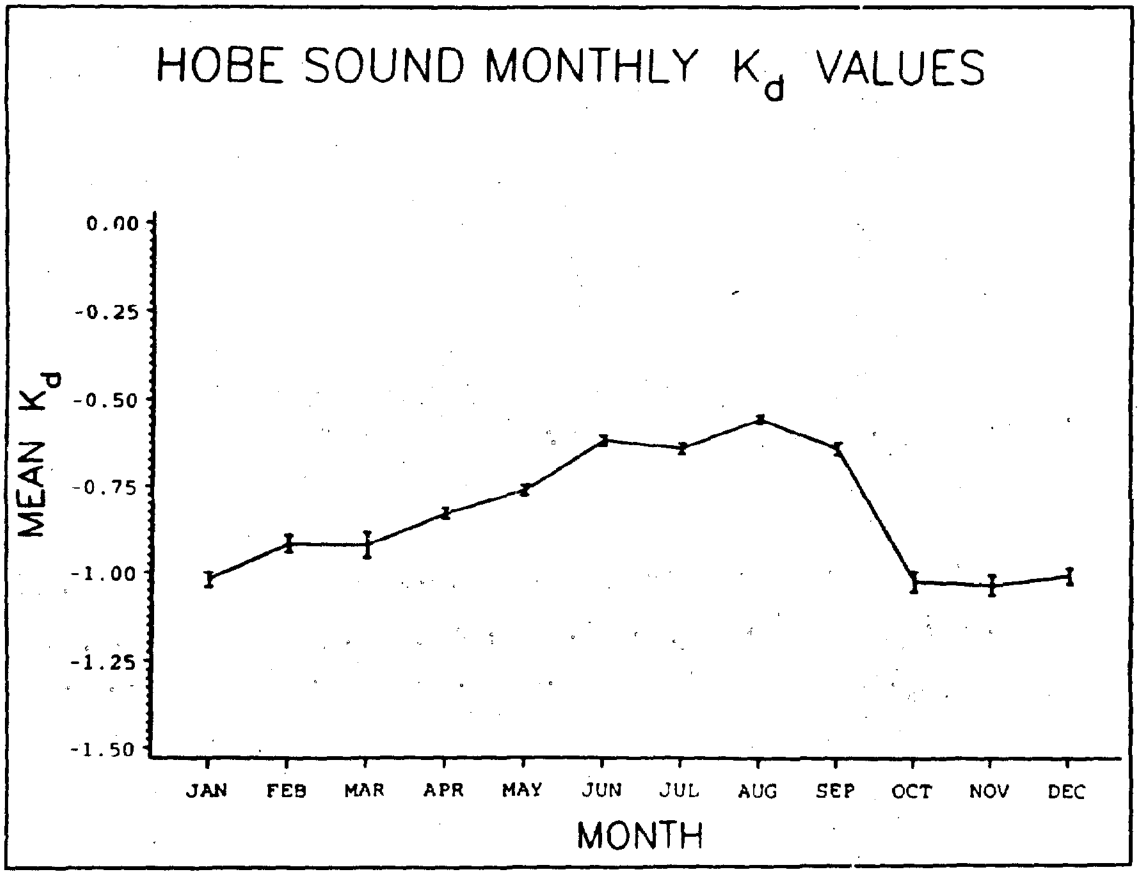

Figure 3. Seasonal cycle of diffuse PAR light attenuation (K_d PAR) in a shallow tidal lagoon, Hobe Sound, in the Southern Indian

UNDERSTANDING AND PREDICTING SEAGRASS DISTRIBUTION

Because of the wide diversity of watersheds and coastal geomorphology in the Gulf of Mexico, there are a variety of nearshore ecosystems and water qualities. The result is a range of water transparencies that are detectable along spatial and temporal gradients and directly controlled by three commonly monitored water quality variables: 1) total suspended solids (TSS, frequently measured as turbidity by nephelometric turbidity units), 2) chlorophyll (CHL), and 3) dissolved organic matter (DOM, usually measured as color; Kirk 1988, Gallegos et al. 1990, Gallegos et al. 1991, Moore 1991, Kenworthy and Haunert 1991, Morris and Tomasko 1993). Also important are the indirect controls on water transparency operating through CHL and DOM. These are dissolved inorganic nutrients, mainly inorganic nitrogen and phosphorous, which stimulate phytoplankton and macroalgal blooms as well as the growth of epiphytes on the leaves of seagrasses. Both the direct and indirect controls of light attenuation have very strong seasonal signatures (Moore 1991, Kenworthy et al. 1991, Neckles 1991, Kenworthy 1992, Morris and Tomasko 1993) which suggest that mechanisms controlling short-term light limitation may be masked by estimating the minimum light requirements of seagrasses through a simple correlation between an average annual light attenuation coefficient and the maximum depth of growth (Dennison 1987, Duarte 1991, Kenworthy and Haunert 1991, Zimmerman et al. 1991).

The problem with inferring light limitation by a correlation between maximum depth of growth and the average annual attenuation coefficient was illustrated by an intensive study of the submarine light regime and seagrass distribution in the southern Indian River (Kenworthy et al. 1991, Kenworthy 1992). Weekly sampling of the light attenuation coefficients in two coastal lagoons showed significant effects related to time and distance from an inlet. During four years of sampling, a repeatable cycle of summer maximum and winter minimum transparencies was detected (Fig. 3). Based on the average annual light attenuation coefficient, *Halodule wrightii* and *S. filiforme* grew to a maximum depth corresponding to light levels of 15 and 37% of the incident light. Even though light levels exceeded this average value in deeper water during the summer months (May-August), these two species could not establish permanent populations there. Yet, healthy populations of a smaller species, *Halophila decipiens*, grew in the deeper water between May and October (Kenworthy 1992). If observations on seagrass distribution were obtained only during the clear summer period the depth transects would have suggested that *Halophila decipiens* was the species adapted to the lowest light levels, a paradigm frequently assigned to this species for several reasons. The small, low-density, low-relief canopy minimizes self-shading and allows more light to enter, while a shallow rooting depth avoids the potentially phytotoxic effects in the deeper, more reduced sediments. Additionally, *Halophila decipiens* has a simplified anatomy including thin cell walls and densely packed chloroplasts, which maximize the amount of light reaching the chlorophyll molecules (Josselyn et al. 1986). The individual leaves grow rapidly and turnover is fast enough to minimize the establishment of epiphytes that could further attenuate light on the surfaces of the leaves (Josselyn et al. 1986, Kenworthy et al. 1989). Based on these physiological and morphological attributes, *Halophila decipiens* should have a lower minimum light requirement than the larger species (Josselyn et al. 1986), yet they grow only in summer during maximum photoperiod and intensity.

There is another plausible explanation for the observed seagrass depth distribution that is based on the life history of these species rather than just their physiological and anatomical characteristics. Although sexual reproduction occurs with all the species growing in the Gulf of Mexico (McMillan 1985, Moffler and Durako 1987), *Halophila decipiens* is by far the most fecund. In the southern Indian River (Kenworthy 1992), and even in the tropical environment of the Salt River Canyon in St. Croix (Josselyn et al. 1986, Williams 1988, Kenworthy et al. 1989), ephemeral populations of *Halophila decipiens* are reestablished annually by seed. During the winter periods of low light and low temperatures in the Indian River, populations of *Halophila decipiens* disappear except in the immediate vicinity of inlets, where relatively warmer and clearer water prevails throughout the winter. In other subtropical and tropical locations fall and winter storms contribute to the erosion and burial of existing *Halophila decipiens* beds, leading to a seasonal decline in abundance and cover; this occurs even in tropical deepwater beds of the

Virgin Islands (Williams 1988). In the Big Bend region of the eastern Gulf of Mexico there are vast areas of deep water (depth > 10 m) on the continental shelf that are vegetated by *Halophila decipiens* and *Halophila engelmanni* (Continental Shelf Associates Inc. and Martel Laboratories Inc. 1985, Contintal Shelf Associates Inc. 1989). Although there are no detailed seasonal studies of these deepwater beds, an evaluation of Hurricane Elena's impact in 1985 revealed that *Halophila* meadows were completely destroyed, yet they recovered during the following growing season (Continental Shelf Associates Inc. 1987). This indicates that these populations are based on an annual life history strategy.

The storm-impacted beds in the Gulf of Mexico and St. Croix, and the seasonally ephemeral *Halophila decipiens* beds of the southern Indian River, are reestablished by seed. In the Indian River seedlings emerge in early spring (March-May) and continue to germinate throughout the summer, forming patchily distributed meadows in deeper water but never in the canopy of the larger species that grow in relatively shallower water. Seed germination, seedling growth, and bed development coincide with the highest levels of PAR observed during the year (Kenworthy 1992). Because *Halodule wrightii, S. filiforme*, and *T. testudinum* reproduce mainly by vegetative branching (Tomlinson 1974), they have limited dispersal potential. These larger species cannot utilize the available light in deeper water because the time window is too short for vegetative propagation and dispersal to take advantage of the resource. Volunteer fragments, consisting of a few short shoots, rhizomes, and roots of these three larger species, recruit to the deeper areas in summer but they do not survive the reduced light periods of winter (Kenworthy 1992).

These observations indicate that the depth zonation patterns and the inferred minimum light requirements of seagrasses in the Gulf of Mexico are more complex than can be described by physiology, anatomy, or temporally static depth transects alone. Seagrass light requirements depend in part on the life history patterns of the individual species, reinforcing the argument that an average annual attenuation coefficient may not adequately predict the distribution of some seagrasses (Zimmerman et al. 1991). The survival, growth, and year-to-year persistence of *Halophila decipiens* in the Indian River communities may depend largely on the water quality in summer, when actively growing populations are forming seed stocks that will be the basis for the next year's population. If growth and fruiting slow or cease during cooler months (October-April), the light attenuation values obtained in winter will have no bearing at all on predicting the success of populations in subsequent years.

This same argument probably applies to the three larger species as well, but for different reasons. During the active growing periods of spring, summer, and early fall, good water transparency may ensure an adequate production of belowground storage carbohydrates that can be mobilized to short shoots during periods of algal overgrowth or low light in winter, or for regrowth the following spring (Dawes 1987, Tomasko and Dawes 1989). Equally or perhaps more important, for the larger species that produce considerable belowground biomass, is the immediate production of oxygen and carbon skeletons. These end products of photosynthesis detoxify reduced sulfur compounds and nitrogen (nitrate), whereas the production of alternate end products (carbon compounds) minimizes the phytotoxic effects of ethanol during nighttime and during daytime periods of low light (Pregnall et al. 1984, Smith et al. 1988). Because the three larger species are perennial, growing and metabolizing all year, winter light attenuation will have a greater effect on them than it would on a species like *Halophila decipiens*, which overwinters in a seed bank. An average annual light attenuation coefficient may be a better predictor of depth distribution for the larger species in the more southerly latitudes of the Gulf of Mexico; however, we should continue to examine the concept of a critical time period in order to develop a more sensitive predictor for each of the species, regardless of size (Moore 1991). For example, in more northerly regions of the gulf the annual growth period of *Halodule wrightii* may be shortened by low winter temperatures; this argues for a smaller time window in which light attenuation should impact seagrass growth.

Even within the genus *Halophila* the two species appear to have different requirements for growth (Dawes et al. 1986, Dawes et al. 1989). *Halophila decipiens* will grow right up to the edge of a meadow but is rarely found growing within the canopy of the larger species. *Halophila engelmanni* grows in the understory of the larger species or in mixed beds with *Halophila decipiens* (McMillan 1985, Continental Shelf Associates Inc. and Martel Laboratories Inc. 1985, Onuf 1991, Kenworthy, personal observations in the Banana River, Florida). Both species are often the deepest dwelling but *Halophila engelmanni* behaves more like a perennial than an annual plant.

Based on the above discussion, water quality, particularly water transparency, is expected to have a major influence on determining the species composition and abundance of seagrasses in the Gulf of Mexico. The five seagrass species, with their diverse anatomy, varying structural complexity, and widely ranging habitat requirements, provide different functions and values for the flora and fauna of the gulf. Presumably, seagrasses can act as a mediary in transmitting the detrimental effects of degraded water quality to secondary production and the health and well-being of fish and wildlife (Kenworthy and Haunert 1991).

SEAGRASS CONSERVATION AND RESTORATION

Our efforts to protect and maintain the diversity and productivity of seagrass communities in the Gulf of Mexico will depend on our ability to sustain good water quality. In order to do this we must develop comprehensive water management plans that include functional and reliable optical water quality models that enable resource managers to identify the parameters having the greatest influence on transparency (Kirk 1988, Gallegos et al. 1990, Gallegos et al. 1991, Kenworthy 1992, Morris and Tomasko 1993). Within a comprehensive plan, regional and local resource agencies would establish desirable goals for seagrass species and coverage based on existing and/or historical seagrass distribution and abundance data. These goals would be matched with the species pool, current water quality conditions, and the bathymetry of the watershed, lagoon, or estuary in order to evaluate the goals with respect to the cost of achieving such goals. An essential feature to this plan is a scientifically based water quality monitoring program that identifies a functional variable (e.g., the attenuation coefficient) for predicting seagrass species and their distribution. In addition, the monitoring program must be capable of identifying the water quality factors that control the functional variable (e.g., DOM, TSS, CHL, and dissolved inorganic nitrogen). When properly calibrated, optical water quality models can be used to quantitatively compare the relative contributions of the individual factors. For example, a dependent variable such as the light attenuation coefficient or the percent of surface irradiance can be evaluated as a function of one or several independent variables on a contour plot to estimate their relative contributions to PAR attenuation (McPherson and Miller 1987, Vant 1990, Gallegos et al. 1991, Dennsion et al. 1993, Gallegos and Kenworthy 1993, Gallegos In Press). This type of comprehensive analysis provides a means for determining the target parameter for management efforts needed to improve water transparency. This approach avoids the inadequacies of traditional water quality criteria and standards where single numerical values or vague narratives are assigned as targets for which water quality parameter values cannot be exceeded. Given the diversity of environments and seagrass habitat requirements known to exist in the Gulf of Mexico, a more flexible approach is needed. Any effort to impose the same standard for water transparency in the Florida Keys, the barrier island lagoons of Mississippi, and the Laguna Madre will probably fail because the species pools and factors controlling water transparency in these coastal ecosystems are likely to be very different.

Future efforts to conserve and restore the valuable seagrass resources of the Gulf of Mexico depend on a scientifically based understanding of the light requirements of the individual species and the environmental and anthropogenic factors affecting the submarine light regime. Research efforts should continue to focus on developing scientifically based water quality monitoring programs that not only measure water quality but also analyze and interpret the parameters so that factors influencing water transparency can be evaluated for the protection of seagrasses.

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SUBMERGED AQUATIC VEGETATION MAPPING

WORKING GROUP REPORT

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The primary goal of this working group was to review, discuss, and recommend criteria for mapping the location and extent of submerged aquatic vegetation (SAV) in the coastal region of the Gulf of Mexico as an indicator of nearshore environmental quality. The area under consideration for this discussion is the Louisianan Province of Environmental Monitoring and Assessment Program -Estuaries, which includes the coastline of the Gulf of Mexico from Brownsville, Texas, to Anclote Key, Florida. This includes the coastlines of the states of Texas, Louisiana, Mississippi, and Alabama, and the northwestern coast of Florida. The area of concern includes bays, sounds, and estuaries from their offshore limit to the inland line of astronomical tidal influence.

EXISTING MAPPING PROJECTS

What maps, data, or information are available and planned by Federal and State agencies within the Gulf of Mexico area? What is the areal coverage of the projects? What kind of cooperation exists among agencies for each project? EMAP-Estuaries has begun a mapping project of SAV within the Louisianan Province. This project will acquire 1:24,000 scale natural color aerial photography of the Gulf Coast over four years. The photography will be interpreted, mapped as overlays to U.S. Geological Survey (USGS) 1:24,000 scale quadrangles, and digitized to provide SAV acreages. The National Biological Survey's (NBS) Southern Science Center is the project leader and is responsible for completing the photointerpretation and mapping. Other project participants include the National Oceanic and Atmospheric Administration (NOAA) for seagrass mapping protocols, and the National Park Service (NPS) and the states of Florida, Alabama, Mississippi, Louisiana, and Texas for review and ground-truthing.

The NBS is responsible for most of the seagrass mapping in the Louisianan Province completed to date. They prepared seagrass atlases for the Gulf of Mexico from aerial photography acquired in 1983, and their wetland and upland maps developed for each of the coastal states include SAV. Inconsistent identification of SAV limits the utility of these historical wetland and upland maps. Seagrass trend maps at a scale of 1:100,000 have been developed for the Laguna Madre of Texas using 1988 field mapping and master's theses for two dates. Seagrass maps have been developed for trends analysis for the Chandeleur Islands of Louisiana for nine time periods, for Perdido Bay, Florida-Alabama, for four time periods, and for the NPS Gulf Islands National Seashore, Mississippi-Alabama-Florida, for three time periods. Seagrass mapping for four time periods for St. Andrew's Bay, Florida, is in progress.

Although NOAA has developed a major seagrass mapping program for the North Carolina coast, they have not mapped any areas in the Gulf of Mexico. They have been the principal instigator and coordinator in the development of a seagrass mapping protocol. The Minerals Management Service funded the development of seagrass atlases for the Florida Big Bend area in 1985 and the Florida Bay area in 1985-1987. These atlases are being done at a scale of 1:100,000.

The NPS has funded the U.S. Fish and Wildlife Service (USFWS) to map the Gulf Islands National Seashore for three time periods and is currently developing a contract for field inventory of seagrasses present. If funding is available they will fund the USFWS to develop seagrass maps for the Gulf Islands for the early 1940's.

The states around the Gulf of Mexico coast have varied in program development related to seagrass inventory and mapping. Texas and Florida have active mapping programs, and Alabama mapped the seagrasses of Mobile and Perdido bays in the late 1970's, but Louisiana and Mississippi have never inventoried or mapped their SAV (although the Louisiana Department of Natural Resources Coastal

Management Division was very active in the review and ground-truthing of the aquatic beds in the 1988 USFWS wetlands habitat maps for coastal Louisiana).

The University of Texas Bureau of Economic Geology has mapped the entire coast of Texas for SAV for the late 1950's and for 1979-1980. The Texas Department of Parks and Wildlife has inventoried and mapped Galveston Bay, San Antonio Bay, and Nueces Bay. They also have an ongoing project for Corpus Christi Bay.

The Florida Department of Natural Resources has completed trends analysis for St. Andrews Bay, and has ongoing projects to redo the 1983 USFWS seagrass photographic atlases and to establish trends for Tampa Bay.

BASE MAPS

Do we have adequate base maps? Base maps are a common map depiction of the coastline in a common coordinate system at some level of map accuracy standards, such as USGS 1:24,000 topographic quadrangles or 1:40,000 National Ocean Survey (NOS) nautical charts. It will be difficult to complete historical mapping or to match mapping projects from one state or region to another without the application of a common base map series.

The 1:24,000 USGS topographic quadrangles are the most available and widely used base maps and should be considered the minimum base map, in terms of format and scale, to be used for seagrass mapping.

There are advantages and disadvantages to working with the USGS 1:24,000 maps:

ADVANTAGES:

- USGS is the national standard.
- Matches other programs (e.g., National Wetlands Inventory).
- Applicable to county- and parish-level planning.
- Used for screening permits and regulatory monitoring.
- Widely available.
- Allow visualization in the field.
- USGS has an active updating program.

DISADVANTAGES:

- Too coarse for small impacts (e.g., prop scars, boat docks).
- Minimum of 1/4 acre mapping.
- For some quadrangles only orthophotos have been produced.
- Digital data for quadrangles lacking for many areas.
- Lack of submerged information (e.g., bathymetry).
- Many maps are outdated for changing coastlines.

There are alternatives to the USGS topographic quadrangles as base maps. The NOS shoreline manuscript maps are at scales of 1:20,000 or 1:10,000. However, they are limited in their availability, they are not available in a digital form, and other coastal features (e.g., marsh, cultural features, and roads) are lacking. Other projects are developing their own base maps because the scope of the projects demands maps at scales of 1:20,000, 1:12,000, or 1:6,000. Other mapping efforts may use 1:100,000 scale USGS base maps that cover large offshore areas and/or areas where detailed data are not available nor deemed necessary.

GROUND DATA TO COLLECT IN THE MAPPING EFFORT

What site-specific data should be collected in the field as indicators for photointerpretation?

Ground-truthing for SAV mapping should be done by the photointerpreter. The ground-truthing focuses on the identification of the SAV photo signature. Point-specific locations of "questionable interpretation" are primary field check sites, and other areas of "confidently interpreted" SAV are covered by a grid system, transects, or random point field check sites. There is a difference between ground data to be acquired as aids to photointerpretation and that used as verification of the mapping completed. EMAP requires that if a monitoring location is placed in an area where seagrasses are mapped on the 1:24,000 quadrangles, seagrasses must be present. Therefore, mapped seagrass beds must be verified as present or absent through field review. The key elements in tying ground data to the photointerpretation are species present, signature identification confirmation, nonvegetated features, and location. Other field data that may be collected as part of the mapping effort but are not critical as aids to the photointerpreter in SAV delineation include vegetation density, water depth, presence or abundance of epiphytes, evidence of prop scars, sediment type, light attenuation, salinity, and presence or abundance of macroalgae.

Species Present: In most instances, species cannot be distinguished in a photo (although there are a few exceptions). Although aerial photographic signatures for *Halophila sp.* have been identified through fieldwork in water depths greater than 15 m, aerial photography is not practical for mapping in deep water because the water often obscures detection of grass beds during photo interpretation and even slight amounts of turbidity destroy the signature.

Signature Identification: The photointerpreter (PI) gains confidence with repeated signature identification. That identification includes photointerpretation and the collection of data in the field. Although study has shown interpretation can be done without PI field participation, it is generally recommended that the PI be involved in the field effort. The PI has to know how the signatures correspond to SAV in the water. In addition, a PI lacking field experience may not know all the pertinent information to ask the field worker, thus affecting the accuracy of the final product.

Nonvegetated Features: When at a site, the field person should be aware of objects that could be confused with SAV on the aerial photographs (e.g., eroding peat banks, geologic formations, etc.).

Location: The correlation of a field collection site, transect, or plot with a location on the aerial photographs is essential to photointerpretation and verification of signatures. This is even more important when looking at vegetation density and species composition.

Density: Estimating density requires extensive field sampling and is potentially a major resource expenditure that can limit the number of sampling stations. There are two types of density that can be estimated: 1) the ground cover approach estimates the density of SAV within a patch or bed, i.e. the percent of surface covered by blades and stems, and 2) the patch density approach estimates the density of patches of SAV across the area, i.e., the number, size, and distribution of patches compared to the amount of bare ground across the surface. The ground cover approach is certainly the most desired, but it requires considerable control in terms of scale, emulsion, water clarity, water depth, and field work. Accurate estimation of ground cover through photointerpretation is not always achievable because water clarity and depth can lighten submerged vegetation, making it appear less dense. Also the relation between photographic signature and density can vary between species and even within a species depending on blade length, width, pigmentation, degree of epiphytization and aspect (lying over versus standing upright). To achieve an estimate of ground cover with a stated degree of accuracy requires considerable fieldwork. As a result, it is time-consuming and expensive. Estimating patch density is more economical and feasible through photointerpretation, thus providing accurate descriptions of SAV distribution.

Water Depth: Although not essential in the photointerpretation process, data on water depths (soundings, pole measurements, bathymetric maps, etc.) can aid the PI by identifying the areas within the optimal range for SAV growth, or by identifying dark signatures in the water as resulting from deep water rather than from SAV. Water depth at the time the aerial photography is acquired can affect the signature of the SAV present. The vegetation will appear darker if the water level is low and the blades are lying over than if the water level is high and the blades are more upright.

Epiphytes: The amount and type of epiphytes present are important field data to be collected to determine the health and condition of SAV, but they are very seasonal in occurrence and it is not possible to photointerpret them. In addition, sampling epiphytes is extremely time consuming and would therefore require a large committment of resources.

Scars: Prop scars are easily identified on low-level (e.g., 1:6,000 scale) aerial photography. They may be mapped and their revegetation followed for subsequent time periods. They help in establishing locations on the aerial photography.

Sediment type: Surficial sediments are easily collected at field sites. Data derived from samples may include redox readings, dry weight organic content, statistics on sediment grain size, or the percent sand, silt, and clay. Although data on sediment types are important in the comparison of sediment type and organic content to submerged vegetation density and species composition, the sediment type data have little application in the photointerpretation process.

Light Attenuation: Turbidity plumes in the water column caused by suspended sediment or algae can obscure the signature of SAV. Data on light attenuation can be gathered by use of light meters lowered within the water column. Such data are important in understanding the growth, structure, and composition of SAV. Turbidity is easily identified in aerial photographs, but attenuation data are not essential in the identification of SAV signatures.

Salinity: Although salinity can cause considerable variation in SAV species composition, density, and growth, salinity data are not necessary in the identification of SAV signatures.

Macroalgae: Macroalgae take two forms: drift algae moving with bottom currents, and attached macroalgae, generally found in shallow low-energy water. Although macroalgae are generally found in shallow water they may appear darker than other SAV and often have circular patterns within the signature. More often the signature of macroalgae is indistinguishable from that of other forms of SAV, and field determinations are necessary.

NEW TECHNOLOGY IN SEAGRASS MAPPING

The most important questions surrounding new technology associated with image acquisition are:

- What remotely sensed imagery exists that we could successfully use?

- Is the remotely sensed imagery effective at identifying SAV?

- Should programs be looking at these new advances in the long term?

The working group expressed the opinion that eventually SAV mapping should get away from the use of aerial photos because of the increasing costs and complexity of flight mission planning and coordination. The general consensus of the working group was that, at the present time, remotely sensed imagery, i.e., satellite and airborne scanner data, cannot provide accurate and consistent SAV identification. However, the group believes that future technological advances will bring scanner data on SAV within the realm of consideration. Therefore we should stay current with all new technology even though we may not be able to use it at this time.
Use of Global Positioning System (GPS) is considered to be the most important technological advancement in the mapping of SAV. Points to consider in using GPS include:

- Aircraft navigation technology is advancing rapidly and positioning using airborne GPS technology allows precise location of the plane at the moment the photo was taken.

- GPS provides real-time display of location and coverage of the photography collected to ensure acquisition of the areal coverage specified.

- GPS technology is advancing very rapidly.

- GPS can reduce the amount of time needed to physically locate the beds appearing in aerial photographs during post-flight ground surveys.

- To allow for statistical accuracy, more pre-flight field time is required for putting out targets that can be seen on the photo (unless permanent visible features are already present).

- GPS provides horizontal control of aerial photography and maps.

- GPS solves digitization problems with rectification and geopositioning because it incorporates GPS digital data into the process.

- GPS-controlled photography costs four-to-five times as much as standard photography.

- Certain photos require a target present in order to be triangulated with other photos, which increases cost and time for coordination.

The working group strongly recommended that anyone collecting point data in SAV fieldwork use GPS technology and perform differential correction on the GPS data acquired.

The use of the analytical stereoplotter is another technological advance that can potentially be of importance in SAV mapping because it will reduce the time required for mapping and the cost of mapping in the long term. The analytical stereoplotter incorporates the use of GPS field data to rectify the aerial photography and allows for photointerpretation and digitization in a one-step process.

CLASSIFICATION

The primary question formulated by the working group was: What has been traditionally classified when seagrasses are mapped?

Most historic mapping projects have simply delineated the presence versus absence of seagrasses, because of the scale of the mapping effort, the limited funding often available, a demanding schedule, lack of fieldwork, and lack of PI expertise in recognizing seagrass signatures. Also, the simple presence versus absence of seagrasses allows easier replication of effort to determine trends of seagrass change. Macroalgal presence is also identified as a separate category in some projects.

The working group agreed that it is better to have fewer classifications. The simpler the classification, the fewer "gray" areas for interpretation. The interpretation of seagrass density has been attempted in several projects in the past, are each with inconsistent results. Generally, the intent in seagrass mapping is to describe the morphology of the bed as a whole, not the density of seagrasses within the bed. In a USFWS study, preliminary data indicated the accuracy of interpretation of seagrass densities over 70% and under 30% was nearly 70%, whereas interpretation of the moderate or medium density range (30-70%) was approximately 50%. The classification of seagrasses by species, or the separation of freshwater species from seagrasses, has also been attempted, but it cannot be consistently interpreted from aerial photography and requires extensive fieldwork and ground-truthing. Interpretation of species composition and density is affected by the lack of homogeneity (although turtlegrass may be interpreted with some consistency as a darker signature, other seagrass species are not as easily discerned and the species composition of mixed beds is impossible to determine from aerial photography) and changing water depths (as water depth increases the water signature gets darker).

Morphologic classification can be accomplished from aerial photography. Past projects have identified "continuous" beds (large areas of seagrasses) and "patchy" beds (small scattered units of seagrasses). "Patchy" seagrass beds can be further classified by a range of densities of patches within an area. A density classification system is presented as part of the implementation plan for NOAA's Coastwatch-Change Analysis Project (C-cap; Dobson et al. 1994).

The Louisianan Province SAV mapping classification for EMAP includes a gradient of SAV patch densities (from continuous coverage through four density classes), and the presence of macroalgae beds.

STRATIFICATION OF SAMPLING

Once the baseline mapping for SAV present in the Louisianan Province is completed, EMAP intends to develop a monitoring program to assess status and trends of these habitats. Because SAV beds vary widely in size, shape, and ecological characteristics, some form of a priori stratification is necessary to ensure adequate and representative sampling.

Sampling may be stratified by several criteria:

- Geographic location (distance from shore, estuaries, river mouths, islands, behind barriers, open Gulf).
- Salinity (may not be repeatable from year to year as salinity can change radically).
- Substrate type.
- Anthropogenic stresses (dredging, boating access, contaminants).
- System size.
- Areal extent of SAV beds.
- Water depth.
- Relationship to physical stress (fetch).

- Special management/jurisdiction.

- A tiered approach is suggested for the stratification of sampling.

FIRST TIER

The first tier of sampling strata is based on geographic location and system size. This will provide adequate distribution of sampling throughout all ecological systems available within the Louisianan Province.

Lagoons - sounds or bays, protected by barrier islands without large freshwater inflow.

Estuaries - includes large and small systems (for sampling purposes include all systems on an equal basis rather than weighting systems by areal extent).

Big Bend Area, Florida - unique area (open coastal).

River deltas - freshwater to brackish SAV.

SECOND TIER

The second tier of sampling strata is based on seagrass bed morphology and ensures representation regardless of size, coverage, water depth, or sediment type. This tier is based, primarily, on the ability to delineate seagrasses and map them. The polygon delineates the boundary of SAV beds or patches on a map. Potential stratification variables include:

Polygon class - continuous or patchy, density of patches over area.

Polygon size - ranges of polygon sizes should be formulated.

Polygon shape - probably not feasible because of wide variation of shapes within each geographic location to be sampled.

Depth - ranges of depths should be sampled.

Sediment type - sand, silt, organic mucks.

MONITORING

The mapping working group suggested that the EMAP monitoring of SAV should:

Tie in with existing mapping and monitoring programs of NOAA, the NBS, state agencies, the U.S. Environmental Protection Agency Gulf of Mexico Program-habitat degradation committee, and regional and county mapping programs.

Repeat the mapping for the Louisianan Province every four years to assist monitoring, ensure repeatability of sampling locations, and establish trends related to the ecological health of the province's SAV.

Rely on the protocols developed from the 1990 NOAA-sponsored seagrass workshop and the C-CAP program (Dobson et al. 1994).

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ECOLOGICAL INDICATORS

WORKING GROUP REPORT

by

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The charge to this working group was to identify a suite of indicators of the ecological condition of submerged aquatic vegetation (SAV) beds appropriate for long-term monitoring. Ideally, indicators would function on a regional scale over a period of decades. Indicators must be applicable across a range of SAV habitat types, related to ecological condition in a way that can be quantified and interpreted, quantifiable in a standardized manner with a high degree of repeatability, and appropriate within the constraints (financial, logistical) imposed by the spatial and temporal scale of a regional, long-term monitoring program: i.e., the long-term and regional variability of an indicator must not be masked by short-term or local variability. The Environmental Monitoring and Assessment Program (EMAP) attempts to limit broad scale data collection for indicators of environmental quality to a single index period per year, when responses to anthropogenic and climatic stresses are anticipated to be most severe (see Summers et al. 1991). The overriding concern expressed by this working group during discussions of candidate indicators was the potential to yield meaningful information if sampled only once during the year at sites separated by kilometers.

Working group members were asked to consider parameters that could be measured to quantify integrated responses of SAV to individual or multiple stressors ("response indicators"), and parameters that could be measured to quantify pollutant exposure or habitat degradation ("exposure indicators"). Participants were asked also to recommend the optimal timing and methods for measurement and to suggest whether threshold values separating desirable from undesirable habitat conditions exist for candidate indicators. It became clear during discussions that, in many areas, further research is necessary to improve our ability to characterize SAV habitat condition over broad spatial and temporal scales.

RESPONSE INDICATORS

Many plant processes can be expected to respond to changes in environmental conditions. Consequently, a wide range of plant characteristics should reflect environmental change. The working group generated an exhaustive list of candidate response indicators and then combined them into general categories for discussion. The categories in Table 1 were selected from the more extensive list by consensus as the best indicators of habitat condition.

None of the proposed indicators has been tested at the regional and decadal scales inherent in EMAP sampling. Seagrass beds are dynamic, complex systems, and many of the parameters used to characterize habitat condition exhibit considerable temporal and spatial variability. The working group agreed overwhelmingly that to accurately assess seagrass ecosystem condition the EMAP sampling network should include frequent sampling at selected permanent stations. The proposed indicators would yield the most information on seagrass habitat status and trends if sampled along permanent transects established perpendicular to the depth gradient.

ABUNDANCE

Measures of plant abundance are among the most important indicators of habitat condition. Working group members identified various morphometric and population parameters that tend to respond to environmental change and then prioritized these measures for inclusion in a long-term monitoring program. All candidate indicators are estimable from quadrat-based sampling. Prioritization was based on ease of measurement, predictability of response to environmental stress, and degree of temporal and spatial variability (Table 1). Abundance measures should be added to a monitoring program in order of priority as resources permit.

RESPONSE INDICATORS	
Abundance	
	Shoot density by species
	SAV biomass
	Algae biomass
	Leaf width
	Leaf area index
Plant constituents	
	Soluble carbohydrate concentration
	Ratio of C:N:P
Species composition	
	Seagrasses
	Macroalgae
	Filamentous algae
Depth limit of bed	
Genetic diversity	
Stress proteins	
Animals	
Productivity	
EXPOSURE INDICATORS	
Light	
Nutrients	
	Total nitrogen, total phosphorus
	Ammonium, nitrate, soluble reactive phosphate
Dissolved oxygen	
Physical conditions	
	Physical energy regime
	Sediment characteristics

Table 1. Ecological indicators proposed for inclusion in the EMAP sampling network.

Shoot density: Density decreases predictably with declining availability of light and sediment nutrients and is less subject to variability caused by grazing than are other measures of abundance. Shoot density has historically been one of the most frequently measured parameters of seagrass populations. Thus, a long-term data base for seagrass density under varying environmental conditions exists in the literature from which thresholds of responses could probably be generated. Because seagrass species differ in their susceptibility to environmental stress and competitive interactions, a record of densities of individual species would yield more information than would a record of total macrophyte density. For example, among tropical seagrasses, *Thalassia* is the most sensitive to certain environmental stressors and is the strongest competitor for nutrients. An increase in density of other seagrasses could thus signal a decline in environmental condition if coupled with a decrease in density of *Thalassia*.

SAV Biomass: Although susceptible to the confounding effect of grazer leaf removal, biomass integrates leaf length and width and therefore may be more responsive to environmental stress than leaf morphometry. The allocation of resources between aboveground and belowground biomass can also yield insight into environmental stressors.

Algal Biomass: Algal growth is frequently correlated with nutrient enrichment, such that high biomass of either epiphytes or unattached macroalgae may signal declining water quality. Algal biomass is a result of interactions among many abiotic and biotic controls, however, and ordinarily exhibits extreme temporal and spatial variability. Therefore, environmental condition cannot be interpreted definitively from algal biomass alone. To improve the utility of algal biomass as an indicator of SAV condition, research is particularly needed to elucidate the complex interrelationships among light availability, nutrient concentrations, grazing intensity, and algal response.

Leaf Morphometry: Leaf width can be used to diagnose environmental changes within *Thalassia* populations; in general, declining leaf widths suggest environmental stress. Information does not exist, however, to interpret differences in leaf width among populations. Therefore, leaf width should be considered as a local response indicator for *Thalassia* when monitored at permanent stations only. Since leaf width varies with shoot age as well as with environmental conditions, trends in other response and exposure indicators should be considered to help interpret any temporal changes in leaf width. Before leaf width is considered as a geographic indicator, further research is needed to quantify the spatial variability of this parameter and its relationship to environmental gradients.

Leaf Area Index: LAI integrates leaf size and density and thus may be more responsive to stressors than leaf width alone. The effort required to determine LAI manually, however, reduces the utility of this measure for large-scale manual sampling. A meter that measures LAI by light obstruction is currently used in terrestrial systems and is adaptable for underwater applications. Research is needed to determine whether such a meter can be calibrated reliably in aquatic systems. Instrument-automated LAI measures may thus be available in the future.

PLANT CONSTITUENTS

Concentrations of soluble carbohydrates and ratios of C:N:P in plant tissue generally reflect environmental conditions. For example, carbohydrate concentrations in *Thalassia* have been shown to decline with light limitation. Because concentrations of chemical constituents also show considerable seasonal variation, samples for comparative purposes must be restricted to similar times of year, plant growth phases, and tissue types. Although a long-term change in soluble carbohydrate concentrations or C:N:P ratios at a site would indicate a change in environmental conditions, insufficient data exist to assign critical levels for any seagrass species. Research is needed to determine thresholds of constituent concentrations indicative of environmental stress.

Constituent concentrations in SAV tissue will be the most useful for evaluating environmental conditions. There may be some benefit in sampling C:N:P ratios of macroalgae also, as an index of recent water-column nutrient availability. Despite the ephemeral nature of macroalgal growth, repeated sampling over broad geographic areas might be useful to detect patterns of nitrogen and phosphorus loading.

SPECIES COMPOSITION

The physical and chemical requirements of SAV species differ, making SAV species composition a good indicator of environmental conditions. The species composition of existing macro- and filamentous algal communities can also yield information on habitat quality. The presence of *Enteromorpha*, for example, may indicate nutrient-enriched waters. Little is known about the species response of epiphytic microalgae, primarily diatoms, to specific conditions.

DEPTH LIMIT

Declines in cover of submerged macrophytes associated with degrading water quality usually occur first at the deepest edge of the beds. The depth limit of a grass bed is thus a reliable indicator of environmental quality; shoreward migration of the edge of the bed over time indicates a decrease in the availability of light at depth. Scuba diving is most often used to locate the outer limit of a grass bed. Most of the seagrass communities in the Gulf of Mexico exist in water shallow enough to use scuba for bed delineation. Alternatively, an underwater video camera can be mounted on a sled and pulled behind a boat. Use of remote sensing technology is the only practical technique for locating the edge of deeper grass beds such as those in Florida's Big Bend region. Side scan sonar may offer a second remote sensing technique for determining the presence of vegetation in deeper waters. The potential to map distributions of seagrasses on the U.S. west coast has been investigated using this technique. Further research is necessary to determine the applicability of side scan sonar to the Gulf of Mexico. The mixed species composition of seagrass communities may limit the utility of this technique in Gulf waters, as it is unlikely that side scan images would allow species determinations.

GENETIC DIVERSITY

The magnitude of genetic variability within plant populations is a function of environmental, demographic, and genetic events. Genetic diversity is necessary for long-term persistence of populations and adaptation to changing environmental conditions. A decline in genetic diversity may signal reduced resistance to environmental stresses and disease. Gel electrophoresis surveys of specific loci have been performed for seagrass beds. Although biomolecular techniques for extraction and fingerprinting of seagrass DNA are currently in research and development stages, rapid advances in forensic technology and applications suggest that routine genetic processing of biological material will soon be commercially available. The incorporation of genetic diversity into a seagrass monitoring program is dependent on the availability of technology to process large numbers of samples for genetic composition. However, starch gel electrophoresis of isozymes is well-established for *Zostera marina* and at least 1000 samples a week can be processed easily.

STRESS PROTEINS

Stress proteins are a group of compounds that are highly conserved evolutionarily and that form in response to sublethal stresses. The use of stress proteins as condition indicators stems primarily from crop research, where high levels have been correlated with such stresses as anoxia and repeated metal toxicity. The applicability of stress proteins for monitoring seagrass condition is unknown. Research is needed to determine the environmental factors and duration of exposure eliciting stress protein expression in seagrasses, as well as the thresholds of response indicating degraded habitat conditions.

ANIMALS

Animals exert strong direct and indirect influences on many of the macrophyte parameters proposed as ecological indicators. For example, urchin grazing can directly reduce leaf height and biomass. Alternatively, by controlling accrual of epiphyte biomass, mesograzers can indirectly regulate macrophyte biomass, growth, and long-term survival. The importance of higher order interactions in the control of macrophyte dynamics argues for the inclusion of meso- and macrograzers in any monitoring program; without information on animal population densities it will be difficult to ascribe changes in macrophyte and epiphyte characteristics unequivocally to habitat conditions. Grazers exhibit such extreme temporal and spatial variability that incorporation into a monitoring program using widely spaced, infrequent samples would yield little information. However, monitoring grazers concurrent with epiphyte and macrophyte parameters regularly (e.g., monthly) at permanent stations representative of larger geographic areas would contribute substantially to the understanding of local and regional habitat trends.

PRODUCTIVITY

Leaf productivity responds rapidly to changes in environmental conditions, and it is straightforward, albeit labor-intensive, to measure using leaf-marking techniques. Because of seasonal variability in productivity, annual sampling is insufficient to detect regional or long-term trends. If sampled at the appropriate time scale, however, this parameter may be one of the most diagnostic early indicators of environmental change. Monthly productivity measurements at representative permanent stations would provide an excellent assessment of local conditions.

EXPOSURE INDICATORS

Most of the parameters that stress seagrass populations exhibit extreme temporal variability, so that single, annual samples would yield no information on the extent of pollutant exposure or habitat degradation present. Working group members agreed that the only way to quantify habitat quality in terms of many of the most important stress variables is by frequent sampling or continuous monitoring at permanent stations. The number of permanent stations established would be dictated by funding. Station location should be stratified by degree of anthropogenic impacts. Sites close to urban areas are the most susceptible to change, and sites away from urban areas can provide baseline data for comparison.

Although it is possible to list exposure variables that are correlated with seagrass health and therefore should form part of a monitoring program (Table 1), scientific understanding of the causal relationships between multiple environmental stressors and macrophyte response is limited. The need for further research to validate the proposed variables as exposure indicators cannot be overemphasized: the evolution of seagrass management requires elucidation of the complex interrelationships among light availability, nutrient concentrations, epiphyte biomass and composition, macro- and mesograzer activity, and macrophyte response.

LIGHT

The most important indicator of seagrass habitat quality is the availability of photosynthetically active radiation (PAR) at depth. PAR should be monitored continuously at permanent stations. The sampling array for each station consists of a data logger connected to two spherical sensors offset vertically and separated by 0.25 - 0.5 m, depending on water clarity (see also Morris and Tomasko 1993). The sensors will have to be cleaned regularly. The frequency of maintenance visits required will be site specific; the maximum interval between cleanings will probably be two weeks or less. Light is already monitored intensively at several sites in the Gulf of Mexico as part of ongoing research efforts. EMAP should attempt to collaborate with these existing programs.

Technology is also available for continuous monitoring of chlorophyll concentration and turbidity. These measurements should be coupled with light monitoring as funds permit.

NUTRIENTS

Nutrient enrichment enhances growth of phytoplankton and epiphytic algae, and therefore can indirectly limit the amount of light reaching leaf surfaces. Dissolved nutrient concentrations are subject to considerable temporal variability; data are most meaningful if derived from frequent samples. Ideally, water quality should be measured at the same permanent stations used for continuous light monitoring. The need to visit sites regularly for light sensor maintenance provides at least biweekly opportunities to take water samples. Samples should be analyzed for total nitrogen, total phosphorus, nitrate, ammonium, and soluble reactive phosphate.

To provide a spatial assessment of nutrient concentrations and the potential sources of nutrient enrichment, frequent water quality sampling at a small number of sites should be coupled with annual or semiannual sampling at all of the sites forming the EMAP network. All nutrient sampling should be restricted to a 6-8 week window. The precise timing of nutrient sampling should be determined from existing records to minimize confounding effects of temporal variability. Ideally, periods of maximum and minimum runoff should both be included for each site in order to identify potential extremes of nutrient concentration. Samples should be analyzed for chlorophyll in addition to those nutrients identified for frequent sampling.

DISSOLVED OXYGEN

The diel fluctuation in dissolved oxygen concentration is an index of ecosystem health. Hypoxia limits secondary producers directly, and effects may also cascade to seagrasses by limiting grazers and consequently enhancing epiphyte growth. Dissolved oxygen should be measured continuously at each sampling site long enough to characterize the magnitude of diel variation and the duration of hypoxic conditions. Pilot tests of up to a week of continuous measurement should be undertaken at a limited number of sites to determine an appropriate monitoring interval for use in regional sampling. Continuous PAR monitoring at the same sites as oxygen measurement could assist in interpreting temporal and spatial patterns of oxygen concentration.

PHYSICAL CONDITIONS

Most of the seagrass parameters considered as response indicators are affected by physical conditions. Interpretation of response variables may be assisted by classifying sampling sites according to energy regime and sediment characteristics. Valuable data for such postsampling stratification include wave energy density, physical exposure index, effective fetch, tidal current velocity, sediment depth, sediment grain size distribution, and sediment carbonate and organic contents.

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SUBMERGED AQUATIC VEGETATION RESEARCH NEEDS

WORKING GROUP REPORT

by

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The purpose of this portion of the workshop was to identify and prioritize research requirements for submerged aquatic vegetation (SAV) ecosystems and give some direction to the U.S. Environmental Protection Agency concerning which research issue could be addressed with 1992 fiscal year funds. This working group also discussed problems associated with designing, implementing, and interpreting an assessment program (Environmental Monitoring and Assessment Program; EMAP) for SAV communities.

ESTABLISHMENT OF ECOLOGICAL LIMITS

There was general agreement among the members of the working group that the quality and quantity of light are the principal ecological factors that control the presence and growth of SAV and that light requirements for subtropical SAV species have not been adequately determined. Also, the minimal ecological requirements for establishment and growth of SAV species are species-specific and may vary geographically within the range of a species. Data on northern species (e.g., *Zostera* in Chesapeake Bay) are not directly transferable to predictive models for southern, subtropical systems (e.g., *Thalassia* in Florida Bay). Many more species of SAV exist in warmer waters, which compounds the problem of establishing ecological limits for SAV communities. Further, species found in coastal waters stained by organic acids probably have different ecological requirements than do different species or the same species growing in spring-fed waters.

Light requirements cannot be considered alone, because the availability and quality of light are controlled by other environmental factors. Absorption of incident light can occur as a result of water column attenuation and macroalgae-epiphyte attenuation. The amount of light-absorbing phytoplankton and epiphytic growth may be proportional to nutrient concentrations. Thus, although there is agreement that light is the principal controlling mechanism, it is necessary to quantify the relationship between light, nutrients, phytoplankton standing crop and species composition, suspended sediments, color, macroalgae and epiphyte standing crop and species composition, and grazers for each SAV community in different geographic areas.

Research to establish the minimal ecological requirements must be multifaceted and should proceed in two directions to determine:

- The causes and mechanisms of light reduction; and,

- How plants and their community respond to changes in the quality and quantity of light and other ecological stressors.

Information is needed on the effects of stressors on plant morphology and carbon balance. Also, the association between nutrients and light availability must be quantified.

Research must be performed in the field and in the laboratory (microcosms and mesocosms) through manipulation of environmental variables. Results must be modeled and their predictability tested. Research is required on development of culture methods for subtropical species of seagrasses before mesocosms can be used to establish and test limits to growth.

RESTORATION

Restoration and creation of *Thalassia* and other SAV communities was discussed at length and it was concluded that there are no documented examples of successful replacement of a *Thalassia* community. Once *Thalassia* disappears from an area, it will take a long time for that area to recover. The reasons for poor recovery, whether the area is planted or not, are many and complex. Resuspension of sediments in unvegetated areas and changes in sediment chemistry are primary factors that inhibit colonization by *Thalassia*. The working group concluded that all existing *Thalassia* meadows must be preserved and that no losses of "climax" SAV species caused by development should be tolerated.

Halodule is a pioneer species of seagrass that may recolonize a site within several growing seasons. Once a bed of *Halodule* is established, sediments become stabilized and the area may be invaded by *Thalassia*. Species, population, and community responses during decline may not be the same as those observed during recovery of an SAV community. Research is required to define optimum conditions for revegetation by SAV species and determine plant, population, and community parameters indicative of declining and recovering systems.

SPECIFIC RESEARCH TOPICS

The working group identified specific research projects for consideration for future funding, two of which were discussed in some detail. First, it was suggested that a detailed mapping and monitoring program could be used to identify research priorities. If SAV communities are mapped on a regular basis, areas of decline may be detectable before vegetation completely disappears. Research could then be initiated to assess ecological conditions and identify indicators of stress at various levels of ecological organization. It was noted that there appears to be a strong empirical correlation between presence of fringing emergent wetland communities and presence of SAV communities. Regional mapping efforts are required to substantiate this observation and, if documented, research must be performed to establish the mechanisms controlling this phenomenon.

The second research project discussed concerned establishment of the absolute maximum depth for each SAV species throughout its geographic range. Physical and chemical measurements taken over the depth distribution could be used to establish minimum ecological requirements for each species.

General concern was expressed over extrapolation of measurements and observations determined on one scale to other scales. It was agreed that scaling experiments must be performed before generating predictive models based upon site-specific observations or mesocosm manipulations.

The following is a list of the highest priority SAV research given by each member of the working group. Although specific research topics were later consolidated into broader areas, there is a benefit in reproducing the complete list here to identify the range of specific topics that were identified. Also, although many topics listed appear nearly duplicative, there is a benefit in listing the slightly different emphasis that different scientists gave to areas of similar concern.

Priority Research Topics

1. Quantify minimum and optimum physical and chemical requirements for all SAV species.
2. Quantify the link between nutrient input and light regime in different near-coastal systems.
3. Establish the "lethal dose" that results in a declining SAV community.
4. Identify the suite of environmental variables that best predicts the abundance and survival of SAV species.

5. Identify and quantify combinations and interactions of environmental parameters that control SAV distribution and abundance.

6. Identify the interaction of sublethal and lethal effects on SAV communities that are associated with water and sediment quality.

7. Investigate mechanisms of recovery of seagrass ecosystems including comparison of the relative importance of sexual and asexual propagation and community succession.

8. Determine whether remotely sensed sea turtle distribution can be used as an approximation of distribution of seagrasses.

9. Assess the usefulness of carbon balance of plants in detecting stress caused by subtle changes in water or sediment chemistry that may otherwise be undetectable.

10. Monitor genetic differences within a plant species, because they may result in regional differences in tolerance of physical and chemical parameters.

11. Investigate the intensity of plant reponses to alterations of light quantity for SAV species.

12. Quantify response of entire seagrass community, including fisheries productivity, to nutrient loading.

13. Quantify the effects of epiphytes, epiphyte grazers, and macroalgae on seagrass survival and growth.

14. Determine the impact of stressors on the balance of vegetative multiplication and flowering. Is increased flowering an indicator of stress?

15. Map distribution of SAV species over the entire region and overlay with regional maps of depth, currents, nutrient loadings, sediment plumes, and other stressors. Use mapping exercise as a hypothesis-generating tool and determine multivariate response surface for each species.

16. Analyze all existing information and make best estimate on indicators of stress and thresholds.

17. Investigate the potential impact of changes in sea levels to seagrass distribution.

18. Determine the framework for extrapolation of measurements made on one scale to other scales.

19. Investigate the biology and ecology of *Halophila* spp. Species of *Halophila* have not received much research attention and may be important to sediment stability, food chain productivity, and ecosystem dynamics.

Research topics were grouped into five main areas and summary statements were made to consolidate individual areas of concern. Major areas of required research were summarized in a model that identifies important stressors to SAV ecosystems (Fig. 4). Research efforts are required to identify and quantify responses at various levels of ecological organization to environmental stresses, including determination of thresholds.

1. Physiological responses of plants to ecological factors.

   a. Determine the physiological responses of SAV species to various levels of stresses. Does plant sensitivity change seasonally?

b. Identify a suite of plant-level responses to evaluate sublethal stresses so that environmental controls can be implemented before thresholds of population decline and change in community structure are reached.

c. Investigate the interaction between light intensity and light quality.

d. Determine the response surface of SAV to temperature, salinity, and light.

2. Responses at population level.

a. Quantify the species-specific water quality and light requirements and their interaction on long-term maintenance and establishment of SAV species.

b. Determine the mechanisms of recruitment.

3. Responses at community level.

a. Determine the interaction of epiphytes, epiphyte grazing, and nutrient loading on growth and survival of SAV species.

b. Investigate ecological variables and functions of communities dominated by *Halophila* spp.

- Does *Halophila* stabilize sediments?
- How rapidly does it turn over?
- Does *Halophila* enhance biodiversity and abundance?
- Is it a good indicator of ecological conditions?

c. Investigate the effects of macroalgae in light attenuation.

d. Determine the relationship between nutrient levels and community structure.

4. Mapping exercises.

a. Develop regional maps of SAV distribution and physical and chemical parameters to generate hypotheses and predications concerning the effects of stressors.

5. Overriding factors.

a. Research is required to distinguish between natural and anthropogenic changes in seagrass distribution and community structure. Natural cycles and impacts of episodic events must be considered. Analysis of long cores may be useful in detecting changes in community structure and correlating with historical events. Does succession or do episodic events control species dominance? What is the temporal scale of response?

b. The management policy should be no net loss of climax SAV species because conditions required for their recruitment are difficult or impossible to replicate.

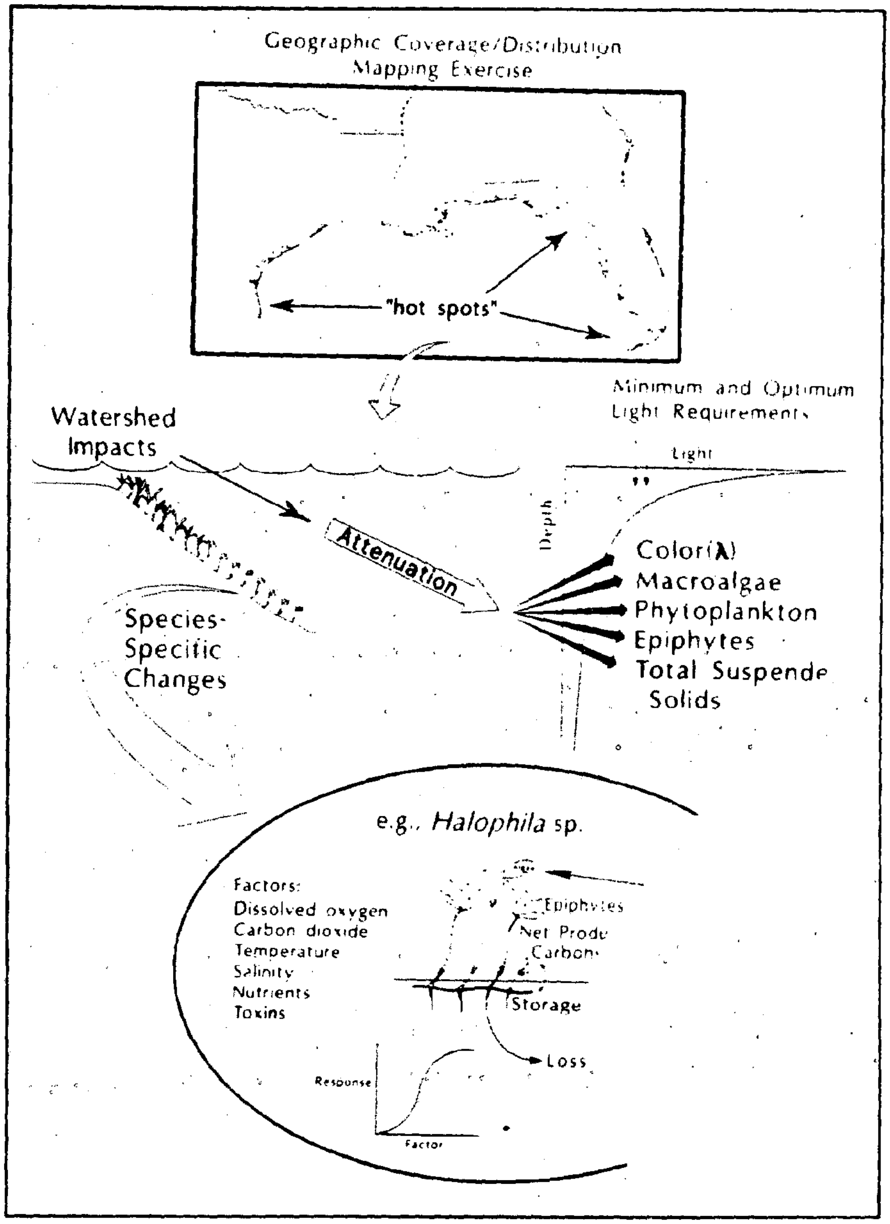

Figure 4. Summary of areas of research emphasis for SAV communities. All areas must consider scale, time, and space components.

c. It is necessary to determine the effects of watershed management and nutrient and salinity effects on light regimes in estuaries and near coastal waters.

d. Scaling considerations are necessary to allow confidence in predictive models.

e. The effects of meadow fragmentation on ecosystem function must be determined. What is the minimum patch size? Do many small patches function as well as a continuous meadow?

f. New and emerging technologies, such as DNA fingerprinting, should be applied to seagrass communities.

g. Genetic diversity of SAV species must be maintained in transplant efforts.

ENVIRONMENTAL ASSESSMENT

Environmental assessment programs (e.g., EMAP) must be carefully designed so that they have the sensitivity required to detect changes (deterioration or improvement) in environmental conditions. Careful consideration must be given to the selection of ecological indicators to assess the status of the "health" of SAV ecosystems. The nature of environmental problems and their indicators may change with regions and species. Thus, preparing a plan to assess the status of seagrasses in a large geographical area is not a simple matter.

Once a problem has been identified, the next step is to determine the causes of the problem. An environmental assessment program must be sensitive to the fact that it is extremely difficult to distinguish changes that result from anthropogenic causes, natural successional processes, or long- or short-term variations in climatic conditions. In many cases, there is not enough information on the response of SAV species to various stressors to determine the causality of SAV decline. For example, although disease (e.g., caused by *Labyrinthula* sp.) is known to play an important role in the demise of eelgrass (*Zostera*) on the North Atlantic coast and Europe, it is not clear if disease organisms play a similar role for subtropical seagrass species. Further, the association between other environmental stresses and incidence of disease must be determined and quantified.

A monitoring and assessment program must also be sensitive to the fact that SAV species may respond to stressors slowly and that environmental conditions observed when the decline is observed may not represent the same conditions that initiated the decline. Because of this time lag, natural SAV communities may not be good indicators of current environmental perturbations. However, they are excellent integrative indicators of long-term ecological conditions.

SEAGRASS CONSERVATION IN THE GULF OF MEXICO: AN ACTION AGENDA

SUMMARY OF WORKING GROUP REPORTS

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Following a day and a half spent summarizing knowledge of mapping, monitoring, and research on seagrass habitats, workshop participants reorganized to translate this information into specific actions necessary to reduce habitat degradation. Four working groups met to address the question, "What can our agencies and institutions do together to begin to reverse the trend of seagrass loss in the Gulf of Mexico?" Each group was asked to develop, by consensus, a list of the four highest priority actions for seagrass conservation. Proposed actions were to adhere to the following four criteria: 1) actions must lead to significant habitat improvements; 2) it must be possible to verify or measure whether actions have been accomplished; 3) responsible parties must be willing and able to undertake the proposed actions; and 4) any necessary financial resources must be available. Working groups were given 1.5 hours to produce their lists. The short time frame served to focus working group attention on the most urgent conservation needs.

As a springboard for discussion, each working group developed a fairly exhaustive list of potential conservation actions. Individual suggestions fell into the categories of water quality improvement, public education, habitat restoration, regulation, enforcement, research, coordination, monitoring, and seagrass sanctuaries. Various approaches were used within working groups to reach a consensus on the top priorities, including combining like statements into inclusive conservation objectives and ranking proposed actions by democratic vote. The final lists from each working group are presented in Appendix 1.

As evidenced by the high degree of overlap among the lists generated independently by each work group, seagrass experts generally agree on the immediate courses of action necessary to reverse habitat losses in the Gulf of Mexico.

Workshop participants reconvened in a plenary session to consolidate the four groups of conservation objectives into a single action agenda. The following actions were concluded to represent the four highest priority objectives for conservation of Gulf of Mexico seagrass systems.

ESTABLISH A POLICY OF NO SEAGRASS LOSS

The National Wetlands Policy Forum recommended that United States adopt a policy of "no net loss" of wetlands, to be achieved through compensatory mitigation for all permitted habitat conversions. This policy implies a 1:1 replacement for all permitted losses so that the net wetland acreage remains constant. It is exceedingly difficult, however, to successfully establish seagrass beds, so that compensatory mitigation has not yet been effective for this habitat. The best way to ensure no net loss of seagrass systems is thus to avoid impacts altogether. Written policy must allow no loss of existing seagrass communities through any permitting programs. This is particularly important in the case of *Thalassia* beds, which are the most difficult to establish through planting. *Thalassia* population growth and coverage rates are very slow, so that it takes many years for transplants to coalesce. The potential for physical disturbance, bioturbation, and depletion of fauna in the interim further reduces the likelihood of establishing a functional *Thalassia* meadow through transplanting. Therefore, permitted conversions of *Thalassia* beds invariably result in a net loss of seagrass. To date, no examples of successful replacement of *Thalassia* habitat have been documented. The only way to avoid reductions in total *Thalassia* acreage through the permit process is to stop all permitted losses.

IMPROVE WATER QUALITY

The primary cause of declines in seagrass habitat is deterioration of water quality. Restoration of seagrasses to historical levels in the Gulf of Mexico will require widespread water quality improvements, which in turn will require reduction of anthropogenic nutrient and sediment loading. Public and legislative support for necessary changes in watershed management could be gained through the development of demonstration projects linking specific reductions in nutrient discharge or sediment inputs with seagrass recovery. Research is needed to define the minimum water quality requirements of subtropical seagrass species and the sources of water quality degradation, thereby providing targets for management efforts. Minimum water quality requirements can be derived from empirical relationships between water quality gradients and seagrass distribution, as has been done in the Chesapeake Bay (Dennison et al. 1993), and the factors contributing to water column light attenuation can be determined from models relating optical properties of the water to specific water quality parameters (Gallegos et al. 1991). Experimental research should be promoted to elucidate the causal relationships between environmental variables and seagrasses at various temporal and spatial scales.

DEVELOP PUBLIC EDUCATION PROGRAMS

Legislative initiatives to protect and restore Gulf of Mexico seagrass communities depend ultimately on strong public support. Education programs must be developed to increase public awareness of and appreciation for the ecological and economic values of seagrass habitats. Public appreciation for natural resources is enhanced by involvement. Programs should therefore be designed not only to disseminate information, but also to encourage public participation in seagrass conservation. For example, regional and local programs should be developed to include citizens in monitoring and restoration activities. The words of a vocal seagrass constituency can translate into legislative support for necessary conservation measures.

FORM A SEAGRASS WORKING GROUP TO DEVELOP POLICY AND IMPLEMENT DECISIONS

Effective seagrass conservation requires the cooperative efforts of Federal, State, and local agencies, research institutions, and various user groups. A coordinated approach to Gulf of Mexico seagrass habitat conservation should be formalized through establishment of a working group representing all interests. A lead coordinating agency must be selected to facilitate interaction among representatives and to act as a clearinghouse for information. The SAV Working Group of the Chesapeake Bay Program serves as a model for coordinated efforts of scientists, resource managers, politicians, and the public; collaboration among the interest groups resulted in the development of baywide and regional submerged aquatic vegetation water quality requirements and distribution restoration targets (Batiuk et al. 1992).

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APPENDIX A

Highest priority actions for seagrass conservation in the Gulf of Mexico, as determined by individual working groups.

Group 1

- Develop, fund, and implement cost-effective sewage and storm water treatment systems.
- Establish a written seagrass policy and an implementation plan including research, agency, and public interests.
- Develop a baseline of information on seagrass distribution and abundance for the Gulf of Mexico.
- Develop and coordinate a system of citizen advisory, public education, and monitoring groups across the Gulf of Mexico.

Group 2

- Demonstrate the linkage between improvements in point source discharges and seagrass community response at specific sites.
- Reduce point source and non-point source nutrient and sediment loading to attain defensible, historical values of light attenuation for individual estuaries.
- Develop legislative and public support for seagrass systems through education.
- Require that local comprehensive plans include potential impacts to seagrass ecosystems.

Group 3

- Actively support the preservation and restoration of seagrass habitats.
- Establish a seagrass management working group with scientific, management, regulatory, and user group representatives to devel p policy and a strategic management plan for the Gulf of Mexico grassbeds.
- Build a seagrass constituency by increasing public and user group appreciation of the importance of seagrasses.
- Improve the water quality of seagrass habitats.

(*Appendix A, continued*)

Group 4

- Change no net loss to no loss of seagrasses because mitigation and enforcement are not effective.
- Promote experimental research and mapping at various scales to determine causes of habitat loss.
- Revise and enforce water quality criteria to protect submerged aquatic vegetation.
- Encourage enforcement of existing laws, policies, and rules through public education.

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