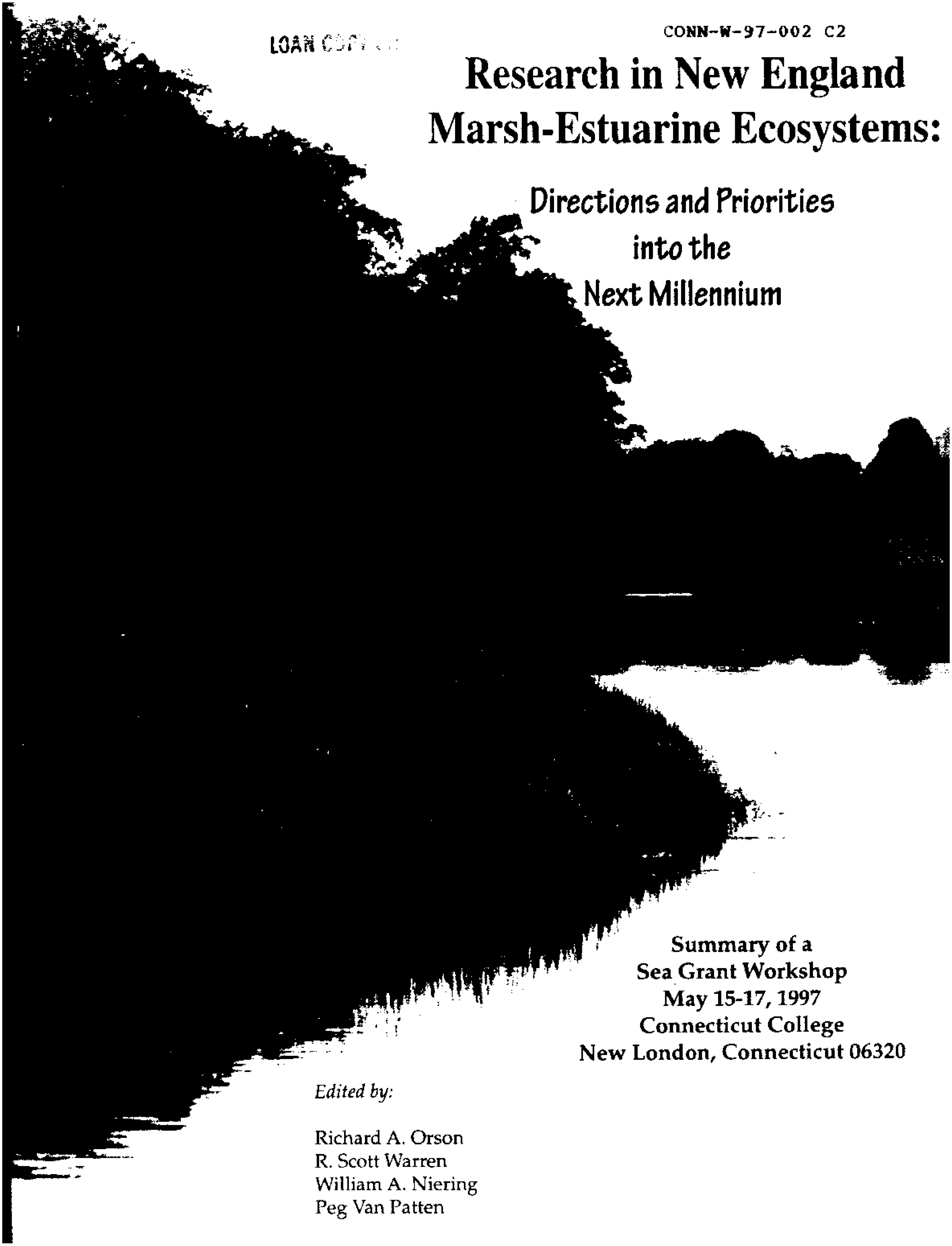

Research in New England Marsh-Estuarine Ecosystems:

Directions and Priorities into the Next Millennium

Summary of a
Sea Grant Workshop
May 15-17, 1997
Connecticut College
New London, Connecticut 06320

Edited by:

Richard A. Orson
R. Scott Warren
William A. Niering
Peg Van Patten

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"Windswept" Photo by Edna Tiemann, Old Saybrook CT

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A tidal marsh in Guilford, Connecticut, on Long Island Sound.

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FOREWORD

As the discussion in this volume makes manifest, our tidally-influenced wetlands and marshes are very complex but exceedingly valuable components of New England's coastal and estuarine environment, yet we lack much of the baseline knowledge critically needed for appropriate conservation, restoration and management decisions. This volume and the workshop that preceded it attempt to assess the current status of marsh-estuarine systems and restoration technologies from a multidisciplinary perspective, to assist us in deciding what should be restored, why, and how.

The Connecticut Sea Grant College Program was pleased to sponsor, in partnership with the Rhode Island Sea Grant College Program and the host-institution, Connecticut College, this focused workshop on "Research in Marsh-Estuarine Ecosystems: Directions and Priorities in to the Next Millennium" in New London, Connecticut on May 15-17, 1997. We were delighted that additional Sea Grant programs from Maine to New Jersey sponsored the participation of experts from their jurisdictions in this workshop.

The workshop itself, and this resulting volume, have confirmed our belief that workshops of this sort, directed at urgent or important topics dealing with our coastal marine environment, are effective tools for long-range planning and the development of potential regional research initiatives.

We particularly wish to thank the nationally recognized salt-marsh experts in the Botany Department of Connecticut College, Professor Bill Niering, Professor Scott Warren, and Dr. Richard Orson, for their leadership in the conduct of this workshop.

Dr. Edward C. Monahan
Director, Connecticut Sea Grant College Program

EXECUTIVE SUMMARY

The estuaries and coastal marshes of the northern Atlantic seaboard of the continental United States have long been recognized for their importance in maintaining the environmental health and economic wealth of the region. Even though laws now protect many of these areas from large-scale disturbances, these habitats are still under increasing pressure from many quarters, including continued urban sprawl and sea level rise. More recently these coastal habitats have faced a new challenge in the form of reduced availability of funds for research and management purposes. In order to meet the challenge of continuing to protect and understand these important natural areas, it will be up to the scientific and management communities to work closely together to direct research priorities so that the limited financial resources may be applied in the best possible direction.

The New England Sea Grant Offices sponsored a three-day workshop that brought together 25 estuarine research scientists, managers and Sea Grant personnel to assess the status of our knowledge of coastal marsh systems in New England and identify future trends in research. For the purposes of this workshop, coastal marsh systems were defined as wetlands that are influenced by tides (or would be influenced by tides had humans not interfered) and extend from the saline marshes along the coast to the brackish and freshwater marshes farther up estuary. For purposes of discussion, the upper border and adjacent uplands and areas which extend into the intertidal zone (less than 3 meter depth) that include portions of the near-shore environment such as eelgrass beds and intertidal/subtidal mud flats were also included. This definition was a working guideline for the participants, but could be extended if any group felt it was necessary.

In order to assess the information on coastal marsh systems, the workshop participants were grouped into one of five subject areas that included plants and primary production, animals and secondary production, nutrient/biochemistry, physical processes and management sciences. Each group organized the information from their particular area of expertise into one of three main categories; (1) what is currently known?, (2) what requires additional research?, and (3) what is least understood about the subject area? Within the context of these levels of understanding, the following questions were posed to aid in directing the gathering of the information; "what roles (if any) do tidal marshes play in coastal systems?", "what parameters define and modulate their roles?" and "how does human activity influence these systems?".

The question of what role tidal marshes play in coastal systems became the focal point for many of the discussions. Implicit in this question are the values associated with coastal marshes, including such paradigms as:

Tidal wetlands are nurseries for fish.
Tidal wetlands are some of the most biologically productive habitats in nature.
Tidal wetlands act as filters for the estuary.
Tidal wetlands are important flood storage systems.

Other values that were considered included aesthetics and ethics - the idea that protecting these systems is the right thing to do, regardless of value to human society.

Although it is accepted that tidal wetlands act as nurseries for a number of fish species, much work is still required on secondary productivity and the linkages between tidal wetlands and near-shore areas, particularly the role that these systems play in supporting marine transient species. On the question of biological productivity, there is no doubt that carbon and other nutrients are produced in tidal wetlands (salt, brackish and freshwater), however, the fate of these materials is still in question. Linkages between the wetland and surrounding habitats need to be defined, and sources of carbon that support secondary production need to be identified. In discussions of wetlands and their ability to filter the estuary, it was noted that the relationship between peats and intertidal muds still must be determined. There was general agreement that the wetlands are acting as filters for sediments to a point. However, the sequestering and retention of metals and pollutants may be indicative of a trap rather than a filter. Flood storage and other hydrologic characteristics were important topics yet to be examined. The sponge analogy is a good concept and like a sponge, once it is saturated, water storage does not increase; however, the rate of release is influenced, so there is some benefit. Flood storage leads directly into the topic of wetland hydrology, a field of study that was identified by all groups as requiring additional research.

The second question required identification of the parameters that define and modulate the role of these wetland systems to the landscape. This included identifying important forcing functions particular to a system, determining independent and dependent variables that may control or influence tidal marsh areas and establishing and identifying geographic variables and variation along latitudinal gradients. For example, one subject area that will require attention in the future is the lack of gradient analysis both within and between systems. Our understanding of the changes in productivity along salt gradients and the exchange of nutrients between the various salinity regimes within a system is very limited. Across regions, few attempts have been made to connect processes across latitudinal gradients. It was also observed that forcing functions must be better identified and held constant when comparing systems between different geographic regions (i.e., ice impacts on the marshes in northern and southern New England).

The last question posed to each group was to define the impacts and influences anthropogenic activities have had on these systems. Besides the obvious physical impacts, a number of other factors were identified. For instance, disturbance is common to all natural systems (i.e., fire, hurricanes, sea level rise), however, are human induced disturbances different in scale or rates of change or are they just another type of disturbance (paleoecology will be important here). Further, can anthropogenic influences be reversed and if so how may that be accomplished. Certainly, coastal marsh systems that have been impacted by human activities can be utilized as a large scale natural laboratories to identify and assess specific disturbances (i.e., restriction of tidal hydrology), the question then becomes "how can we best incorporate this aspect into our research".

One result of the workshop was to identify a serious lack of information for the tidal fresh and tidal brackish wetlands. Indeed, our understanding of the mid to upper estuary is so limited that even some of the most basic questions in ecology could not be answered (i.e., plant community structure, primary productivity gradients). Therefore, the upper estuary was identified as an area of immediate concern for future research plans.

To help improve our understanding of these systems and fill in major gaps in our information, the following topics were identified by the workshop participants as primary areas of concern for future research in New England systems:

Hydrology
Secondary Productivity and its Linkages to Fisheries
Identifying when a Disturbance is a Disturbance (natural vs. anthropogenic)
Basic Ecology of the Mid and Upper Estuary (brackish and freshwater)
Developing and Testing Quantitative Models (The "Big Picture")
Information Exchange between Scientists and Managers
Scientific Criteria for Assessing Management

Having identified the important gaps in our knowledge of tidal systems, there are a number of approaches (listed below) that were identified that could be used to improve our understanding of tidal marsh systems:

Utilizing regional comparisons
Identification of and response to forcing functions
Manipulative studies using altered wetland habitats as a natural laboratory
Using an ecosystem approach rather than an individual species approach
Using target species to understand wetland processes
Careful resource inventory and assessment
Adapting and testing of quantitative models
Interpreting the geological/paleoecological record
Coordinating research between regions and information exchange between all sectors

The workshop participants agreed that in many instances current information appears to be too site specific and attempts must now begin to focus on a more generalized approach to our understanding of how these systems function. It was also the opinion of the workshop participants that, at least for some subjects, the data is available to begin to test broad ranging theories, especially in areas of nutrient exchange and plant community structure.

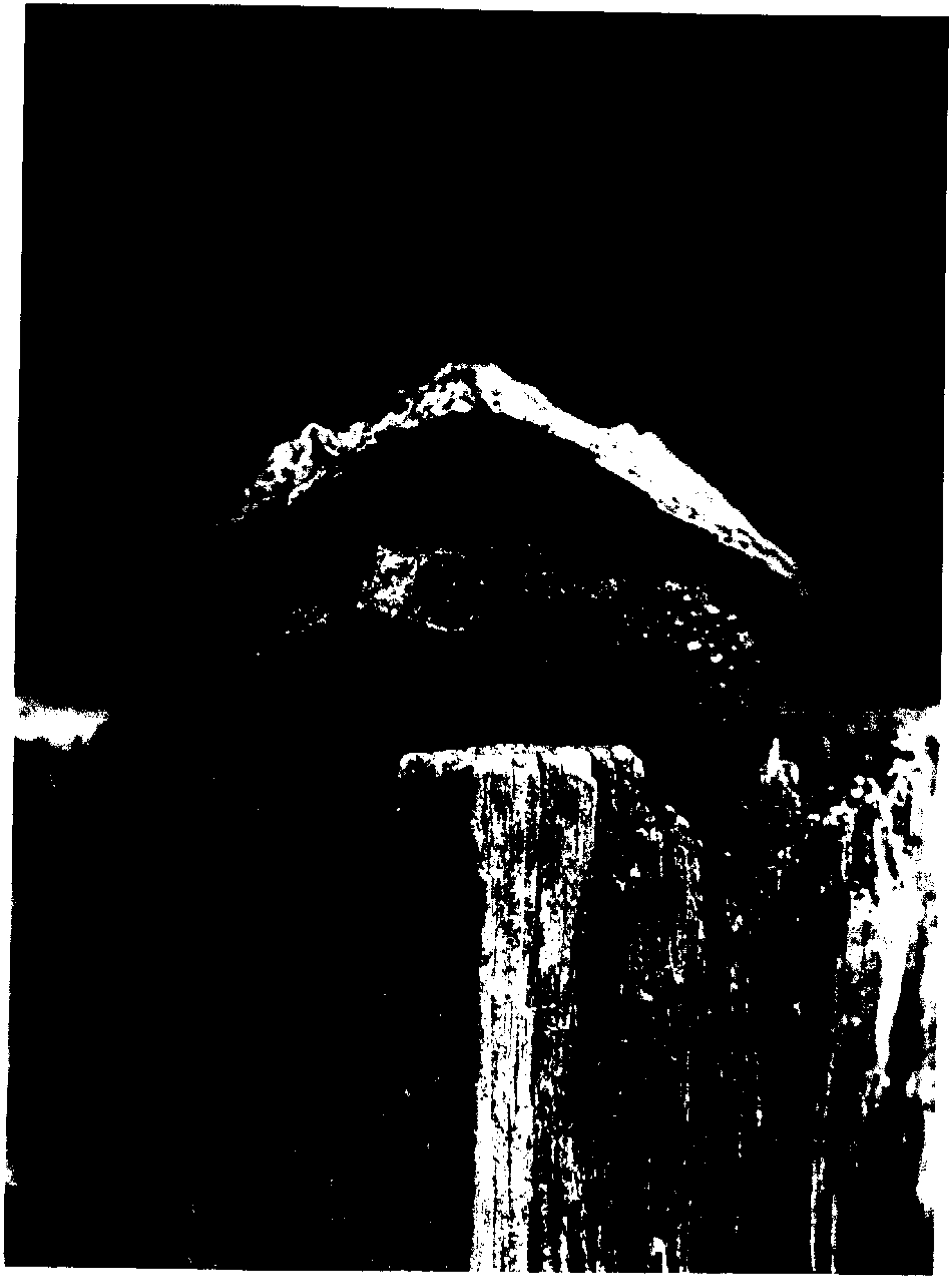
The results of the workshop are being presented to help guide Sea Grant and other funding agencies in their task to direct limited funds towards improving our understanding of these systems and help advance coastal marsh sciences into the next millennium.

ACKNOWLEDGMENTS

The Editors would like to thank all of the New England Sea Grant College Programs, particularly the offices of Connecticut Sea Grant, Dr. E. Monahan, Director and Rhode Island Sea Grant, Dr. S. Nixon, Director for their support in this project. A note of appreciation is extended to Connecticut College for financial and facilities support. We also want to acknowledge the workshop participants for their input and dedication to this project. Illustrations were graciously provided with permission from the Connecticut College Arboretum, Glenn Dreyer, Director, except where noted.

Richard A. Orson
Workshop Chair

TABLE OF CONTENTS



Chapter One: INTRODUCTION

Statement of Purpose:

The estuaries and coastal marshes of the northern Atlantic seaboard of the continental United States have long been recognized for their importance in maintaining the environmental health and economic wealth of the region. Even though laws now protect many of these areas from large-scale disturbances, these habitats are still under increasing pressure from many quarters, including continued urban sprawl and sea level rise. More recently, these coastal habitats have faced a new challenge in the form of reduced availability of funds for research and management purposes. In order to meet the challenge of continuing to protect and understand these important natural areas, it will be up to the scientific and management communities to work closely together to direct research priorities so that the limited financial resources may be applied in the best possible direction.

Workshop Approach:

Although coastal marsh systems have been the focus of scientific research for over a hundred years, there are still many gaps in our knowledge of these systems which need to be addressed if we are to successfully manage this coastal resource. The place to start, therefore, is identifying what is and isn't known about these coastal marsh systems. In order to identify the status of the science pertaining to coastal marsh systems, the New England Sea Grant Offices sponsored a three-day workshop that brought 25 northeast research scientists, managers and Sea Grant personnel together to identify current trends and knowledge of these marsh systems. The workshop was divided into two major divisions including research specialty groups in one of five particular areas of interest (plants, animals, nutrient/biochemistry, physical and management sciences) and a collective session which identified and synthesized the findings of the specialized groups and interdisciplinary discussions.

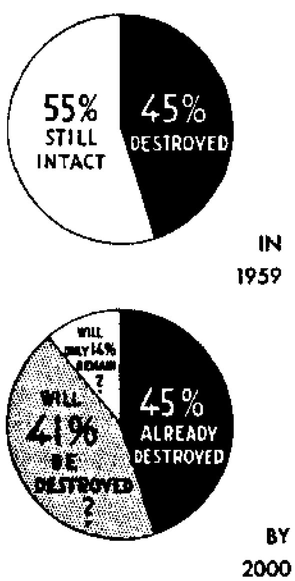
It has long been recognized that there is a continuum between all landscapes and that one cannot separate one from another. However, attempting to study all landscapes at the same time becomes unwieldy to manage. It is therefore important to begin by defining what we considered in our discussions of coastal marsh systems (Figure 1). For the purposes of this workshop, coastal marsh systems were defined as wetlands that are influenced by tides (or would be influenced by tides had humans not interfered) and extends from the saline marshes along the coast to the brackish and freshwater marshes further up the estuary. For purposes of discussion, we also included the upper border and adjacent uplands and areas which extend into the intertidal zone (less than three meter depth) that include portions of the nearshore environment such as eelgrass beds and intertidal/subtidal mud flats. This definition was a working guideline for the participants, but could be extended if any group felt it was imperative.

The workshop identified three main approaches to use in organizing and assessing the information on coastal marsh systems. The first question asked was "what roles do tidal marshes play in coastal systems?". Implicit in this question are the values associated with coastal marshes, including: are coastal marshes important nurseries for fish (particularly transient species)? Do these marshes act as filters for the landscape? Is flood storage an important role for these systems? Do these marshes cycle air pollutants and other anthropogenic impacts on the estuarine environment? Some newer values that must also be addressed include aesthetics and the perception that protecting these systems is the right thing to do, regardless of value to human society.

Systematic Approach:

The next stage in assessing the current status of the science was to identify which parameters define and modulate the relationship of these wetland systems to the landscape. This required identifying important forcing functions particular to a system, determining independent and dependent variables that may control or influence tidal marsh areas and establishing and identifying geographic variables and variation along latitudinal gradients.

What is Happening to
CONNECTICUT'S TIDAL
MARSHES?
36.5 Square Miles in 1914



Finally, after the roles and parameters were defined, then anthropogenic impacts or influences on these systems were identified. While disturbance is common to all natural systems (i.e., fire, hurricanes), it is not known whether human induced disturbances are different in scale or in rates of change or whether they are just another type of disturbance. Further, it is important to find out if anthropogenic influences can be reversed, and, if so, how can that best be accomplished. Coastal marsh systems that have been impacted by human activities can be utilized as large-scale natural laboratories to identify and assess specific disturbances (i.e., restriction of tidal hydrology). The question becomes how to best incorporate these natural laboratories into our scientific investigations.

Publication Goals and Approach:

The information presented in this report is based on the findings of the three-day workshop. The findings from each specialty group is reported in separate chapters. Each chapter includes the basic information as well as the areas of research that the participants felt were most important for defining how these systems function and what research will be required over the next ten to twenty years. Although the workshop focused on New England systems, discussions included issues facing coastal marshes in general. The final chapters include a synthesis of these ideas and approaches which may best answer some of these questions from an interdisciplinary perspective.

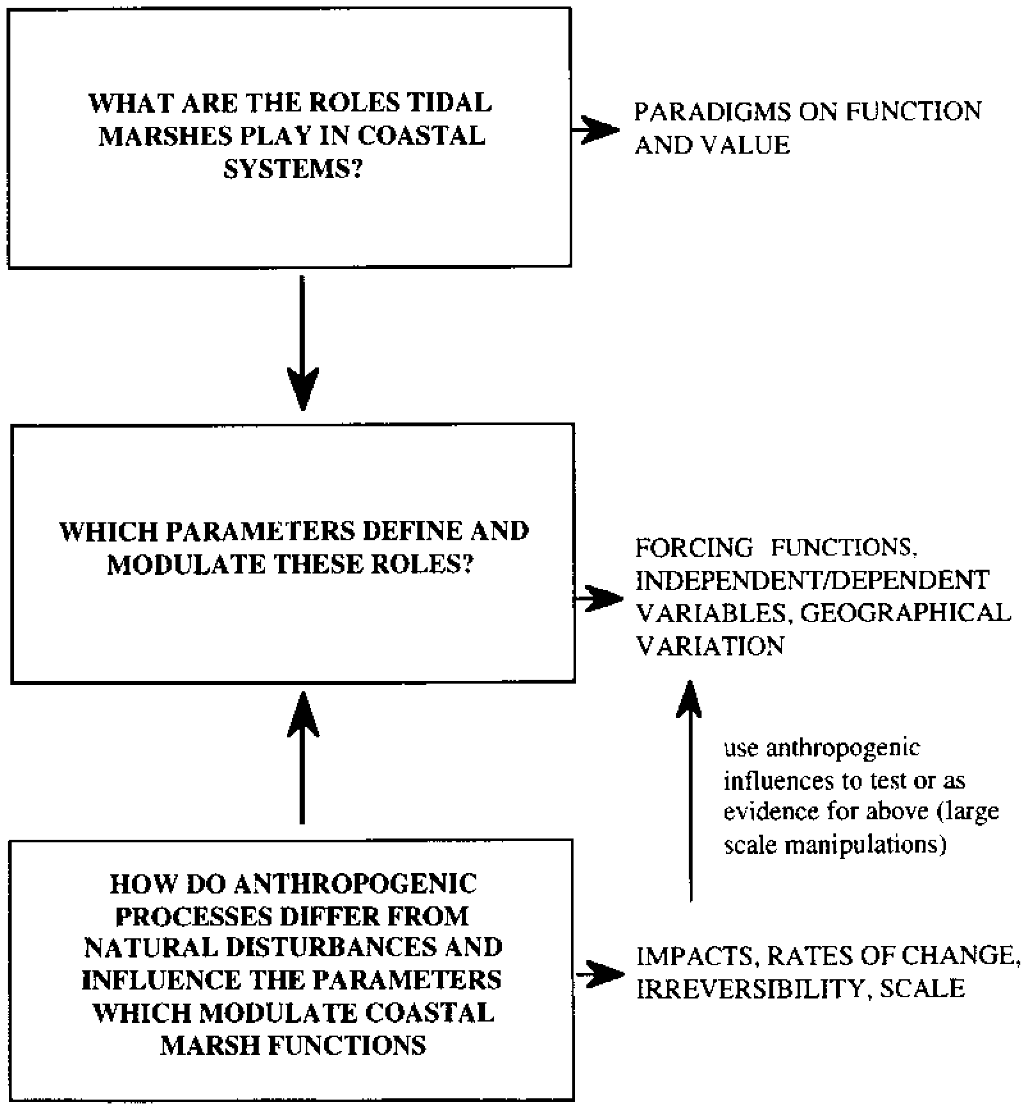


Figure 1. Flow chart showing linkages between the different parameters.

Chapter Two: PHYSICAL PROCESSES

PHYSICAL PROCESS CONTROLS ON TIDAL WETLAND DEVELOPMENT

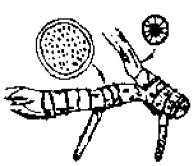
Participants:
Dan Belknap - University of Maine
Ed Monahan - Connecticut Sea Grant Office
Richard Orson - Connecticut College
Johann Varekamp - Wesleyan University
Larry Ward - Jackson Lab, University of New Hampshire

The PHYSICAL PROCESS group identified a number of subject areas important in our understanding of how physical processes influence these systems. Section I identifies the topics for which we appear to have adequate information at the present time. Sections II and III identify those areas where less is known about the subject. Within these assessments, individual topics have been singled out for additional research such as the need to improve our understanding of marsh hydrology and our ability to interpret when a disturbance is actually a disturbance to wetland developmental processes.

New England tidal marshes have received extensive attention from geologists and geomorphologists for more than a century. The early models for marsh development include the Mudge (1858) concept of transgression of the marsh over upland, including abrupt invasion of freshwater systems (Penhallow, 1907), and the Shaler (1886) model of regression of salt marsh over tidal flat and sea grass beds. The classic synthesis by Redfield (1972) incorporates both concepts in a back-barrier setting, in response to rising sea level and progressive sheltering by a barrier spit (based on Sandy Neck, Barnstable, Massachusetts). Investigators such as Bloom (1964) and Kaye and Barghoorn (1964) studied accumulation and compaction in marshes, relating the peat record to rising Holocene sea levels. These studies set the stage for a wide range of modern research into the geologic setting, stratigraphy, sedimentology, and physical process controls in marshes. Present work includes detailed analysis of stratigraphy and paleoecology using plants and microfossils, geochemistry and isotopes. Detailed investigations of marsh hydrology, including surficial currents and groundwater flow, have begun to elucidate transport mechanisms. Most importantly, recent work has begun to integrate a systems view of tidal marshes in coastal environmental settings, as a component of estuarine, backbarrier, and upland-fringing environments. Marshes have long been a meeting place for interdisciplinary scientists, and future work will require an even greater collaboration among sedimentologists, botanists, paleoecologists, stratigraphers, physical oceanographers, paleontologists, and other coastal systems scientists.

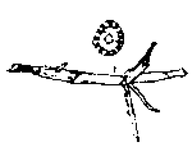
In order to plan for future research in tidal marshes, it is useful to take stock of what we know reasonably well, what we understand to be debatable or unclear at the present time, and what areas clearly require extensive research to understand tidal marsh development, evolution, modern processes, and potential for change. The following discussion is broken up into these three areas, and then summarized in a table of topics.

Spartina alterniflora



Distichlis spicata

Juncus gerardi



Spartina patens

I. CURRENT UNDERSTANDING

A. Geomorphic Setting

It is quite well known that geomorphic and geologic setting influence the type of marsh produced and its evolution. For example, marshes may occur in riverine margin, upland fringe, back-barrier, or open coastal settings. Antecedent geology and topography further control drainage, thickness of peat accumulation, and influence stratigraphic evolution. As with many coastal systems, tidal marshes are best studied as part of a geomorphic site - process response system, considering influences such as external sheltering or exposure, sediment supply, tidal range, and climatic setting. For example, upland fringe marshes transgress the land, altering the upland environment and encasing earlier soils and freshwater vegetation beneath an increasingly marine-influenced peat. Marshes in tidal river valleys are strongly affected by the topography and the stream, commonly recording numerous lateral shifts of the channel, with only the upland fringes recording a relatively complete sequence. Broad marshes on gently sloping substrates record the upland transgression and, in addition, often show evidence for progradation and a regressive sequence as sea-level rise slowed in the late Holocene. The outer edges of these marshes are affected by ongoing estuarine edge erosion. Back-barrier marshes are more influenced by barrier migration and overwash, as well as shifts in tidal inlet positions.

B. Stratigraphic Record

Tidal marsh sediments can provide an excellent stratigraphic record, preserving proxies for geologic history in a relatively continuous sequence of accumulation. Sea-level change is well recorded in marshes, by plant fossils and other markers. Marsh stratigraphy also records the relative balance of sea-level rise and subsidence (accommodation space) versus sediment input. Sediment comes from external sources (allochthonous), primarily terrigenous clastic silt and clay, as well as organic materials that grow in place (autochthonous). Marshes also record the rare event, such as flood sediments or washover sand brought into the marsh by extreme events.

C. Developmental Processes

Marsh development processes are understood on the moderately short-term scale. These include accumulation of peat, admixture of suspended sediments, and relative preservation of organics in the water-saturated low oxygen zone. There are clear differences between rapid accumulation in low marshes, dominated by *Spartina alterniflora* and abundant clastic sediment, and accumulating up to centimeters per year, and the high and higher-high marsh, dominated by *Spartina patens*, *Distichlis spicata*, and *Juncus gerardii*, accumulating fibrous peat low in inorganic sediment at rates of millimeters per year.

D. Hydrology

Hydrology of surficial processes, such as flow in tidal creeks, riverine and estuarine current patterns is moderately well known. Timevelocity asymmetry of flow, and aerial differences in flow velocities, tidal range, and tidal curve phase shifts are reasonably predictable. Response to aperiodic events is documented, although less well known.

E. Function

The standard concept of marshes serving as storm buffers, by decreasing wave attack on uplands, is well established. However, details of sediment transport and relationship of frontal loss to surficial accumulation are not well known.

II. AREAS IN NEED OF ADDITIONAL RESEARCH

A. Marsh Functions

It has been casually stated for many years that marshes act as filters or traps for pollutants and turbidity. Is this true? In fact, it is quite debatable whether marshes filter out or trap heavy metals, pesticides, and flotsam. The actual case may be unclear, the marshes may simply adsorb a certain load, and then release portions, resulting in a new equilibrium flux, or throughput, of material. The case for nutrients is even less certain: do excess nitrogen, phosphorus and other compounds increase productivity in the marsh, thus removing nutrients from the water column, or is there an equilibrium flux there as well?

B. Tidal Range

Tidal range effects are not well understood. There is an active debate being fueled by observations that increases in rates of sediment accumulation accompany increases in tidal range in Connecticut marshes, versus the observation that tidal range has little impact on sediment accumulation rates in Maine marshes. Similarly, there is a distinctive increase in the vertical range of low marsh plants from the low tidal range in Long Island Sound, through the Gulf of Maine and into the Bay of Fundy, but the high marsh vertical range increases only slightly. This has important consequences for understanding sea-level curves and potential records of changes in tidal range through the Holocene.

C. Ice

Ice effects are a regionally important phenomenon. Ice effects have been studied in detail in the St. Lawrence River, but only preliminary work has been done in the Gulf of Maine and almost no work has been completed for southern New England.

D. Substrate Compaction

Marsh peat compaction is a well-known phenomenon, resulting in deformation and compression of the record (Kaye and Barghoorn, 1964). However, the exact causes, and variation with marsh composition is not well understood. Dewatering and decay of organic material occurs at different rates depending on depth in the succession, and regional differences in temperature and organisms has a significant, but poorly studied, effect. For example, some northern New England marshes appear to show little compaction displacement of dated peats, due either to inorganic content or possibly even to ice pre-compaction (Belknap et al., 1987; Kelley et al., 1995). In mid-Atlantic marshes, however, differential compaction is clearly demonstrated (Belknap and Kraft, 1977). Recently, Pizzuto and Schwendt

(1997) have reported on modeling studies of autocompaction in Holocene marsh muds, and find that autocompaction has resulted in lowering of marsh surfaces at one-third to one-half the rate of sea-level rise. The compaction occurs primarily within the organic-rich layers.

III. LEAST UNDERSTOOD SUBJECT AREAS

A. Gradients

Among the many aspects of physical processes of marshes that are not well understood are the regional gradients in marsh type: geographic and climatic gradients, tidal range, ice effects, and geo-botanical interactions. Much more research is required to compare Bay of Fundy, Gulf of Maine, Long Island Sound, and mid-Atlantic marshes.

B. Sedimentation Processes

Sediment sources and pathways are seemingly obvious, but in fact, the details of dominant sources of sediment (eroding bluffs, fluvial input, inlet inflow, ice rafting, storms and floods versus normal processes) are very poorly understood. A wide-ranging and detailed study of mineralogy, textural, and accumulation rate is necessary to separate the processes. The potential for unraveling the history of changing sediment sources, such as background/ natural versus colonial deforestation or modern urbanization raises important questions for mitigation of anthropogenic effects. One approach to understanding sediment sources is to search for unusual pulses, such as the effects of the 1938 hurricane, or other historically documented storms, to potentially supply marker horizons to quantify rates of accumulation of marshes (Orson et al., in press). Sediment budgets, including short and long-term differences, have proven very difficult to complete, because of unknown sinks and sources, inaccurate measurements of fluxes, and the like. Advances in techniques and better understanding of reservoirs and fluxes is required to close the loop in budget studies.

C. Peat Record and Recorded History

A large unknown is: what does the peat record show - how incomplete and/or biased is the record? The development trajectory for peat is only known in a sketchy manner. Peat is a complex of inorganic and organic sediment. It undergoes partial decomposition, dewatering and compaction with time, yet many New England peats retain identifiable rhizomes and other plant parts for thousands of years. What is lost in this partial decomposition and compaction, and how biased is the record from the preserved fraction? These subsurface processes are difficult to model or determine experimentally in a laboratory setting, and require extensive field study.

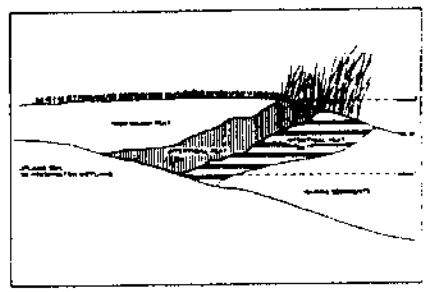
D. Marsh Transgressive Sequences

A related subject is the processes operating at the leading edge of the transgressive system - development and evolution of the early stages of the marsh. In some areas, salt marshes transgress peat bogs (e.g., Jonesport, Maine). More commonly, marshes lap onto uplands, submerging woodlands, soil on slopes, or *Typha* and *Phragmites* wetlands. The resulting changes in soil composition, changes in groundwater flow, and sediment input are poorly known.

On the other edge of the marsh, processes of erosion or redistribution are poorly understood. Tidal creeks show evidence for erosion, including large block failure, in some areas, yet long-term air-photo analysis suggests relative stability. Eroding cliffs and tidal creek banks tend to calve off blocks that fall into the mid-tide range, where they are rapidly colonized by *Spartina alterniflora*. The potential rate of sediment accumulation in this low marsh is orders of magnitude higher than on the high marsh, resulting in a rapid return to mean high water level. This recolonization and accretion method is a natural feedback mechanism that stabilizes the marsh. Only the most general aspects of the rates, aerial extent, and importance of this mechanism, and the crucial role that *Spartina alterniflora* plays in it, are yet understood.

E. Sea-Level Rise

Marsh Transgressive Sequence
(after Redfield 1972)



A critically important corollary to these questions is the relationship of peat development to sea-level rise; that is, the production of accommodation space versus accumulation and subsidence. Only the most general trends in sea-level change are now known. These sea-level trend curves are most reliable when constructed from basal peat dates. Within the peat section, detailed analysis of geochemistry, foraminifera, pollen, and other indicators can reveal high-frequency fluctuations, possibly related to global climatic events (e.g., Gehrels et al., 1996; van de Plassche, 1989, 1992; Varekamp et al., 1992). These analyses establish the "indicative meaning" of the sea-level points, the relationship of a peat component to the sea-level in which it was deposited. These studies elucidate two different time scales: long-term trends vs. decadal-century cycles or pulses. Much more work is needed in these areas both locally and for regional correlation.

F. Hydrology

There is very little published on the hydrology of the marsh subsurface, either groundwater or in-peat flows (i.e., Harvey et al., 1995). Groundwater may affect vegetation zonation and trajectories of peat alteration. Low permeability within the peat column creates waterlogged sediments. Interaction between peat groundwater and surface flows creates the hydrology of salt pannes. The detailed mechanism of these systems are only now being studied, in limited areas. Similarly, detailed hydrodynamics and sediment transport mechanisms on the marshes have rarely been done in New England marshes. Recent advances in thin-film anemometry has allowed measurement of the currents within the marsh plant canopies (e.g., Leonard and Luther, 1995).

G. Pannes and other Surficial Features

Salt pannes have long been a mystery in marshes. Pannes serve important ecological functions, including serving as nurseries for juvenile finfish and as ponds for migratory waterfowl. There are a number of competing hypotheses for panne formation and evolution, i.e., rotten spots, ice plucking, evolution from tidal flats, hydrological control, and creek cut-offs, not to mention human excavation or trampling by cattle. It is not well understood how pannes relate to health or age of a marsh, and geographic differences are poorly understood. The identification of salt pannes in marsh peat sequences is difficult, and in fact pannes are seldom recognized in the stratigraphic succession. Such down-core analysis requires further research into potential stratigraphic markers, such as *Ruppia maritima* seeds. Study of the evolution of salt pannes has potential for new discoveries about marsh evolution in general, and potentially into differences between modern marshes and those of pre-colonial times.

H. Pollution Impacts

Pollution of marshes is an issue covered in other subgroups, but deposition of heavy metals and other pollutants can act as excellent marker horizons in marshes for determining sedimentation rates, and fluxes of material. It is unclear whether the accumulation of such compounds is purely by deposition, or by enhanced adsorption, complexing, or scavenging. There are many unresolved issues over whether pollutant flux scales with drainage basin area, how regional variations depend on atmospheric deposition versus drainage basin input, and other related issues. The use of anthropogenic inputs as dating mechanisms, such as the accumulation of ^{210}Pb and ^{137}Cs in salt marshes are presently compromised by a poor understanding of sources. For example, atmospheric deposition is assumed, but some material may be reworked from upland sources and brought in through the drainage basin.

I. Separating Anthropogenic Influences from Natural Cycles

Finally, a critical area of research is the monitoring of stress in marshes. Are marshes being significantly altered by human activity, both on the local and regional scale? Is recent acceleration in sea-level rise, documented by tide gauges over the past 80 years or so, resulting in submergence? Is submergence causing widespread alteration of marsh zonation, or even causing marshes to drown in place? Monitoring for anthropogenic change must take these global, regional, and local effects into account, to separate the causative factors. Only then can recommendations for amelioration or restoration be effective.

Table 1. Quantifying rates of change in tidal wetlands

NATURAL FRAMEWORK FOR DEVELOPMENT	SEDIMENT & BIOLOGICAL PROCESSES	HYDROLOGY
Sea-level rise Antecedent Geology Stratigraphy Dating techniques & rates of change* Subsurface processes* Peat record Indicative meaning* Archive & predictive tool Peat Development	Traps vs. filters * Sediment Transport Accumulation/accommodation Pulse vs. Cycle relation to tidal range Panne formation Peat cliff/tidal creek margins Ice processes	Surface runoff tidal Groundwater * Flood storage Ice processes
	COMPARATIVE/RELATIONS	
Anthropogenic * Δ sea level Clearing of watershed Time history of influxes: metals, sediments	137-Cs Pollen	Δ flood storage Restrictions

Modifiers of above: Time Scale, Regional Gradients

*Important Priorities

Chapter Three: PLANT INTERACTIONS AND PRIMARY PRODUCTION

PLANTS AND PRIMARY PRODUCTIVITY

Participants:
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David Burdick - University of New Hampshire
Peg van Patten - Connecticut Sea Grant Office
Charles Roman - US Geological Survey/University of Rhode Island

The PLANT/PRIMARY PRODUCTION group identified a number of subject areas important in our understanding of plant community structure and primary productivity. Section I identifies the topics for which there appears to be adequate information at the present time. Sections II and III identify those areas where much less is known about the subject. Within these assessments individual topics have been singled out for additional research such as the need to improve our understanding of the fate of standing crop (carbon) and the need to investigate the role of microalgae in these systems.

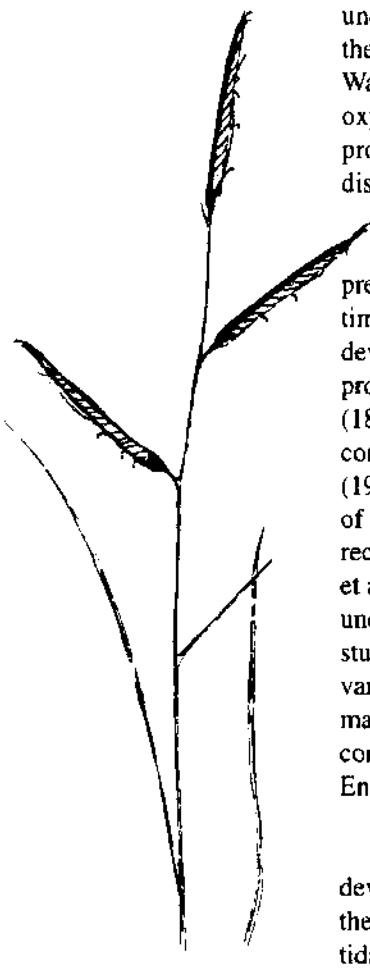
New England tidal marshes have been studied extensively during the last 100 years. Some of the most classic papers in marsh ecology are based on studies centered around New England systems (Nichols 1920a, 1920b, Miller and Egler 1950. Redfield 1972). Basic marsh ecology and plant community structure has been addressed through the years by Nichols (1920a, 1920b), Miller and Egler (1950), Chapman (1960), and Niering and Warren (1980). Factors that influence the distribution of plant species have been investigated by Britton et al., (1915), Taylor (1939) and Shea et al., (1975) and processes important in understanding marsh development are represented by Mudge (1854), Davis (1910), Knight (1934), Bloom and Ellis (1965) and Redfield (1972) among others.

Taken together, the literature on New England tidal marsh systems has provided a detailed understanding of a number of aspects of marsh ecology, making these systems some of the best understood in marine science today. However, even though there are many aspects that are well understood, gaps remain in our information that limits our ability to completely understand how these systems function on the landscape. The following sections outline the status of our knowledge of plant life in these systems and identifies those subject areas that will require additional research.

I. CURRENT UNDERSTANDING

A. Plant Community Structure.

The structure of the dominant angiosperm community of the New England type tidal marsh (Chapman 1960) is well documented. The dominant plant communities are distributed in belted patterns across the marsh surface, best described as a mosaic of vegetation types by Miller and Egler (1950). These associations were further refined by Chapman (1960) and Niering and Warren (1980) who related distribution patterns and vegetation dynamics to detailed elevational studies. The generalized vegetation bisect presented by Niering and Warren (1980) may be applied to a majority of the New England type salt marsh. Besides knowledge of the plant community structure, a number of studies have provided us with an understanding of the factors that influence the distribution of plants within the community. Studies on salinity (Taylor 1939), elevation (Niering and Warren 1975), nutrients (Nixon and Oviatt 1973a, Valiela et al. 1978), oxygen (Woodfin 1976) and interspecific competition (Bertness 1991) have provided us with a good understanding of what primary factors influence the distribution of these species.



Saltmeadow Cordgrass
Spartina patens

B. Stratigraphic Record and Developmental Processes

Tidal marsh peats have provided an excellent stratigraphic record, preserving both the geologic history as well as vegetation changes through time. Information about long-term sea-level change and marsh developmental processes have been well documented by some of the most prominent studies in the field. The works of Mudge (1858) and Shaler (1886), the earliest attempts to understand marsh development were both conducted on marshes in New England. Subsequent research by Davis (1910), Knight (1934), Bloom and Ellis (1965) and Redfield's classic studies of the 1960's (best summarized and assessed in his 1972 paper) and more recent by those of Orson and Howes (1992), Varekamp et al., (1992), Roman et al. (1997) and Orson et al., (in press) have provided a high degree of understanding of how marsh systems develop through time. Together these studies have shown that New England marshes are responding to sea-level variations over thousands of years and that they are capable of recording many aspects of history in the stratigraphic record. Indeed, when one considers the body of research on this subject, the ontogeny of the New England type marsh is the best understood of all tidal marsh systems.

C. Anthropogenic Influences

Human development of the coastline has had many impacts on the development and health of the coastal marsh system, the most obvious being the expansion of reedgrass into former salt marsh areas. Roadways and other tidal restrictions have been well documented as to its influence on marsh vegetation patterns (Niering et al., 1977, Roman et al., 1984) as have mosquito control ditches (Britton et al., 1915) and infilling (Niering and Bowers 1966). European settlement and early historic changes (farming, milling industries) are not well documented.

Restoration of tidally restricted marshes have been relatively successful through the years, depending on the degree with which tidal flushing can be reintroduced into the system. In Connecticut, for example, marsh vegetation will replace much of the reedgrass within a period of about ten to twenty years without further controls (Barrett and Niering 1993). Although this time frame may be reduced with the addition of active management techniques (i.e., burning, applying herbicides), such an approach also increases costs (Portnoy and Giblin 1997).

D. Function

The standard concept that the primary production of coastal marshes is high is well established (Steever et al., 1976, Nixon and Oviatt 1973b) although the fate of the carbon and other nutrients remains in question (Nixon 1980).

II. AREAS IN NEED OF ADDITIONAL RESEARCH

A. Plant Community Structure

Although the dominant angiosperms have been documented in the New England type salt marsh, there are still areas of information where our understanding is less than complete. For example, relatively little information exists for the Bay of Fundy type (Chapman 1960) marsh and will require attention in the future. The increased role of reedgrass (*Phragmites australis*) in the New England type system is also somewhat puzzling. Reedgrass, a relatively common upper border plant, is now making its way onto the marsh surface. Although a good portion of its expansion can be tied to tidal restrictions (Roman et al. 1984), there are aspects of its distribution today that don't fit known patterns of expansion for this species. Colonization into areas not restricted from tides and inundated regularly with saline waters appears to be new to this plant. Although this plant is native to New England (Orson et al. 1987) some recent work has suggested that we might be dealing with a genetic variant, one that is more aggressive than its predecessor (Besitka 1996). Therefore it will be important to expand our understanding of this grass, particularly as we attempt to control its distribution through management practices. It will also be important to define the role reedgrass plays in these systems and document the ecological function of reedgrass habitat.

Saltwater Cordgrass
Spartina alterniflora

B. Submerged Aquatic Vegetation (SAV)

The distribution of eelgrass (*Zostera marina*) for portions of New England is well documented, however, there are still some aspects about the plant that require additional research. For example, very little information exists about the distribution of this plant in Connecticut. Questions about its disappearance in the 1930's and 1940's are still not decided (pollution vs. disease). Other problems such as "how does pollution influence this plant today" and "will it be possible to restore eelgrass beds to their former habitats" are some of the questions that still require our attention.

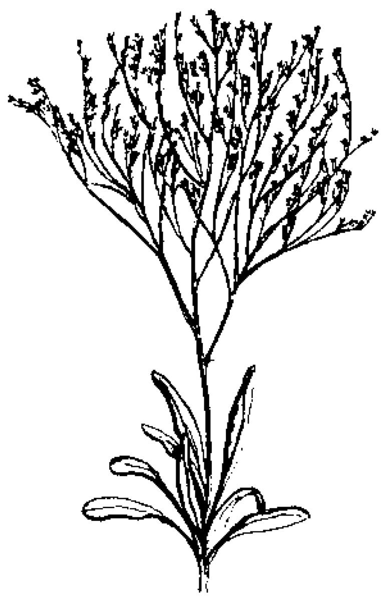
C. Algal Communities and Other Interactions

The identification and distribution of marine algae in New England has been documented by Taylor (1957). However there are still some serious gaps in our knowledge of these plant systems. For instance, what role do macroalgae play in overall bioproductivity of the salt marsh system? The interactions between microalgae, macroalgae and angiosperms still requires attention, particularly as attempts are made to understand the linkages between coastal marshes and open water habitats. The ecological function of microalgae still remains unknown. Additional research will be required before we can link these plant systems to the marsh environment and near shore areas.

It is well documented that mycorrhizae are important in terrestrial habitats, however the same information is not available in tidal marsh systems. Fungi and its associated mycelia, need to be investigated and interactions understood, especially as it pertains to nutrient utilization and exchange between and within the marsh system.

D. Stratigraphic Record and Developmental Processes

Although the information available for long-term developmental processes are some of the best in the science, there are still some aspects of paleoecology that still need to be addressed. The shorter term changes (those that occur over centuries and decades) are still not well understood. We know that the European settlement period had impacts on these systems, but we don't know how they exhibit themselves in the peat record. We still do not have a firm grasp of the resolution with which these peats can be interpreted, especially when dealing with periods of less than one hundred years. More research is required so that we can use the peat record to better understand short-term changes in the plant community through time and improve our ability to predict how these systems may develop into the future.



Sea Lavender
Limonium carolinianum

E. Anthropogenic Influences

Although vegetation restoration can be achieved through restoring the hydrology, there are still many systems where it is not feasible to reintroduce tides. In these systems it is still not known how the vegetation may be restored without extensive active management and large expenditures. Another aspect that still requires research is the impact changes in plant community structure may have on system hydrology. When tides are first reintroduced into a formerly restricted marsh, surface water movements must contend with dense reedgrass stands and resistance to flow. However, as the reedgrass is replaced by the shorter salt marsh grasses, the movement of water faces less resistance and changes its flow characteristics. Therefore we need to understand better the relationship between plant community structure and surface and subsurface hydrology.

F. Marsh Function and Linkages

Although marshes are biologically productive, there are still many areas of detail that are lacking. Primary productivity across latitudinal gradients have yet to be determined. It has been reported that tidal range has an influence on marsh productivity (Steever et al. 1975) in Connecticut, however this requires testing over geographic and latitudinal gradients. We also need to improve our understanding of linkages between habitats (McIvor and Rozas 1996). What are relationships between primary producers and consumers? How are various marsh habitats utilized by nekton? We need to address the question of linkages between the marsh and surrounding waterways including the linkages between primary (plants) and secondary (animals) productivity.

III. LEAST UNDERSTOOD SUBJECT AREAS

A. Plant Community Structure

Almost all of the information we have about tidal brackish and freshwater marshes comes from studies conducted along the mid-Atlantic and Gulf coasts (Simpson et al. 1983, Odum et al. 1984). Subsequently, even the most basic questions about the distribution of this marsh type cannot even be answered for New England. With the exception of a few papers (i.e., Metzler and Rozsa 1982), it is not even known what the basic generalized pattern of species distribution is nor can we determine any historic or present distribution patterns for New England. Add to this the fact that some of these areas are now subject to invasion by purple loosestrife (*Lythrum salicaria*), and it is even more difficult to gain an understanding of the upper reaches of the estuary. Therefore, basic ecological studies of the mid and upper estuary are needed to document the distribution of tidal brackish and freshwater marshes and plant community structure in these systems. It will then be possible to dedicate our attention to the linkages between the upper tidal reaches and lower salt marsh systems, including their role as nurseries and in nutrient exchange.

Although there has been extensive research within upland and salt marsh systems, very few investigations have documented the linkages between the uplands and marshes. The fate of nutrients and hydrological influences are still major gaps in our data base, as are the linkages between the watershed and the coastal marsh system (Valiela et al. 1992).

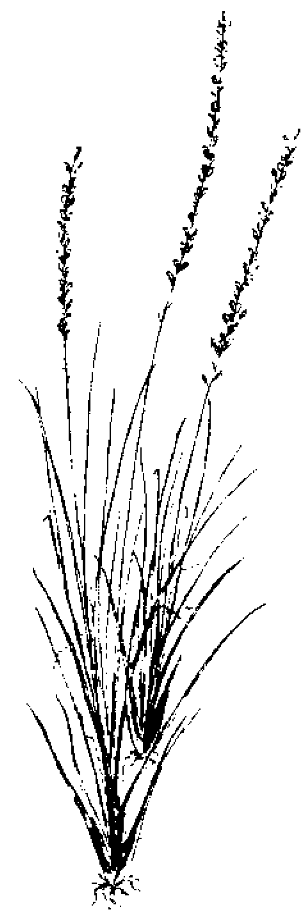
B. Gradients

Among the many aspects of physical processes of marshes that are not well understood are the regional gradients in marsh type: geographic and climatic gradients, tidal range, and geo-botanical interactions. For example, research is required to compare Bay of Fundy, Gulf of Maine, Cape Cod, Long Island Sound, and mid-Atlantic marshes.

Within an individual system there are still many aspects pertaining to gradients that require additional research. For example, salinity gradients are important in estuarine habitats. However, it is not known how patterns of primary productivity among all components of the producer community vary from fresh to saline conditions. Do the patterns of use of this productivity change along the salt gradient? As sea level rises and brackish marshes give way to salt dominated systems, we expect a change in nutrient cycling and ecosystem function , however, the particular changes have yet to be identified.

C. Marsh Transgressive Sequences and Sea-Level Rise (SLR)

Although the processes of peat development are being discussed in detail in the PHYSICAL PROCESSES section, there are considerations that apply here. It has still not been established how complete the peat record records historic processes and events. Problems reading and interpreting the stratigraphic record limits our ability to identify future changes in these systems to such factors as sea level rise. We have only a minor understanding of the transgressive sequences that occur as sea level rise impacts drowned terrestrial habitats and thus we still cannot predict what changes we can expect to occur as more habitats face submergence in the future. Recent work by Warren and Niering (1993) suggests that vegetation changes may have already begun, however, since these changes have come about in light of other anthropogenic influences (i.e., ditches, dikes), it is difficult to find analogous situations in the peat record to use in formulating predictive models for the future. The fact that many coastal wetlands are



Arrow-grass
Triglochin maritima

now situated against areas that have been developed (i.e., houses, roadways) means that future marine transgressions will be limited and that changes to these systems in the future may be dramatic (Orson 1996). It will be important that we increase our understanding of the peat record, especially the period that covers the last 300 years of settlement and the last century of coastal urbanization.

D. Anthropogenic Influences

One of the most significant gaps we have in our understanding of cultural influences on salt marsh vegetation is what impact will additional inputs have on plant community structure and composition. We do not know how long-term nutrient loading or the constant addition of point source runoff will impact plant successional trends. There is some anecdotal evidence to suggest that reedgrass may be expanding in some areas due to nutrient enrichment (in areas where sewer outfall pipes drain into the marsh, quite often it is accompanied by extensive reedgrass development). Does nutrient loading also impact the community structure of salt marsh grasses or other tidal marsh plants? Since nutrient loading causes algal blooms, how will the expansion of marine algae influence the distribution of angiosperms in tidal and subtidal areas (Short and Burdick 1996). Does the concentrated flow of freshwater from storm drains exert a control on plant community structure away from the discharge point? How do other point and non-point discharges influence marsh vegetation? As more pollutants and changes in drainage patterns are forced on these marsh systems, there will be a continuing need for research into these subject areas.

Since these wetland systems are located in many areas utilized for recreational activities, additional research will be required to document the damage they may have on the marsh system. For example what impact are boat wakes having on marsh erosion and the resuspension of sediments. There are dock construction practices that can minimize the impacts of shading (width of dock, height of dock), but the problems of anti-fouling chemicals and preservatives used in the woods still require additional research. Similarly, the paints and anti-fouling agents used to protect boat hulls and the gas and oil discharged during these activities needs to be investigated. Although the redistribution of species between systems has generally been cited as a result of the release of ballast water from larger ships, these smaller recreational crafts can also move species around, especially when the crafts are tailored about over short periods of time. The extent to which this may be impacting marsh systems is not known.

E. SAV

Widgeon-grass or ditch-grass (*Ruppia maritima*), another submerged aquatic, is also a plant of interest (Short et al. 1996). There is very little information as to its distribution (both historic and present) and factors that may control its growth. How much widgeon grass has been lost in the past is not known nor is it known what ecological function wigeongrass plays in the system. Many basic questions remain as to the fate of this plant and its basic ecology.

Chapter Four: ANIMALS AND SECONDARY PRODUCTIVITY

ANIMAL INTERACTIONS AND SECONDARY PRODUCTIVITY IN NORTHEASTERN TIDAL MARSHES

Participants:
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Michele Dionne - Wells Reserve
Paul E. Fell - Connecticut College
Michael P. Weinstein - New Jersey Sea Grant Office

The ANIMAL INTERACTIONS AND SECONDARY PRODUCTIVITY group identified four major areas of concern including physical and biological parameters. Many of these subject areas question some well established paradigms. For example, there is a surprising level of disagreement among scientists regarding the role of Northeastern salt marshes in supporting secondary productivity (especially finfish of economic value). In the Gulf of Maine, salt marshes are not viewed as important contributors to overall fish productivity, compared to riverine estuaries and offshore banks, and therefore remain poorly studied. To the south of Cape Cod, tidal marshes are considered to be "critical" habitat for fish and shellfish that support high fisheries productivity, relative to other coastal habitats. This difference in perspective cannot be resolved with the current state of knowledge, given the dearth of information regarding the elements and processes of salt marsh ecology north of the Cape. This is not a trivial issue, considering the substantial and growing intensity of human use of coastal areas where salt marshes occur (typically behind beaches or in sheltered embayments). There is little dispute about the potential for human activity to alter salt marsh functions, including fisheries productivity. There is an obvious need for research directed at understanding the nature, magnitude and reversibility of these alterations. We present here a framework for research to address questions regarding the salt marsh - fisheries productivity paradigm, and encourage research regarding human-mediated ecosystem change. We focus on those aspects of salt marsh ecosystems thought to influence secondary productivity: geomorphology, hydrology, nutrients, and biological interactions. These ecosystem attributes have been subject to impressive human influence, both in the past and in the present day.

I. GEOMORPHOLOGY

A. Physical Setting

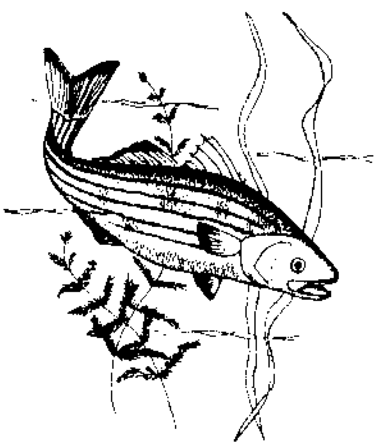
The physical morphology of a salt marsh ecosystem is defined by the contours of the surrounding upland, as well as of the underlying parent material, and by the spatial pattern of surface water storage and flow within the vegetated marsh (drainage channels, open water, salt pannes, and intertidal flats and bars). These aspects of physiography can be quantified by relating the amount of water and/or the amount of shoreline to the amount of vegetated marsh. Drainage density represents one such measure, calculated by dividing the total stream length by the total drainage area (Weinstein et al. 1997). Surface water spatial pattern determines the length and location of marsh edge per unit area within the marsh system, influencing movement of organisms and exchange of nutrients and materials between open water and marsh surface (habitat connectivity). Hence, geomorphology determines the large scale marsh features that determine fundamental landscape ecological processes. Recent studies have shown how salt marsh habitat elements such as subtidal marsh creeks and open water (Rountree and Able 1992; Ayvazian et al. 1992; Allen et al. 1994; Minello et al. 1994; Varnell and Havens 1995), marsh edge (Ayvazian et al. 1992; Baltz et al.; Minello et al. 1992; Miltner et al. 1995; Rozas 1995), salt pannes (Smith and Able 1994), and the vegetated marsh surface (Varnell and Havens 1995; Kneib 1997) are utilized by nekton. It remains to be understood how these habitat elements interact at the landscape level to support salt marsh secondary productivity (Rozas et al. 1988).

B. Anthropogenic Influences

Activities such as ditching, dredging, filling and the construction of dikes, road beds and water control structures can modify salt marsh geomorphology. Habitat connectivity and other landscape level features can be significantly modified as a result of these changes. Only a few studies have addressed the consequences of these changes for the nekton (Herke 1995; Hoese and Konikoff 1995; Burdick et al. 1997).

C. Additional research

The following questions address the connection between marsh geomorphology and secondary production.



STRIPED BASS
(drawing by Judy Ricketts-White)

Drainage:
What is the relationship between fish production and marsh creek drainage density?

Habitat:
Do different salt marsh habitats contribute disproportionately to secondary production?

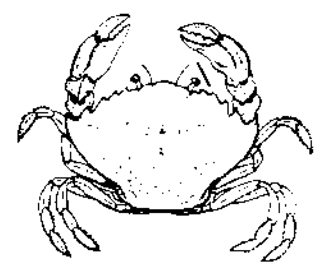
Pannes:
Can salt marsh pannes function similarly to subtidal creeks, specifically in areas of high tidal range? How is panne function related to tidal range?

Landscape:
Does secondary production vary with marsh size?
What is the optimum open-water to marsh ratio?
How is secondary production affected by habitat fragmentation, such as that caused by road crossings and other raised structures?

II. HYDROLOGY

A. Fresh and Salt Water Influences

Salt marsh hydrology is controlled by freshwater inputs from several sources (surface water, ground water, upland runoff, precipitation), and sea water. The estuarine pattern of fresh and salt water mixing is determined by these inputs, modified by marsh geomorphology, tides and sea level. Marshes are subject to annual, seasonal, monthly, daily and hourly variation in water depth, salinity, sediment load and nutrient concentrations. This variability results from temporal variation in inputs from both marine and freshwater sources. These hydrologic dynamics create the conditions necessary for the persistence of salt marsh vegetation, and for peat accretion (Niering and Warren 1980; Stevenson et al. 1986; Olff and Fresco 1988; Bertness 1992; Warren and Niering 1993; Morris 1995; Orson 1996). Partial mixing of freshwater and marine inputs within the estuary results in spatial variation in salinity and other parameters, often in the form of gradients (Wolfe 1986). The combined spatial and temporal variation in hydrology defines the conditions under which nekton must feed, grow, reproduce and disperse. Different species groups or life history stages may perform best at different points within this array of conditions (Morris et al. 1990; Kneib 1991; Racocinski et al. 1992; Rountree and Able 1993; Dew and Hecht 1994; Kneib et al. 1994; Tito de Morais and Tito de Morais 1994; Jassby et al. 1995; Friedland et al. 1996; Vincent et al. 1996; Livingston et al. 1997; Deegan and Garritt 1997; Rountree and Able 1997; Weinstein et al. 1997).


GREEN CRAB

B. Anthropogenic Influences

Both freshwater and tidal inputs to marsh hydrology are subject to obvious as well as subtle human alteration. Dams, causeways, culverts, tide gates, water control structures, and dredging can greatly alter the pattern of freshwater input, tidal inundation and sediment delivery to the marsh (Cahoon and Turner 1989; Cahoon 1994; Hopkinson and Vallino 1995; Portnoy and Valiela 1997; Reed et al. 1997). Forestry, agriculture and urbanization within the watershed further alter the pattern and quality of freshwater input (Correll et al. 1992; Valiela et al. 1992; Valiela et al. 1997).

C. Additional Research

Research regarding the influence of hydrology on salt marsh secondary productivity should address the following topics:

Freshwater:
How does river discharge (flow, timing, residence time) influence secondary production? Does bilayer flow enhance recruitment? How does recruitment in stratified systems compare to that in well mixed systems?

Salinity:
Does fish production vary across salinity zones? Is production greatest at intermediate salinities?

Tides:
How does tidal range, frequency, duration and depth influence fish

movement, use of marsh resources, and productivity?

Sea Level:

Does increased flooding during years of high annual sea level lead to increased fish production?

Habitat:

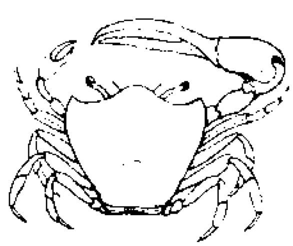
How does habitat variation interact with salinity in its effect on secondary production?

Landscape:

Are there large scale variations in fish productivity related to river discharge, Eckman transport, or other regional hydrologic processes?

III. NUTRIENTS

A. Inputs and Source



FIDDLER CRAB

Nutrient concentrations in marsh-dominated estuaries are controlled by inputs from fresh water, salt water and atmospheric sources. Stratification, mixing, tidal flushing and biogeochemical processes subsequently modify these inputs (Vorosmarty and Loder 1994; Rizzo and Christian 1996; Kelly 1997a; Kelly 1997b). Nutrients drive the dynamics of microalgal communities (both suspended and attached forms) (Staver et al. 1996). Nutrient levels can alter the relative contributions of vascular plants and algae to marsh primary productivity (Madden and Kemp 1996; Gallegos et al. 1997), and the structure of the consumer community that the marsh supports (Montagna and Parker 1997). Epiphytic algae can have direct negative effects on the growth of submerged aquatic vegetation (Neckles et al. 1993; Short and Burdick 1996). An increase in emergent plant nutrient content may fuel increased bacterial decomposition of marsh vegetation (Foote and Reynolds 1997), reducing peat accretion and marsh peat integrity. High bacterial decomposition may depress soil oxygen, reducing vascular plant vigor. Ultimately, excess nitrogen may lead to change in marsh geomorphology, increasing the interspersion of water and vegetation.

B. Anthropogenic Influences

Nutrient enrichment from anthropogenic sources is occurring along some portions of the northeastern coast (Lee and Olsen 1988; Valiela and Costa 1988; Costa et al. 1992; Kelly 1997; Nixon 1997; Valiela et al. 1997), especially in urban areas where freshwater inputs are high and tidal flushing is low. Point and non-point sources of nutrients from coastal watersheds have the potential to influence salt marsh food webs throughout the northeast.

C. Additional Research

Research efforts related to the following questions are needed to assess the processes through which nutrient enrichment may transform tidal marsh food webs:

Inputs:

How important is riverine delivery of nutrients to salt marsh secondary production?

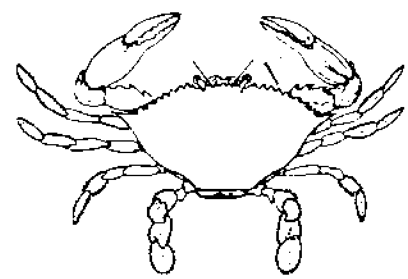
Food Webs:
How does a change in primary producers affect secondary producers?
Does a shift to algal primary production influence fish production and community structure?
Does it favor pelagic fish over benthic fish?

Landscape:
Does excess nitrogen lead to increased channelization of high marsh?
How does the area of low marsh change with loss of high marsh area?

IV. BIOLOGICAL CONTROLS

A. Biological Interactions

Salt marsh biological communities respond not only to abiotic conditions defined by geomorphology, hydrology and nutrients, but are also shaped through biotic interactions (Rountree and Able 1992; Cowan et al. 1993; Kneib and Knowlton 1995; Juanes and Conover 1995; Barry et al. 1996; Lechter 1996; Rountree and Able 1997). Biological control can be mediated from the bottom of the trophic web via resource limitation, or from the top down via predation (Karr et al. 1992). Changes in primary consumers due to increased microalgal production, or the spread of invasive vascular plants, are examples of bottom-up control. A change in primary consumers due to an increase or decline in secondary consumers or the introduction of an exotic species (green crabs, piscivorous fish) are examples of top-down control. Biological controls can be exerted through direct and indirect effects. Predators may consume prey directly, or influence prey growth and survival by inducing changes in prey behavior or the availability of prey food resources (Wooton 1994). Primary producers may influence higher trophic levels not only as an energy source, but as an element of habitat structure (e.g., emergent and submergent grasses, biogenic structures) (Kneib 1995), or as a substrate for other primary producers (e.g., epiphytes on submergent grasses).



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B. Anthropogenic Influences

Biotic interactions in salt marsh ecosystems can be altered by resource harvesting at any trophic level, or by human alteration of habitat. Changes in nutrients, hydrology (e.g. tidal restriction), and predator populations (e.g. fish harvesting) are examples of human influence that can lead to changes in trophic structure and secondary production through their effects on species interactions.

C. Additional Research

Predation:
Does predation really control animal distribution and survival?
How has size-selective removal of top carnivores through fish

harvesting changed the structure of tidal marsh food webs?

Invasive species:
What is the effect of introduced or invasive species on salt marsh food species: webs and secondary productivity?
Does green crab predation alter the influence of filter feeding by clams?
Does *Phragmites australis* or *Codium edule* influence food webs through changes in habitat structure?

Habitat:
How does biologically mediated habitat change influence salt marsh trophic interactions? Do biogenic structures such as bivalve reefs, and processes such as bioturbation, influence salt marsh food webs and secondary productivity?

Marsh-dominated estuaries are accessible, sheltered, coastal ecosystems that are amenable to experimental manipulation in the field. We encourage the development of a regional research program combining descriptive and experimental approaches for both site-specific and comparative studies. Although there is a dearth of information about the life histories of animals that utilize northeastern salt marsh systems, it is important to design studies that not only describe species occurrence, distribution and life history, but also elucidate basic processes and mechanisms governing salt marsh secondary productivity.

We recommend investigations of the processes that produce pattern or change in secondary productivity in response to variation in marsh geomorphology, hydrology, nutrients and biological interactions. The results of these studies will be extremely useful in the economic valuation, management, and restoration of northeastern tidal marshes.

GREAT BLUE HERON
(Ardea herodias)

Chapter Five: NUTRIENTS AND BIOGEOCHEMISTRY

NUTRIENT INFLUENCES AND BIOGEOCHEMICAL CYCLES

Participants:
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Stuart Findlay - Institute of Ecosystems Studies
Scott Nixon - University of Rhode Island
John Portnoy - US Geological Survey

The NUTRIENTS AND BIOGEOCHEMISTRY group identified the need for studies to be more inclusive and to take an approach to the science that includes more general and regional scale-type investigations.

I. CURRENT UNDERSTANDING:

The group was in general agreement that there is quite a bit of available information on nutrient cycling and retention in saline and freshwater tidal marshes. The underlying microbial and plant processes were basically understood at least at the physiological level and at the small plot scale (e.g. Bowden 1986). The missing aspect seemed to be mechanisms for knowing how to generalize site and time-specific results to a broader context, and just as importantly, when such generalization is not warranted. For instance, the biogeochemical processes affecting the net movement of inorganic nitrogen through tidal marshes and other landscape elements has been described (Correll et al. 1992, White and Howes 1994, Childers et al. 1993, Currin et al. 1996) but there is not a widely accepted model for predicting nitrogen movement through a novel system.

Two broad topic areas identified that should help provide a conceptual framework encompassing additional research needs include:

1. functional assessment of marshes.
2. vegetation/hydrology effects on nutrient cycling and biogeochemistry.

II. ASSESSMENT APPROACHES:

A. Functional Assessment Approach

Functional assessment has been proposed (Brinson and Rheinhardt 1996) as a useful approach to simplifying and quantifying the wide array of processes that make wetlands an important component of coastal landscapes. In essence, this approach requires identification of as many as twelve functions which can be as diverse as nitrogen retention and fish habitat. Initially the various functions are given equal weight so that fish habitat is no more valuable than nutrient retention. If accepted policy dictates that one function overrides another, it is at least an explicit decision and one can see what trade-offs are being made. The level of these functions is described with simple models based on easily measured independent variables. In the case of nitrogen retention, one might hypothesize that N retention will be related to some combination of water residence time within the marsh and plant (calibrated) at a set of reference sites spanning the regional (or local) range of marshes to describe existing variability in level of each function. Concurrently, the simple models are validated by direct measurement of the function being described (N retention, fish habitat use, etc.) to ascertain whether the surrogate variables really describe the actual process of interest. Validation may well include mesocosm and laboratory studies to examine the utility of specific predictor variables in describing the particular function. The reference data set and validation components are absolute prerequisites for a useful, defensible functional assessment approach to characterizing marshes within a region. Once accepted, the functional assessment models provide a mechanism for predicting levels of function at novel sites (within the range of conditions represented in the reference data) from relatively simple surrogate variables. This process provides a useful tool for extrapolating site-specific knowledge to the regional scale and may be used in regulatory decisions and assessing the success of restoration.

B. USACOE Approach

For coastal fringe wetlands, a set of nine functions has been proposed in the national guidebook being prepared by the Army Corps of Engineers. These functions range from tidal surge attenuation to wildlife habitat utilization potential. These functions and the models proposed to describe the levels of these functions must be viewed as strictly hypothetical prior to validation studies in a set of reference wetlands. These models can however, serve as organizational templates for research in specific sites and force investigators to consider how their particular results might (or might not) be generalized to other wetlands in the region.

C. Precision and Assessment:

These models will never have the level of certainty or precision that detailed process measurements can provide for specific sites. However, identification of simple, often surrogate, variables provides a broad context for site-specific measurements while validation within a regional reference provides a guide for generalization (or inability to generalize). Moreover, the initial statement of all the functions deemed important to include in an assessment makes it quite clear that marshes perform many functions and regulatory decisions should encompass the complete range and not be based on perceived benefits to a single species. Also, the statement of functions is essentially a list of hypotheses about the roles coastal wetlands play and functions can be added to, or removed from, the list as information becomes available.

III. HABITAT AND PROCESS LINKAGES:

In addition to describing the need for regional functional assessment, the group developed a series of questions that fall under the general heading of linkages between vegetation, hydrology and various wetland functions. The rationale for this topic is that vegetation and hydrology in coastal wetlands are changing rapidly due to both natural and anthropogenic factors. The consequences for wetland function is unknown and we certainly have no ability to predict how these systems will respond. Hydrology is changing as sea-level rises, as dredging alters tidal dynamics or as restoration activities remove dikes (e.g. Portnoy and Giblin 1997, Weinstein et al. 1997). Similarly, vegetation changes as marshes undergo succession, as new species (exotic and endemic) change in abundance or as managers attempt to eradicate plants perceived as undesirable. Since plants and hydrology are widely recognized as master variables in affecting wetland structure and function, it seems likely that any of these changes will feed-back to influence nutrient relations, sediment dynamics or habitat value for fishes, birds and invertebrates. A whole series of specific research questions can be organized within the framework of these changes, again serving to provide a broader context for site-specific projects.

IV. ADDITIONAL RESEARCH

1. Water Quality Effects of Restoring Tidal Circulation to Previously Diked Wetlands.

   What are the immediate and longer-term consequences of opening diked wetlands to reinvasion by higher-salinity waters (e.g. Portnoy and Giblin 1997)? How is nutrient retention altered and how long is the transition period?

2. Ability of Varying Types of Vegetation to Maintain Elevation Relative to Sea Level Through Organic Matter Production and Sediment Trapping.

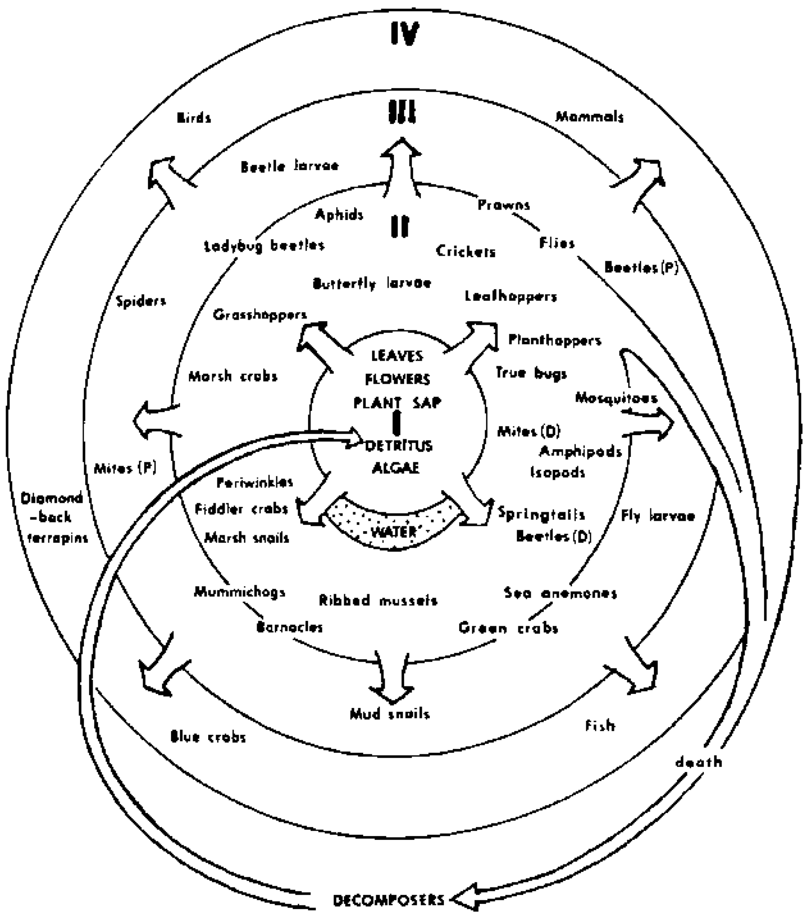
   Is episodic and long-term sedimentation differentially affected by variations in vegetation composition? What is the relative contribution of inorganic particle trapping versus peat accumulation to maintenance of marsh elevations?

3. Maintenance Of Detrital Resources in the Face of Changing Plant Sources and Conditions of Decomposition (Water Chemistry and Hydroperiod).

   What is the range in detrital food quality for litter derived from native and exotic plant species? How does food quality and nitrogen retention vary as local hydrology changes?

These general issues are relevant to a wide range of tidal wetlands and may serve as an organizational framework with the overall goal of providing a broader context for site-specific research.

FOOD CHAIN



Simplified food chain of tidal marsh animals. The different trophic (feeding) levels are represented by Roman numerals. Level I, the base of the food chain, is made up of the detritus which results from the breakdown of dead animal and vegetable material, and of the living green plants and algae (the primary producers) which trap energy from the sun. Subsequent trophic levels are increasingly removed from the primary source of energy. Level II consists of the herbivores, which feed directly on the plants and algae, and the detritus-feeders. The small predators, or carnivores, which prey upon the herbivores and detritus-feeders make up Level III. The marsh food chain culminates with Level IV, the larger predators, which feed upon the animals in Level III.

The names of those animals which are both herbivorous and carnivorous straddle the line between Level II and Level III. Within a few of the groups some species are predators (P), while others are detritus-feeders (D). (Drawing by Allen T. Carroll)

Chapter Six: MANAGEMENT

TIDAL WETLANDS MANAGEMENT GROUP

Participants:
Fred Short - Jackson Lab, University of New Hampshire
Bruce Carlisle - Massachusetts Coastal Zone Management
Robert Shields - US Coast Guard Academy
Heather Crawford - Connecticut Sea Grant Program
Frank Richardson - New Hampshire Dept. of Environmental Services
Ron Rozsa - Connecticut Dept. of Environmental Protection

Wetlands defined: as used here, wetlands means those emergent and shallow coastal wetlands such as tidal wetlands, submerged aquatic vegetation, intertidal flats.

The TIDAL WETLANDS MANAGEMENT GROUP identified a number of major areas that are in need of additional research and consideration including Oil Spill Protection (a subject area that has not been addressed adequately for northeast systems), Wetland Compensation and Mitigation (a topic that has received much attention but is in need of standardization), Wetland Restoration, Nutrient Loading and Hydrologic Manipulations, Sea Level Rise, Habitat Protection and Creation and Habitat Linkages, among others. Within these individual topics, a number of common approaches were identified such as the need to properly define what is restoration or compensation, the need to establish a set of scientific criteria for assessing both the level of and the success of wetland compensation programs and the need to better the lines of communication between the scientific and management communities. Although this list is not exhaustive, the areas of information identified during the workshop will be the most important over the next decade and will require additional attention by the various communities involved with the protection and understanding of these wetland ecosystems.

The following section outlines the results of the workshop group and presents a series of questions still requiring additional study and consideration.

I. OIL SPILL PROTECTION AND PLANNING

A. Sensitive Area Assessments - we need better mapping and characterizations of these areas. One of the oil spill planning approaches involves the development of sensitive area assessments. This includes the identification of sensitive resources/areas and characterization of such. There are a variety of standard resources that have been partially mapped such as bedrock, sandy shore, intertidal flat sand, intertidal flat mud, eelgrass and tidal wetlands. If this mapping were more complete, it could provide a higher level of information that would be useful for resource protection in situations such as an oil-spill response. Examples of types of information that should be increased are:

- differentiation between types of tidal wetlands (e.g., salt marsh, brackish meadow marsh, brackish reed marsh, and tidal fresh wetlands).
- defining the differences between ditched marshes, degraded marshes, and marshes with permanent or long term research potential (e.g., factors that could be used to prioritize wetlands or identify impediments to protection and cleanup operations).
- identification of specific areas which contain rare plants/animals, wildlife concentrations, finfish concentrations, seasonal utilization by particular organisms and recognition of the differences between habitats and their impacts on utilization (access across of *Phragmites* dominated marsh will be more difficult than a meadow marsh).

It is important to develop ways to display this data that allow for rapid updating through the use of GIS. In addition to the spatial data, the development of attribute data tables are a means to provide information that currently does not exist or is not readily accessible. The Connecticut Dept. of Environmental Protection is currently developing a protocol for the mouth of the Connecticut River to determine the best ways to display and disseminate this information (e.g., GIS, world wide web, Arcview for the internet/intranet). Once a protocol is developed, it can be used to develop an oil spill GIS for other parts of Long Island Sound and the technology could be exported to other regions in New England.

B. Efficacy of Various Bioremediation Techniques

Additional research is required to evaluate the efficacy of various bioremediation techniques in wetlands that have been impacted by oil. In some locations, the oil in wetlands is burned in order to reduce its penetration into soils, thereby minimizing toxicity to plants and animals. In some cases, it has been suggested that no action be taken in hopes that the wetland vegetation will recover quickly (however, at least in one marsh along the Arthur Kill in New York City, recovery was extremely slow).

C. Post Oil Spill Research.

Very little research has been conducted upon oil-impacted wetlands in the northeast to evaluate the effects of oil upon wetland systems. Oil spill response program personnel should, in cooperation with researchers, identify a research protocol to be employed during an oil spill. In addition, oil spill programs need to identify a funding mechanism to support research.

The impacts of oil upon wetlands would best be accomplished through a New England wide study of previously impacted wetlands.

II. MITIGATING LOSSES THROUGH COMPENSATION

General note: Compensation is the offsetting of proposed wetland losses using techniques such as restoration or creation. It is therefore important not to confuse environmental restoration with compensatory restoration, for the requirements for each are very different. For example, a regulatory agency will often require specific objectives that MUST be met for compensation whereas environmental restoration may simply reset a degraded wetland on the trajectory towards becoming a self-maintaining ecosystem again.

A. Time Considerations

Observations of tidal wetland (environmental) restoration projects have shown that the conversion from a degraded *Phragmites* wetland to salt marsh, may take as long as 20 years, especially on larger marshes (> 50 acres). There is a growing body of evidence to suggest that the high stem densities noted in these *Phragmites* marshes (live and dead - the latter for up to five years) retard the penetration of the tide across the marsh surface. For example, in both a mesohaline brackish marsh at Barn Island, Stonington, CT (Impoundment IV) and a salt marsh at Great Meadows, Stratford, CT, after 10 years *Phragmites* is still a dominant plant species in many areas (although in many areas it is now stunted). Because water movements are restricted out of the channels in these *Phragmites* zones, there is a subsequent increase in height of tides in channels feeding areas that pose less resistance to the flow of water (i.e., short-graminoid vegetation, marsh areas devoid of vegetation). As *Phragmites* stem densities reduce through time, the tide can penetrate across the marsh faster and across a greater distance. This in turn allows water to move out of the tidal creek more efficiently and results in depressing the tidal curve within the system. In other words, the hydroperiod is readjusting to the changes in the plant community structure for much of the time it requires to fully restore salt marsh to the system. Thus, the most meaningful monitoring to insure that the compensatory wetland has achieved its restoration objectives may require decades to determine its success.

B. Functions and Values Assessments.

Research needs to be conducted to determine whether or not compensation projects are attaining their objectives, especially with respect to the replacement of functions and values.

C. Compensation Area.

Monitoring should be conducted to insure that the amount of area required for compensation is achieved after the project has been built out. Studies conducted in Oregon and Florida have shown that many projects fail to meet the levels of compensation agreed upon during the planning phase (i.e., mitigation goals were met in only 30% of the approved projects, Cruse 1993).

There are currently no easy ways to quantify the amount of compensation required. How much compensation should be required when the impacted area is healthy tidal wetland, but the restoration site is degraded wetland dominated by *Phragmites*. There is a need to differentiate between drained or tidally-flooded as well. Dry, *Phragmites* marshes appear to have lower functions and values to the landscape (i.e., wildlife utilization) when compared to the natural marsh system.

Should the amount of compensation required be increased by an amount commensurate with the anticipated amount of time it will take for the full return of functions and values to occur?

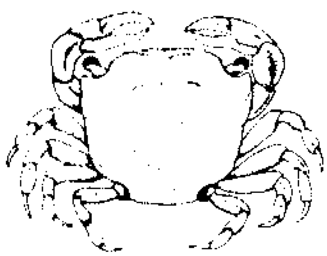
D. Evaluate Cumulative Impacts to Wetlands.

There are numerous minor but incremental losses of wetlands that eventually can add up to substantial habitat loss (e.g., small amounts of backyard fill). A research assessment of these losses should be conducted. Similarly, the cumulative impacts from activities such as walkways and docks need to be evaluated. What are the cumulative effects on wetlands. Do these structures cause fragmentation of the system at least with regard to wildlife utilization and movement?

E. Compensation Site Monitoring

Monitoring of compensation sites should be expanded in order to evaluate compensation success. What parameters or functions and values are most important to evaluate? What specific functions and values should regulators require as part of a monitoring program, as it is unlikely that every function and value could be measured?. How long should sites be monitored? Are the most meaningful measurements made after 5, 10 or 15 years?

Measuring all functions and values would likely be cost-prohibitive. So some set of functions should be defined over specific periods of time to allow for meaningful monitoring and assessment of program success.



MARSH CRAB

F. Compensation and Banking Credits

There is a critical need to develop scientifically sound criteria that can be used to quantify the amount of compensation required for proposed wetland losses. In the case where compensation is achieved through restoration, compensation credit would be determined on the basis of area and the difference in "value" between the pre-restoration and post-restoration condition.

In New England, regulatory programs recognize the greater success rate for low marsh restoration on salt marshes. How do you then treat proposed loss of high marsh with compensation by low marsh habitat?

III. MITIGATING LOSSES THROUGH RESTORATION

Need to define restoration, and differentiate between environmental restoration and restoration as a tool for compensatory mitigation.

A. Hydrology

Tidal hydrology in *Phragmites* dominated marshes is not well understood and will require additional research in the years to come. This will be particularly important as tides are reintroduced into areas historically restricted from tidal exchange and the system experiences changes towards salt marsh vegetation (see discussion on changes in hydrology as restoration proceeds in this chapter under Section II-A).

B. *Phragmites* and other Invasive Species

1. - More information of fish and invertebrate use of *Phragmites* is required. If *Phragmites* actually impedes the penetration of tide into the interior areas of dense stands, it should follow that snail and other invertebrate densities will be low and fish access may be limited to interior areas.

2. - There is a need to conduct salinity studies for various plant species, especially *Phragmites*. Are spring salinities more important than summer salinities or growing season averages?

3. - Although *Phragmites* is a native plant species, there is evidence to suggest that a new strand or an invasive form of the plant is interfering with native strains (Basitka 1996). Is the invasive more aggressive than the original native stock? If this is a more aggressive plant variety, then the question of whether or not this plant is native becomes less important because we are now dealing with a variant that exhibits different growth characteristics.
4. - More information on the functions and values of *Phragmites* including borders adjacent to salt marshes is needed. For example, presentations made this year at ERF '97 (Estuarine Research Federation Biannual Meeting, Providence, RI, Oct 1997) suggested that *Phragmites* may be described as the "great leveler" because it reduces the complexity of the microtopography into a more uniform surface elevation and, due to the growth of *Phragmites* root systems, tends to eliminate the low marsh slope in favor of a horizontal surface with steep banks. This change in surface topography changes the hydrology and may reduce access time to the low marsh zone by foraging killifish. Such information illustrates the importance of how our understanding of this system will be necessary to properly control and assess a management response to *Phragmites* invasion.
5. - There is a need to properly identify the values and problems associated with *Phragmites*. At present, there is a lot of public confusion over a number of the values and functions associated with this plant. Are these areas really low value when compared to salt marshes? Recent findings from research in mixed communities along the Connecticut coast has suggested that bird populations and certain invertebrates may use *Phragmites* with the same frequency that they use *Spartina* marshes (personal communication R. Scott Warren, May 1997). Whether or not these findings can be extrapolated to other systems or large monocultures of *Phragmites* still needs to be tested.

C. Eelgrass and other SAV's

Eelgrass beds and other SAVs need to be mapped and identified, particularly the historic distribution of these plants. It will also be important to define the value and function of these systems before determining what level of restoration must be considered. At present restoring eelgrass beds have met with only limited success (problems with currents and foraging invertebrates). Inexpensive methods to restore eelgrass beds must be identified.

IV. DEGRADED TIDAL WETLANDS

A. Identify and Map Degraded Tidal Wetlands

Before degraded wetlands can be mapped and identified, we must first define what is meant by the term "degraded tidal wetlands" for the New

England region. This definition must apply across the region so that a more comprehensive approach can be taken towards restoring our coastal zone. [Note: Massachusetts and NY-Hudson River are currently developing some information and field assessment techniques.] Once defined, then these areas can be mapped through aerial photography and ground-truthing techniques. GIS is preferred for this as it allows for rapid updating and the establishment of a relations between the spatial and attribute data. Metadata should be used to define the delineation procedure, sources of information, etc. Such information is necessary to set restoration priorities or to quickly locate potential compensation sites adjacent to or near the area where the permitted impacts are to occur.

It is critical to identify the type of degradation (i.e., the specific type of hydromodification: drained, impounded, ditched, unimpaired tidal flooding) and the historic condition of the marsh at least into broad categories (e.g., polyhaline, mesohaline, oligohaline; oligohaline marshes will continue to support *Phragmites* at a minimum, even after tidal flow restoration). Also, it is critical to understand the hydrological setting. For example, freshwater discharges in tidal marshes on major rivers like the Connecticut, are high enough so that salinities in lower estuarine tidal marshes may be oligohaline during the growing season (May - July, when plants reach full maturity), but only mesohaline after the growing plants reach full maturity.

B. Prioritize Restoration Sites

Developing a rating system to prioritize restoration sites should be completed for all of New England. Such an approach has been developed for Long Island Sound using several biological indicators. Other factors that will need to be considered for rating restoration sites should include the availability of funds and community support; however, top priority should still be given to the biological factors. Prioritizing sites may also include an assessment of rare habitat types. Does restoring a smaller marsh in a highly urbanized watershed have a greater impact on the system than restoring a larger site in a system less developed?

C. Quantify the Effects of Various Land Uses Upon Wetlands

Land use adjacent and upstream of wetlands can influence their quality and functions and values. For example, nutrient enrichment through groundwater can cause reductions in SAV; stormwater discharges can dilute soil salinities and promote the spread of invasive species such as *Phragmites*; development may interfere with the landward migration of tidal wetlands.

D. Best Management Practices (BMP)

What are the best management practices available to minimize adverse impacts to wetlands from upland uses?. Compilation of BMP's for upland activities that would help to reduce impacts to wetlands (e.g., stormwater retention, zoning density to reduce groundwater nitrogen levels for individual septic systems) are needed.

E. Boating and Other Recreational Activities

Wetlands can be impacted by boating activities and attendant support structures such as docks. Special considerations include dock and dock design, fragmentation effects from multiple docks, scour induced from boat wakes, prop wash which increases sedimentation, blowouts from jet skis, boat rafting which increases nutrient levels.

The functions and values of wetlands, particularly for species of commercial and recreational importance, need to be better defined.

V. NUTRIENT LOADING

Many questions remain about the importance of nutrient loading to the coastal zone. What specifically is nutrient enrichment doing to our tidal wetlands? Is the excessive production of algae on some of our wetlands and eelgrass beds the result of nutrient enrichment? We need to develop better indicators of nutrient enrichment and examine loading conditions and residence times of these compounds.

VI. SEA-LEVEL RISE

A. Tidal Wetlands

Regional examination of sea level rise effects in New England might provide us with a better understanding how sea level rise will impact a particular system. It will also be important to establish the causes associated with vegetation changes and discern those effects directly associated with sea level rise. For example, it has been noted that in the areas of Connecticut where the tide range exceeds 1.0 m, there appears to be a loss of *Spartina alterniflora* in lower elevations while in the areas of the State where the tidal range is relatively low, vegetation changes appear to be more dramatic along the high marsh/upper border vegetation. Are these changes symptoms of sea level rise (Warren and Niering 1993) or are some other factors influencing these vegetation changes?

As sea levels continue to rise, will the entire marsh unit transgress landward. At least some research suggests that a part of the answer lies in types of surrounding land use and position in the estuary (Orson 1996). Even if the marsh unit transgresses, does it follow that there won't be changes in habitat structure (i.e., the ratio of high marsh to low marsh) during transgression?

B. SAV. As sea level rises, the greater water depth means less light penetration through the water column to the sea floor. Loss of light can reduce the survival of eelgrass and other SAVs and therefore reduce these habitats.

Common Reedgrass
Phragmites australis

VII. HABITAT LINKAGES

There is a critical need to examine and quantify the linkages/ relationships between different estuarine habitats as well as animal species linkages. The influence of the upland on salt marsh systems is only barely understood. As more development occurs along the upper border it will be important to identify these linkages, particularly in the areas of freshwater inputs and nutrient enrichment from the various land-uses. These linkages will be important as management attempts to balance the need of restoration with function and value to the coastal zone.

VIII. HABITAT CREATION

It will be necessary to develop and define how we determine the replacement value and function of a newly created marsh system, particularly if the project was completed as part of a compensatory program. Besides the values associated with newly created marshes, we must also be able to model and define the trajectory of wetland and eelgrass development in these created systems.

IX. RESOURCE ASSESSMENT

One of the most important types of resource assessment is the mapping of all tidal wetland resources, including healthy and degraded types.

Control marshes for comparison purposes are often picked indiscriminately (i.e., the nearest healthy marsh or perhaps a marsh that might have resembled the restoration marsh prior to alteration). However, in the case of drained marshes, there are numerous long-term biophysical changes that have occurred, such as subsidence. When flows are restored, the hydrology is often different than that of the pre-disturbance condition and very different than that of the control marsh. Many of our subsided marshes are now sitting at elevations comparable to the low marsh or below. Does it make sense to compare the functions and values of the restored marsh to a control marsh that, for example, may be predominantly high marsh? Since it takes 15 to 20 years for the conversion of a *Phragmites* marsh back to one that is predominantly salt marsh vegetation, and since the control marsh itself has undergone changes during that time (e.g., sea level rise), how meaningful are these comparisons?

X. INFORMATION EXCHANGE

It is very important that we find better ways to exchange information/ ideas between the scientific and management communities. There are many "gray papers" the management community possesses that are unknown to the scientific community. Similarly there are many publications and non-published results that the scientific community possesses that the management community does not have time to collect and digest. We need to better our exchange of information in both directions through improving libraries and meetings between the two groups. Examples of ways in which we have already begun to improve our ability to exchange information includes publication of Sea Grant annual abstracts and a tidal wetland restoration bibliography presently being compiled by the Massachusetts Coastal Zone Management group for the Gulf of Maine.

One suggestion which may improve communication between various research groups and agencies would be to develop more synthesis documents on various aspects of wetland ecology/restoration. Such documents may be assembled by graduate and undergraduate programs and help tie education further into the process.

All researchers and managers need to better define the biophysical setting for their investigations such as tidal hydrology (e.g., semi-diurnal, microtidal, tidal range) or other settings (e.g., drained, impounded, unimpaired tidal flooding, ditched).

Chapter Seven: GENERAL DIRECTIONS IN RESEARCH

One of the more striking aspects of the workshop was the identification of a few major themes that were common to all specialty groups. Paradigms and areas of research and information exchange were addressed by all participants. A number of questions arose as to our ability to address some of the more important paradigms that have held sway over the marsh community for the last few decades. For example, the Animal Specialty Group noted that to this day we still don't have enough information to explicitly identify the relationship between tidal marsh systems and their roles as nurseries and secondary biological production sites to open water habitats. Similarly, The Physical Science Specialty Group found that we still cannot say whether these marshes act as filters or traps for pollutants and other particulates to the landscape. Besides questioning the paradigms, a number of areas of basic research were identified which require additional work. All groups independently acknowledged that the upper estuary has been largely ignored and even the most basic aspects of the science (i.e., descriptive ecology) need to be addressed. The groups also identified wetland hydrology as being a topic of great importance and one which requires immediate attention. Workshop findings also approached some of the more theoretical aspects of the science. It was noted by the group as a whole that we need more testable theories as to the large scale workings of these systems. Current information appears to be too site specific and attempts must now begin to focus on a more generalized approach to our understanding of how these systems function. For example, there are many site specific studies conducted on nutrient exchange rates within particular estuaries; however, theories connecting the systems and processes between geographic regions are very limited. It was the opinion of the workshop participants that the data is available to begin to test broad-ranging theories as to how nutrients and other processes behave in these systems and the surrounding habitats.

The workshop identified those areas of information where additional efforts will be necessary in the future. Some of the results will require specific investigations to test major paradigms, fill in glaring gaps in our data-base and begin to think on a more regional and interdisciplinary scale, as well as attempt to use this information to further our ability to manage these systems. The following section presents the primary areas of research that participants felt would be required to ultimately lead us in a direction which improves our ability to understand how these marsh systems operate.

I. PARADIGMS REVISITED

For many years now, marsh ecology has followed a set of values first suggested during the early 1970's in the classic works of wetland scientists such as Odum, Teal, Gosselink and de la Cruz (i.e., Teal and Teal 1969, de la Cruz 1973, Gosselink et al. 1974). Collectively, these researchers showed that tidal marshes are some of the most productive and valuable systems in nature and many of their ideas have now become paradigms in wetland ecology. Although there is little argument as to the validity of many of these paradigms, there is still much we don't know about them. For example, the export of carbon and nutrients from these systems is deemed to be important in bioproductivity. However, as shown by Scott Nixon (Nixon 1980) and others (Simpson et al. 1983) during the 1980's, not all tidal marshes exported their carbon and/or nutrients and therefore play a number of roles on the landscape (i.e., they can be sinks as well as exporters) that may affect their value ratings. Therefore, the workshop participants directed some of their efforts to identify how far we have come in being able to support or refute these paradigms. Although many of the basic concepts appear to be sound, there are at least a few of these paradigms that could not be accepted outright based on the level and type of research that has passed since they were first suggested 20 years ago. These paradigms are listed below. For additional information see Chapters Two through Six.

Are tidal wetlands nurseries for fish?

- Much work is required on secondary productivity and the linkages between tidal wetlands and nearshore areas. Do these marshes support marine transient species?
- The relationship between tidal fresh and brackish wetlands and their roles are still unknown.

Are wetlands some of the most biologically productive habitats in nature?

- There is no doubt that much carbon is produced in tidal wetlands (salt, brackish and freshwater); however, the fate of the carbon and nutrients is still in question. Linkages between the wetland and surrounding habitats are still needed, as well as the identification of sources of carbon that support secondary production.

Are tidal wetlands filters for the estuary?

- The relationship between peats and intertidal muds must be determined. The wetlands are acting as filters for sediments to a point. However, the sequestering and retention of metals and pollutants may be more along the lines of a trap rather than filter. Stability of the peats to withstand erosion or mixing may be one of the keys here.

Are marshes important flood storage systems?

- The sponge analogy is a good concept and like a sponge, once it is saturated, water storage does not increase. However the rate of release is influenced so there is some benefit. Flood storage leads directly into the general topic of wetland hydrology.

II. PRIMARY RESEARCH NEEDS

Besides paradigms, participants were also charged with identifying topics where informational gaps were most important to our understanding as to how these systems function. Discussions in all groups ultimately led to the identification of not just areas of research important to the individual specialty group, but also topics which transcended all subject areas to become a general theme throughout the workshop.

To help improve our understanding of these systems and fill in major gaps in our information base, the following topics were identified as major areas of concern for future research in New England systems:

Hydrology
Secondary Productivity and its Linkages to Fisheries
Identifying Natural vs. Anthropogenic Disturbances
Basic Ecology of the Mid and Upper Estuary
Developing and Testing Quantitative Models
Information Exchange between Scientists and Managers
Scientific Criteria for Assessing Management

Wetland Hydrology

To date there is relatively little information on hydrologic processes influencing tidal marsh systems beyond the body of work conducted on tidal flows (i.e., Redfield 1950). With the exception of a few papers from other regions of the country (i.e., Stumpf 1983) groundwater movements, surface flooding and drainage patterns are largely unknown and remain a big gap in our understanding of these systems. Likewise the linkages between upland and wetland groundwater flows and influences of freshwater are also in need of research. Wetland hydrology was identified as one of the single most important gaps in our understanding of tidal systems.

Secondary Productivity

Much has been written about the importance and value of tidal marshes to both shellfish and finfish industries. Although it is accepted that tidal marsh systems do contribute to ocean fisheries, the extent of that contribution is still not settled. For example, the relatively limited area of tidal marsh in the Gulf of Maine suggests that riverine estuaries and offshore banks may be more important contributors. In contrast, the more extensive marsh area along the southern New England coast may make these habitats critical to these industries. The uncertainty of secondary productivity linkages between tidal marshes and open water habitats both within and between regions is particularly important where transient species and species that spend most of their life cycle in deeper waters are concerned. The link between secondary production in these marshes and the near coastal zone must be further investigated before the contribution of tidal marshes to off-shore resources can be determined.

Disturbances

One of the most important areas of future research will be determining when a disturbance is a disturbance. Tidal marsh systems are constantly being subjected to natural disturbances such as hurricanes and prolonged flooding. They are also exposed to many anthropogenic disturbances such as ditching and diking. We must better identify natural cycles and separate them from anthropogenic impacts. Identifying wetland loss or vegetation changes has no meaning unless we can show that the impact is directly attributed to some cause. A better understanding of the paleo-environment is paramount to the identification of real disturbances to the marsh system. Towards that goal, it is important that we learn to interpret the peat record and identify the history that is recorded by these systems.

It is also important to interpret rates of change as well as identify potential thresholds. For example, does the construction of a roadway have any more impact on a system than the closing or opening of an inlet during a major hurricane? How does accelerated sea level rise fit into the extent to which upland areas have been developed? We must answer questions such as these before we can begin to define disturbance and anticipate successful marsh/habitat restoration.

The Upper Estuary

Although extensive investigations have been conducted on the upper reaches of the estuary along the mid-Atlantic and along Gulf coasts, virtually no work has been completed for these systems in New England. Not only was it not possible to discuss these systems in terms of paradigms, it was not possible to identify even the most basic level of information including plant and animal community structure and nutrient and sediment exchange rates between systems. It was agreed that more effort will have to be directed towards the upper estuary, before we can begin to understand how fresh and brackish marsh systems influence other portions of the landscape. It was also noted that we will never gain a full understanding of the role tidal marsh systems play on the landscape unless we investigate these tidal brackish and freshwater systems.

Regional Comparisons and Modeling

Although many studies have been conducted on New England marshes, much of the information tends to be site specific. There are specific areas of research (i.e., plant community structure, bioproductivity, nutrient exchanges) for which there are large sets of data already available. It will be important that we begin to approach such topics on a more regional basis and use this data to compare and contrast latitudinal differences. The ultimate goal is not to merely compare the information, but to begin to establish a more theoretical approach towards our understanding of these systems and identify the processes important to all tidal marsh systems.

Comparisons between regions will require the identification of forcing functions within the system. For example, the role that ice plays in northern New England marshes (covering marshes and tearing up surface sediments) differs from its role in southern New England marshes (mainly limited to edge erosion due to rafting), yet both will contribute to our understanding of how winter impacts these systems on an annual basis.

There is a need to develop models that can be quantitatively tested and test them. The need for these models is a result of observations that additional regional comparisons are required. It is important to look at the "big picture" if we are to make significant advances in marsh sciences during the next few decades. Many of our present models were developed decades ago and need to be updated.

The Science and Management Communities

One of the biggest needs of the management community is access to information. Even though many articles have been and are being published, managers do not always have the time to sift through libraries and keep abreast of the latest information. This does not even include "gray literature" publications which are generally much harder to find but important nevertheless. Similarly, there is much information and experience within the management community that does not filter back to the scientific community. We must develop ways of increasing the information exchange between the two groups and present it in a way that is understandable to all.

It is important for both communities to work together to develop sound scientific criteria for evaluating and designing management strategies that will have the greatest chance for success. Joint research projects between wetland managers and wetland scientists would be a step in the right direction. Additional strategies could include conducting more interactive workshops and a real commitment by professional societies to include management personnel in their annual meetings. Towards these goals, societies such as Estuarine Research Federation and The Society of Wetland Scientists have already begun to include management as a regular session and in some cases have made management the primary focus of its meetings.

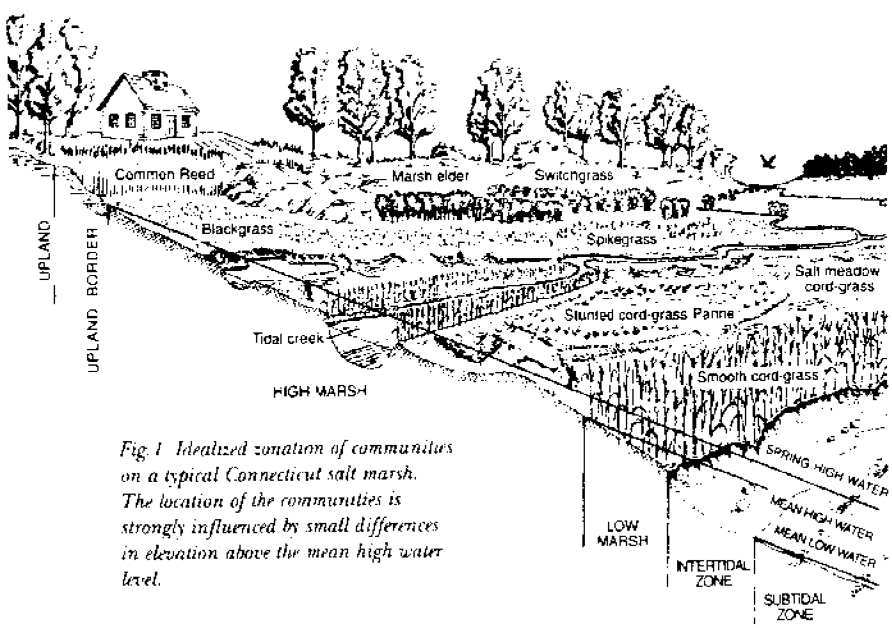


Fig. 1 Idealized zonation of communities on a typical Connecticut salt marsh. The location of the communities is strongly influenced by small differences in elevation above the mean high water level.

Chapter Eight: APPROACHES

Having identified the important gaps in our knowledge of tidal systems, we identified a number of approaches that could be used to improve our understanding of tidal marsh systems and advance the science into the next millennium. This chapter will focus on a number of these approaches which will help promote our ability to investigate the major areas of concern noted in Chapter Seven.

Regional Comparisons

For a number of subject areas there is enough information to begin to piece together a regional approach to establishing generalized, testable theories as to how tidal marsh systems may function. For example, salt marsh vegetation patterns have been identified for most systems. What is presently required is that we take that available information and begin to interpret general vegetation patterns and responses that these systems may have to a particular forcing function, particularly as we use these systems to test and predict how management may influence the marsh in the future. Similarly, nutrient exchanges between the marsh and open water have been collected in many individual systems. Using this rather large data base it should be possible to sit down and identify regional processes which may control and influence exchanges between the coastal zone and larger bodies of water (i.e., Long Island Sound).

Identification of and Response to Forcing Functions

Forcing functions are important in assessing any marsh system. Identifying these functions will be paramount to our efforts to understand the "big picture" and design predictive models of marsh development. The forcing functions must not only be identified, but held constant when comparing systems over a region or latitudinally.

Manipulative Studies Using Altered Wetland Habitats as a Natural Laboratory

We have available to us a great laboratory which needs to be utilized more often. Marsh systems that have been separated from tidal flow or manipulated for some agricultural or cultural purpose provides us with an opportunity to compare altered systems to unaltered systems. This will not only be important as we attempt to assess the merits of any one particular management plan, but will also be paramount to further our understanding of the basic processes functioning within a marsh system. If we truly understand how these systems work, we should be able to predict how restoration will proceed. If not, then these systems can be used to help identify and test basic ecological principles about wetland function. The level with which cultural modifications have influenced these systems could never be repeated experimentally (nor would it be allowed.... consider going to a State or local wetland agency and asking if you could destroy tens of acres of wetland for the purposes of scientific inquiry). By viewing these degraded habitats as a laboratory, we will improve our ability to understand the basic workings of these systems and be able to design more efficient restoration and creation programs.

Ecosystem Approach

Throughout the workshop it was noted that we can no longer continue to micro-manage these systems and expect to be successful in restoring and retaining their function to the coastal zone. Creating or restoring a habitat for an individual species should be approached with caution. Systems must be understood and managed from an ecosystem point of view, not an individual species approach, even when that species is threatened or otherwise endangered. The time, costs and benefits of saving any one individual species must be balanced against the need to restore and maintain the functional equivalence of the marsh system.

Target Species

The use of the investigation of target species to understand a particular process is not new. Such investigations should be continued to be incorporated into research programs and should be expanded to include information from other portions of the world. For example, *Phragmites australis* is an important economic and environmental plant in Europe, while in New England it is a pest species. Similarly, *Spartina alterniflora* is a plant of great importance along the New England coast while in parts of California and other west coast states, it is a plant slated for eradication. Much can be learned from the use of target species, especially when they are compared across large regions.

Resource Inventory And Assessment

It is extremely important that we continue to inventory our marshes as to area, species richness, and diversity and to periodically assess any changes to these systems. Such studies are generally not expensive and to conduct them, the help of volunteers and students can be elicited. These inventories will help provide information on trends and cycles inherent in these systems and aid our ability to understand some of the impacts anthropogenic influences have had and continuing to have on the marsh and its associated habitats.

Quantitative Modeling

The need to test and adapt quantifiable models will become more important as we move into the next millennium. These models will become the basis for additional theorizing and help establish criteria for judging both the health of a system and the success of a management plan. In a number of subject areas (i.e., nutrient exchange rates) the data already exists and what needs to be accomplished now is to take the data and apply it to quantitative models.

Geological/Paleoecological Record

The paleo-record can provide many of the answers we need to properly understand how these systems work. This is particularly important because of the fact that most systems had been modified (either directly or indirectly) prior to the first real attempts to study these areas beginning in the mid 1800's. Using the paleo-record will be paramount as we begin to decipher how we interpret and classify disturbances to these systems. Many basic processes and cycles can only be interpreted through a detailed understanding of how these systems have developed and functioned in the past. Separating anthropogenic influences from climatic or other forcing functions will have to be determined through the stratigraphic record. The approach of using historic and prehistoric studies will be very important in our ultimate ability to understand and protect these tidal marsh systems.

Coordinated Research Between Regions and Information Exchange

As research dollars become more scarce and the need to identify generalized patterns of marsh development becomes more important, it will be necessary to conduct tidal marsh studies utilizing a more integrated approach. Information exchange between researchers and among researchers and the management community must be increased if we are to properly understand and protect these systems. This information exchange must be relatively uncomplicated and synthesized in a manner such that individuals not trained in a given area of expertise will still be able to understand and use the information properly. This information exchange must also be a two-way street. Not only is it important for managers to be given information acquired from the research community, it is also very important that lessons or information learned by the management community be available to the scientific community as well. Regional cooperation between disciplines will also be important. It is not always necessary to "reinvent the wheel" because an arbitrary line drawn on a map. A more coordinated response between regions will not only save money but will also help identify gaps in the data necessary to begin to develop more generalized, testable theories concerning marsh function and interaction on the landscape.

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