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The Standing Stock of Organic Matter in a Man-Made Brackish Marsh and its Resource Management Implications

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THE STANDING STOCK OF ORGANIC MATTER IN A MAN-MADE BRACKISH MARSH AND ITS RESOURCE MANAGEMENT IMPLICATIONS

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This thesis is submitted in partial fulfillment of

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ABSTRACT

Two separate vegetative communities, *Spartina alterniflora* and a mixed community, were used in determining primary production in a man-made marsh. A peak biomass estimate of 933 g m^{-2} for aboveground and 329 g m^{-2} for belowground results in a total estimate of 1260 g m^{-2} in the *S. alterniflora* community. Annual aerial productivity of the mixed community was 855 g $m^{-2}y^{-1}$. A maximum-minimum estimate of belowground production in the mixed community was 420 g $m^{-2}y^{-1}$. Total productivity for the mixed community was 1275 g $m^{-2}y^{-1}$.

The mean sedimentary accretion, determined using marker horizons, over the time interval May 1985 - May 1986 was 0.9 cm. The surficial sediment had a mean density of 0.85 g cm^{-3} and a mean percent organic content of 22.2, giving an accumulation of 1670 g organic matter $m^{-2}y^{-1}$, for the year May 1985 - May 1986.

A review of the historical background of wetlands management explains the present use of wetlands creation as a management tool, and suggests methods by which to assess the success of a man-made wetland. Assessment of the success of wetlands creation for Goose Creek marsh indicates that the site is a successful compensation project.

PROLOGUE

I want to waltz in the wetlands
The swamps, the marshes and the bogs (oh, the bogs).
Yes, I want to waltz in the wetlands
With the birds and the fish and the frogs.

And the river runnin', river runnin', river runnin' down
    flowin' so naturally
And the river runnin', river runnin', river runnin' down
    don't change it for me
The natural cycles all help hold the rain
But everything's changed when you dredge or drain...

I want to waltz in the wetlands, a place where nature gets by
And I... will cry..., will cry when the wetlands are dry.
And I... will cry..., will cry when the wetlands are dry.

*Excerpt from the song "The Wetlands Waltz" is used by permission of the author Jill Jorboe of Pine Jog Environmental Sciences Center, 6301 Summit Boulevard, West Palm Beach, Florida 33415.

THE STANDING STOCK OF ORGANIC MATTER IN A MAN-MADE BRACKISH MARSH AND ITS RESOURCE MANAGEMENT IMPLICATIONS

INTRODUCTION

This study estimates organic standing stocks in a man-made wetland. Organic carbon production and accumulation is just one of many values assigned to wetlands and allows for the assessment of the success of wetlands creation projects.

Wetlands presently are recognized as important natural resources. Important values of wetlands are the provision of wildlife habitats, flood buffer capabilities, erosion protection, primary production and detritus availability, and the potential for wastewater treatment and the improvement of water quality. One third of the nation's wetlands have been lost in the past 200 years, presently more than 300,000 acres are lost annually (Hamon and McConnell 1983, Tiner 1984). While much of the loss of wetlands occurs naturally due to subsidence or erosion, the majority of the loss is caused by man's activities in channelization, flood control efforts, agricultural land conversion, and dredging (Farnell 1981, Wakefield 1982).

The recent realization of the importance of wetlands to the environment has been the impetus to generate conservation measures at all levels of government. The atmosphere of environmental concern in the 1970's brought to light the importance of natural resource legislation and management programs. Many laws were enacted on both state and federal levels to protect the natural environment, including wetlands. State wetlands acts (e.g. Virginia Wetlands Act of 1972, VA Code sec. 62.1-13.2 through 62.1-13.20) and the Federal Water Pollution Control Act (FWPCA) of 1972, with subsequent amendments, were part of the body of environmental legislation enacted during this time.

State and federal legislation and corresponding management programs aimed toward preservation and conservation of wetlands are based, in part, on the scientific understanding of wetlands. The need to verify and justify wetlands conservation efforts have led scientists and resource managers to formulate classification schemes based on ecological, economic, recreational and aesthetic values (Silberhorn, et al. 1974, Gosselink, et al. 1974, Galloway 1978, Smardon 1983). Classification schemes allow for consistent, and repeatable assessment of wetlands management programs as well as the impact of individual wetlands projects. Many efforts have been made to categorize the myriad values attributed to wetlands. As wetland values are condensed and simplified, classification schemes can be developed to determine the relative importance of particular wetland areas. Classification schemes based on ecological values commonly are used in the implementation of wetlands management plans, and these values often are cited within the management plan (or mandating legislation). Those values most often cited are the provision of wildlife habitats, flood buffer capabilities, erosion protection, primary production and detritus availability, and the potential for wastewater treatment and the improvement of water quality. The use of scientific values as justification for wetlands management programs is shown by the the declaration of policy of the Virginia Wetlands Act (Virginia Code Sec. 62.1-13.1) which states, "...this resource is essential for the production of marine and inland wildlife, waterfowl, finfish, shellfish and flora; is valuable as a protective barrier against floods, tidal storms and erosion of the shores and soil within the Commonwealth; is important for the absorption of silt and of pollutants; and is important for recreational and aesthetic enjoyment of the people for the promotion of tourism, navigation and commerce."

Mitigation as a Wetlands Management Tool

States and the federal government have similar approaches to the management of wetlands in order to ensure preservation and conservation of the resource. Several techniques are employed in the management of wetlands: preservation through the prevention of any activity which alters the natural environment, or conservation through compromise on project plans, seeking alternatives, minimizing impacts and replacing lost habitat. Conservation measures of the latter type, prevalent in today's wetlands management schemes, are commonly referred to as mitigation. There are several definitions of mitigation applicable to wetlands management; however, most authors tend to use the following three: 1) prevention of all activity involving wetlands; 2) design and implementation of a project to minimize impacts; and 3) creation of new habitat to compensate for losses (Race and Christie 1982). Harvey and Josselyn (1986) refer to any activity in wetlands with the purpose of positively affecting wetlands as a restoration project. Those activities thus defined include vegetation plantings, seeding, or in any way affecting the hydrology or tidal regime in a manner to create the potential for natural revegetation. It is important to recognize the different levels of effort required for each interpretation of mitigation. Grouping those activities for purposes of definition, discussion, or reporting can be ambiguous and confusing.

Man-made wetlands projects can, and should, be further delineated as compensation or enhancement. Enhancement involves a 'trade' of one wetland habitat type for another. For example, the creation of a *Spartina alterniflora* community in the present location of a *Phragmites australis* community would be an enhancement project. Compensation is habitat creation through the conversion of either a subaqueous or an upland area into wetland habitat. The creation of new wetlands habitat is performed at the expense of some other habitat type. For the purposes of this discussion, mitigation will refer specifically to compensation (defined as the creation of new wetlands habitat).

A relatively new approach to wetlands creation as a management alternative is the wetlands bank. A wetlands bank is a marsh creation project initiated by a public or private concern that foresees potential wetland losses due to future activities. The man-made site (wetlands bank) serves to compensate in advance for wetlands impacts, and operates theoretically much like a savings-bank account. Creation of the marsh is the original deposit and withdrawals are made for each activity requiring compensation. At whatever replacement ratio is designated, once the area(s) impacted equals the area created in the wetlands bank, the bank account is closed.

Wetlands compensation projects are a controversial form of wetlands conservation. Habitat creation is predicated on the theory that man-made ecosystems can function as natural ecosystems. Thus, the goal of wetlands creation is to duplicate natural parameters of the wetland ecosystem. These include, among others, primary productivity, faunal community development, biogeochemical substrate characteristics, as well as cultural and aesthetic values. Artificial wetlands systems are poorly understood with very little scientific information available at present (Shisler and Charette 1984, Race 1985). Many plant species are slow colonizers and may take a long time to attain natural densities for the area. During the development period, which may take years, both plant production and habitat value are low (Thayer, et al. 1986). As a result, the scientific validity of wetlands creation as a viable management tool has been questioned (Race and Christie 1982, Knutz 1987).

The technology involved in wetlands creation has expanded over the years; however, many variables in both project design and the environment affect the success of each site. Considering the complex nature of wetland communities, elevation is particularly important. Variables of project design which also are important include species planted, planting density, fertilizer use and when was the planting done. The tidal range, wave regime and soil type are environmental factors which also must be considered in project design.

To assess the application of habitat creation as a useful wetlands management tool, several other important factors must be addressed including compensation area created versus area impacted, proximity of creation site to impacted site, and type of wetland created versus the type impacted. Some state programs have established required ratios for wetlands compensation projects. Citing the inexact science of wetlands creation and the lag time between site planting and community establishment, many management programs require the creation of wetlands in an areal ratio greater than one for one. Habitat loss resulting from development activities should be mitigated by the same kind of habitat, and the replacement should be adjacent to the area of habitat loss (Thayer, et al. 1986).

The controversy over wetlands creation is exacerbated by the frequency with which creation is included in project designs. The inclusion of mitigation within the project design often will expedite and assure project approval. However, the mitigation proposed frequently involves wetland creation as opposed to compromise and adjustments to the original project design. For each project, every effort should be made to minimize project impact by careful planning and design before turning to compensation as a conservation tool.

The need for mitigation-oriented research has been expressed by several authors (Jahn 1979, Ashe 1982, Race and Christie 1982). Race and Christie (1982) maintain a man-made marsh "is not the functional equivalent of a thousand-year-old marsh." There is a need for additional scientific research and data to evaluate fully marsh creation and restoration as management strategies. There is a need for information for comparison to natural systems, to determine the scientific legitimacy of mitigation (Boesch 1987). What ecological criteria should be used to determine the 'equivalence' of man-made systems to natural systems? This question must be answered not only to determine what type, or how much, habitat creation is necessary to offset habitat destruction, but also to provide the means to determine 'equivalence' once the system is created and as it matures.

The success of wetlands management may be assessed using scientific methods. By analyzing the scientific values attributed to wetlands the impact of man's activities on wetlands can be assessed. This can be an assessment of either the impact of wetlands loss, or the success of wetlands creation. One way to investigate the success of habitat creation as a management tool is through the comparison of wetland area created versus that destroyed. Allowing for any compensation ratio established, this method compares the area of apparently successful creation to the area impacted. In other words, does the apparently successful creation encompass the same area as that which was destroyed? For example, if marsh creation projects are typically 50 percent successful, than a ratio of 2 to 1 would be necessary to compensate equally for the effected wetlands.

The investigation of mitigation projects can be approached from a site specific basis by investigating particular parameters of a single or of several sites. The scientific assessment of a single marsh creation site may establish a baseline and allow for monitoring of future developments in the 'maturation' of a man-made site.

The purpose of this investigation is to determine organic standing stocks in a mitigated brackish marsh. The determination of organics at the site can be used to assess the success of the site as a wetland compensation project and provide data for comparison to other man-made and natural systems. This is accomplished by:

1) Estimation of vegetative productivity, both above and belowground;
2) Determination of yearly sedimentary accretion rate, and organic content profiles, with depth, to the inorganic basement layer. This information, in concert with an estimate of the productivity of the vegetative community, provides a rate of accumulation of organics in the system since creation; and,
3) Review of the historical background of wetlands management, and the definitions and applications of mitigation in light of the present reliance on this type of wetlands management tool by resource managers, agency personnel and the development community.

LITERATURE REVIEW

Historical Perspective on Federal Wetlands Management

The legal preservation of wetlands is predicated on the theory that a private landowner holds legal title to his wetlands property *subject to certain public rights* (emphasis added) (Wood and Hill 1978). The constitutional basis for the assertion of public rights on private property is the congressional power to enact any legislation necessary and proper to promote congressional responsibilities, in this case, interstate commerce. Litigation supporting this congressional power is found in several U.S. district court decisions. One such decision is found in *NRDC v. Callaway* (392 F. Supp 685 D.D.C. 1975). The court found that the definition of the term "navigable waters" in Section 502(7) of the FWPCA to mean "the waters of the United States, including territorial seas," asserted federal jurisdiction over the nation's waters to the maximum extent permissible under the Commerce Clause of the Constitution. Further litigation on this issue is found in *U.S. v. Holland* (373 F. Supp. 665 M.D. Fla. 1974). The decision of the court was that congressional powers over interstate commerce allow for federal regulation of dredge and fill activities in non-navigable waters.

The United States Army Corps of Engineers is the lead permitting agency in the federal government's wetland protection efforts. The 1977 amendments to the Federal Water Pollution Control Act of 1972 (FWPCA), renamed the Clean Water Act (CWA), assigned the power of administrative review over the wetlands permitting program to the Corps of Engineers (Corps). The Corps's regulatory authority over the wetlands permitting program is mandated by section 404 of the Clean Water Act. The historical precedence for this assignment is found in the River and Harbors Act of 1899.

The River and Harbors Act (RHA) of 1899 gave the Corps administrative responsibility for activities occurring in navigable waters of the United States. The purpose of this Act is to regulate encroachment on the nation's navigable waters. In particular, section 10 of that statute specifies that no activity shall occur in navigable waters of the United States without the recommendation of the Chief of Engineers and authorization from the Secretary of the Army. Activities regulated by the act include any construction, excavation, or deposition of materials in navigable waters. Waters are defined as navigable if either navigable-in-law or navigable-in-fact. Waters which are navigable-in-fact are those presently or historically navigable, or susceptible to navigation with minor changes. Waters are navigable-in-law if they are subject to the ebb and flow of the tide (Dennis 1982, Wakefield 1982).

Existing responsibility for regulation of activities in navigable waters under the River and Harbors Act made the Corps a logical choice for the task of administering section 404 of the CWA. The Corps' program under section 10 of the RHA remained intact but was largely superceded by the greater purview of section 404 of the CWA. Both statutes require permits from the Corps for discharge of dredge or fill material in traditionally navigable waters, and both require the Corps' public interest review (Blumm 1980). Section 404 expands regulatory power beyond the RHA by making it unlawful to discharge dredge or fill material into "navigable water" as defined by all "waters of the United States" (emphasis added) without a permit from the Corps of Engineers (33 U.S.C. Sec. 1344). The basis for the permit criteria is the Corps regulations and section 404(b) guidelines established by the Environmental Protection Agency, (EPA). The EPA has veto authority over all permits.

The Corps published regulations in 1974 defining their responsibility for assessing environmental and economic impacts of a proposed project. The regulations were published in response to the enactment of the National Environmental Policy Act (NEPA) in 1969 which expanded the area of regulatory review of all federal agencies to require consideration of environmental factors. All factors relevant to a project would be considered including conservation, economics, aesthetics, historic values, fish and wildlife values, flood damage protection, navigation, water supply and water quality, and in general, the needs and welfare of the people (33 CFR 209.120). These regulations established a policy that no permit would be issued unless issuance was found, through the process of public interest review, to be in the public interest.

Four criteria were established to be used as a basis for the public interest review. The criteria are (1) what is the relative extent of public or private need for the project, (2) what is the desirability of using appropriate alternative locations and methods to accomplish the objectives, (3) what is the extent and permanence of the beneficial and detrimental effects that the project may have on the public and private uses to which the area is suited, and (4) what is the probable impact of the project in relation to the cumulative effects created by the existing or anticipated structures in the general area (33 CFR 320.4). In the 1974 regulations, however, the Corps did not redefine the scope of their jurisdiction to correspond to their new administrative responsibility over waters of the United States as defined in section 404 of the FWPCA.

The extent of the Corps' jurisdiction was questioned and ordered to be revised by the District Court of the District of Columbia in 1975. In the decision of the <u>Natural Resources Defense Council v. Callaway</u> (392 F. Supp. 685, 5 ELR 2085 (D.D.C. 1975), the court found that the Corps must adopt an expansion of its jurisdiction to include waters of the United States, as defined by section 404 of the FWPCA. The court required the Corps to promulgate new regulations to implement their new responsibility.

As a result there were some major changes made to section 404 of the FWPCA in 1977. These changes involved a reworking of the FWPCA, then renamed the Clean Water Act (CWA). The functional wetlands protection language of the CWA is found in the delineation of the scope of review of the Act. The Act regulates all "... dumping or dredging activity in navigable waters or <u>adjacent</u> <u>wetlands</u>" (emphasis added). Wetlands are defined as areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and under normal conditions do support, a prevalence of vegetation typically adapted for life in saturated soil conditions (33 CFR 328.3 b). Broadly construed, dumping or dredging can be interpreted to mean any and every activity.

District Engineers were encouraged in the 1982 regulations to institute joint processing review of permits in order to reduce agency duplication and processing time. The joint processing procedure involves the meeting of state and federal agency representatives (Corps of Engineers, Environmental Protection Agency, Fish and Wildlife Service, National Marine Fisheries Service) to review project applications. The joint processing meetings would save the applicant and agencies considerable time. However, the need to reduce processing time can lead to perfunctory, and insufficient, review of some projects.

The Corps is relaxing its wetlands management responsibility relying on state programs to regulate wetlands activities. State governments, unlike the federal goverment, do not have the power to regulate interstate commerce. The historic basis for the regulation of activities in wetlands must be based on some other power found in the state's consititution. In the case of Virginia, general language in the constitution may be interpreted to allow for the regulation of activities in wetlands. The constitution gives the General Assembly the power to declare streams navigable (VA. Const. Art. IV Sec. 14(15)). The Constitution further states all functions, powers and duties of any department or division under the executive or legislative branch may be prescribed by law (VA. Const. Art. V Sec. 9). This general statement allows for the enactment of legislation such as the Virginia Wetlands Act (VA. Code Sec. 62.1-13.2 through 62.1-13.20). This legislation, similar to other state wetlands acts, applies only to tidal wetlands. There has been growing concern over the protection of non-tidal wetlands and several states have passed (New Jersey), or are researching and developing non-tidal wetlands legislation.

Rosenbawn (1980) studied the status of state wetland programs. Generally, the states use the same methods of environmental protection as the federal government. They have permit programs, formal applications with fees, penalties for noncompliance and environmental standards. However, when compared to federal regulations, state definitions of wetlands and jurisdiction are generally more vague. The well-trained staffs of federal agencies have difficulty with federal definitions but are much better off than their state counterparts. The same holds true for enforceability. The large infrastructure of the federal agencies involved (Corps, EPA, FWS, NMFS) provides for education and training in wetlands ecology and management. Also, there are several agencies with 'overlapping' jurisdiction, each with a slightly different interest in the protection of wetland resources to provide full consideration of proposed project impacts. State governments, however, often have only one agency with the responsibility for wetlands management. As a result states have smaller budgets and work forces to apply to the administration of wetlands management. Rosenbawn (1980) found that the passage of most of the state laws involved a trade-off of specificity for enforcement, or visa versa. It is not uncommon for a state, such as New York, to have idealistic statements of policy and definitions and few provisions for efficient enforcement.

Present Scientific Understanding

Wetlands Ecology

The first work done in the field of wetlands largely involved assumptions made on the processes of interactions between marshes and adjacent waters. The fisheries productivity of estuaries was well documented, and early work in wetlands showed very high levels of organic carbon production. Wetlands ecologists theorized that the primary productivity of wetlands surpassed the respiratory needs of the community and the excess organic material was exported to adjacent waters to be available to support estuarine productivity. Estimates of estuarine productivity were put into perspective by E. Odum (1961), showing estuarine productivity to be greater than most labor intensive crops, including wheat and corn. Teal (1962) determined that marshes export forty-five percent of all organic material produced by the marsh. De la Cruz (1965) estimated detrital export from measurements made over the time interval of a tidal cycle. However, due to the variability of tidal cycles, more accurate estimates of detrital export must be calculated over a larger time scale, preferably a minimum of one year. De la Cruz's study brought attention to the feasibility and emphasized further the need for detrital export studies.

E. Odum (1968) suggested, as a parallel to the role of upwelling in nearshore productivity, that the term outwelling be applied to the interaction between the export of organic material from wetlands and estuarine productivity.

Detrital material from salt marsh vegetation, which is composed largely of refractory carbohydrates, is not readily digestible. Since it is not easily digested, detritus does not, in itself, serve as a major nutrient source for estuarine organisms. De la Cruz (1973) proposed a biological pathway for the use of detritus in estuarine foodwebs. The detritus provides a nutritive substrate to support the growth of microorganisms, such as protozoans, fungi, and bacteria. Estuarine organisms ingest the enriched detritus digesting only the microbes while the tough plant substrate remains relatively intact. However, the author presented no evidence to substantiate the theory that estuarine species relied on this pathway as a major food source.

One of the first determinations of outwelling, organic flux on a yearly scale, was made by Moore (1974). He collected water samples from a brackish marsh tidal creek, a tributary to the York River, Virginia. Water chemistry analysis of dissolved organic carbon and particulate organic carbon, showed a small net export of organic material to adjacent waters.

Several problems of the outwelling theory were brought to light by the work of Haines (Haines 1977, Haines and Montague 1979). Haines's research on the outwelling theory and detrital based foodwebs tended to refute the accepted understanding of the role of salt marshes in the estuarine system. This work involved the use of carbon isotope ratios to determine sources of energy in the estuarine food web. Natural elements may exist in multiple, chemically different, forms called isotopes. Carbon, with ^{12}C and ^{13}C isotopes, is one of these elements. Several different pathways may be used by photosynthetic organisms to incorporate atmospheric carbon into living tissue. Photosynthetic pathways have different uptake ratios of the carbon isotopes, and thereby reflect different isotopic ratios in plant tissues. Estuarine organisms, under the old adage "you are what you eat," reflect the carbon isotope ratios of the plant material on which they feed. Two of Haines' studies in particular, question the paradigm outwelling theory through the use of carbon isotope analysis.

Haines (1977) presented evidence which suggested that Spartina alterniflora did not form the major component of particulate detritus in estuaries. She stated her argument in three points: 1) attempts to document the loss of plant material from salt marshes have yielded contradictory results; 2) carbon isotopic composition of organic detritus does not match values for S. alterniflora; however, it is compatible with terrestrial and phytoplankton sources; and 3) potential inputs from terrestrial and phytoplankton sources are on the same order of magnitude as input from S. alterniflora marshes. A second study (Haines and Montague 1979) involved work on the carbon isotopic ratios of estuarine organisms which indicated that S. alterniflora detritus is not the major energy source for several abundant species. Marsh snails and insects which graze directly on salt marsh vegetation have isotopic ratios very similar to the associated plants. However, the ratios of deposit feeding fiddler crabs were not similar to marsh plant values.

Mud snails and filter feeding bi-valves (C. *virginica*, oyster) had ratios similar to those of pelagic and benthic algae. The authors recognized and encouraged the use of carbon isotope ratios as a tool for further research on estuarine food webs.

In 1980, Nixon published a comprehensive treatise on twenty years of salt marsh research. Nixon provided critical narrative in reviewing the scientific information available on nutrient fluxes in coastal wetlands. He claimed the development of the outwelling theory did not reflect well on wetlands science. The outwelling theory, which originally was presented with more importance than the supporting evidence warranted, was too readily accepted by the scientific community. Zealous statements of the importance of wetlands to coastal waters helped encourage conservation activities and undeniably, few wetlands ecologists disapproved of the results. However, Nixon disagreed with using an end to justify the means by which it was obtained. His conclusion found not so much fault with the outwelling theory itself, but rather with the theory's acceptance and perpetuation in the absence of conclusive supporting data. The outwelling theory is not a panacea to the questions concerning the role of wetlands in estuarine productivity. However, simply questioning the theory does not make it invalid. Questions and research are part of the scientific process necessary to better define the interactions between wetlands and adjacent waters (Nixon 1980).

E. Odum (1980) reviewed the scientific understanding of three theories dealing with marsh-estuarine interactions tidal subsidy, outwelling, and detritus-based food webs. In a discussion of the outwelling theory, he referred to W. Odum who suggested that geomorphology, tidal amplitude and freshwater input would all influence whether an estuarine system would import or export organic materials. E. Odum emphasized the likely periodic or seasonal character of outwelling, associated particularly with high spring tides and storm events. Odum concluded that outwelling was still a viable theory, however, the process is variable and many factors influence the transport of organic materials. Nixon (1980) and Odum (1980) both encouraged further study to clarify some of the problems with the theories on salt marsh - estuary interactions.

As previously noted, one of the problems with the outwelling theory is the carbon isotope dissimilarity between Spartina alterniflora and estuarine detritus and organisms (Haines 1977, Haines and Montague 1979). A possible solution to this question was proposed by Peterson, et al. (1980). The anaerobic decomposition of S. alterniflora by microbes produces energy-rich sulfur compounds. The energy generated by this process supports the growth of bacterial communities which serve as a food source for many estuarine organisms. The bacteria use carbon sources other than S. alterniflora and will not reflect carbon isotope ratios similar to S. alterniflora in laboratory studies. However, in this way S. alterniflora provides essential energy to the system, but is not necessarily the primary carbon source for microbial production. The authors make no attempt to disregard the importance of other sources (i.e. terrestrial) of organic carbon in the estuarine system, but emphasize that the role of S. alterniflora needs to be better understood.

The recent work in the outwelling field generally appears to conclude that outwelling is a viable theory on salt marsh-estuarine interactions. W. Odum (1984) summarizes research attempts to resolve the questions concerning the link between primary and secondary production. Odum notes that using carbon isotope ratios to make definitive claims about estuarine food webs is very difficult. The method works best when the consumer obtains carbon from a single source. However, many estuarine organisms rely on a variety of food sources making the isotope analysis difficult to interpret. He suggested using multiple isotopes as a tool to better understand estuarine trophic relationships. His conclusion reiterated the need for more research, particularly laboratory studies, to advance present understanding of wetland-estuarine interactions.

Peters and Lewis (1984) presented a review of menhaden research undertaken to investigate the theoretical link between wetlands and fisheries production. Laboratory studies on menhaden included feeding experiments using several food sources including S. alterniflora detritus. Studies show that menhaden ingest large amounts of detritus. Whether menhaden feed largely, or preferentially, on Spartina detritus is still unknown. However, Peters and Lewis investigated just one estuarine species and more information is needed to understand estuarine trophic relationships. Coastal management programs require estimates of project impacts to coastal resources, including fisheries. However, Peters and Lewis noted the information on the role of wetlands in estuarine food webs and fisheries production was incomplete, and it was difficult to determine how particular coastal habitat modifications will affect fisheries.

A recent study with a holistic approach to coastal ecosystems suggested that marshes are part of an ecosystem that has three subunits: the marsh, the estuary, and the estuarine plume nearshore region (the nearshore coastal waters into which the estuary empties)(Hopkinson and Hoffman 1984). They provided evidence that the marsh is the only subsystem that produces organic material in excess of respiratory requirements of the marsh community. The organic carbon requirements of nearshore waters are not supported by *in situ* production. This study, coupled with studies on marsh/estuarine community metabolism, suggested an export of *S. alterniflora* carbon to adjacent waters. Exported salt marsh production and riverine inputs support levels of metabolism in nearshore waters unachievable by pelagic primary productivity alone.

Methods Applicable to the Analysis of Organic Standing Stocks

Primary productivity

There are many possible methods for estimating net aerial primary productivity (Linthurst and Reimold 1978). Three methods are most commonly used; peak standing crop, Smalley's (1959) method, and Weigert and Evan's (1964) method. The peak standing crop method assumes that all vegetation reaches peak biomass within a determined time interval and sampling that interval gives a yearly estimate (Wass and Wright 1969, Keefe and Boynton 1973, Burger and Shisler 1983, Roman and Daiber 1984, Vince and Snow 1984).

Smalley's method attempts to account for the mortality of living material within sampling intervals. Smalley's method requires the collection of both living and dead vegetative material and productivity is determined for each sampling interval as follows:

1) If there is an increase in the standing crop of both living and dead material, net production is the sum of the increases.
2) If both living and dead standing crop decrease, production is assumed to be zero.
3) If living standing crop increases and dead biomass decreases production is equal to increase in living material.
4) If dead standing crop increases and living biomass decreases, they are added and if the result is negative, production is assumed to be zero; if the result is positive, the value is assumed to represent production.

Weigert and Evans's method accounts for the disappearance of dead material in the determination of net aerial primary productivity. The instantaneous rate of disappearance of dead material is calculated as:

$$r_1 = (\ln W_0 - \ln W_1)\ (t_1 - t_0)^{-1} \qquad \text{(eq.1)}$$

where r_1 is the disappearance rate in g g^{-1}litter day^{-1},

$t_1 - t_0$ is the time interval in days,

w_0 and w_1 are weights in grams at times t_0 and t_1 respectively.

The dead material disappearing during a time interval (x_1) was computed as:

$$x_1 = [(a_i + a_{i-1})(2)^{-1}] r_i t_i \qquad \text{(eq.2)}$$

where t_i was the interval in days,

a_{i-1} was dead standing crop at the start of the interval,

a_i was the dead standing crop at the end of the interval.

Changes in standing crop of living (^b) and dead (^a) material are computed as follows:

$$\hat{}b = b_i - b_{i-1} \qquad \text{(eq.3)}$$

$$\hat{}a = a_i - a_{i-1} \qquad \text{(eq.4)}$$

mortality (d_i) is computed as:

$$d_i = x_i + \hat{}a_i \qquad \text{(eq.5)}$$

and production calculated as:

$$y_i = \hat{}b_i + d_i \qquad \text{(eq.6)}$$

Weigert and Evans used two different procedures to determine the loss of dead material: paired plots and litter bags.

In the paired plot method, all standing dead material and litter is removed from one plot at the initiation of the sampling interval t_1-t_0, whereas only living material is removed from a contiguous plot. The dead material is removed from the second plot at the end of the sampling interval and the disappearance rate is determined (eq.1) (Reimold, et al. 1975, Hopkinson, et al. 1978).

Determination of disappearance rates using litter bags involves placing a mesh bag, containing a known weight of dead material (w_0), on the marsh surface. The bags are collected after a given time interval, weighed (w_1), and the disappearance rate is calculated (eq.1) (Mason and Bryant 1975, Kirby and Gosselink 1976, Hershner 1977, White, et al. 1978, White and Trapani 1982).

Belowground production

Belowground standing crop is most often determined from soil cores. The cores are retrieved, washed, dried to a constant weight, and weighed (Smith, et al. 1979). Attempts have also been made to separate the living and dead material (de la Cruz and Hackney, 1977; Roman and Daiber 1984), but the results are quite variable and data are commonly reported as total belowground standing crop. Studies show that most vegetation has a maximum belowground standing stock corresponding with late summer, and a minimum standing stock corresponding with winter.

Sedimentary accretion rates and organic analysis

Accretion rates are often determined using marker beds. A marker material is used to cover the marsh surface in a predesignated area at time zero. To determine the total net accretion which occured over a specified time interval, cores are retrived from the site at the end of the time interval. Most often these cores are returned to the lab and frozen. The cores may then be extruded and bisected, or bisected while still intact. Measurements are taken from the surface to the marker layer. Usually several measurements are taken and a mean value is calculated. The marker material can be brick dust (Stearns and MacCreary 1957, Richard 1978), glitter (Harrison and Bloom 1977, Stumpf 1983), a mixture of kaolin clay and quartz sand (Oenema and DeLaune 1988) or spray paint (Vince and Snow 1984). Concern has been expressed in using artificial marker beds to estimate sedimentary accretion. It is probable that the marker material will not behave as the native sediment. It may sink preferentially, or may be more susceptible to resuspension and transportation. Ranwell (1964) combined the use of graduated stakes with a marker bed of coal dust and suggested that a more permanent marker would provide a reasonable check on the rates determined using marker bed materials.

The determination of accretion rates using ^{137}Cs is a proven, common practice (DeLaune et al. 1983, DeLaune et al. 1987). However, it is not applicable to most man-made marshes. The method relies on the presence in the core of a ^{137}Cs peak corresponding to a maximum fallout of atmospheric cesium in 1963. The location of a cesium peak in a soil sample can be used to estimate total accretion since that time (1963), as well as mean annual accretion rates. This method is not applicable to man-made sites younger than the peak fallout date of 1963.

Allison (1965) described a dry combustion method commonly used to determine organics in sediment analysis (DeLaune et al. 1979, Lindau and Hossner 1981, Gosselink et al. 1984). Carbon content may be calculated by converting organic carbon with a correction factor of 0.58 (Wilson and Staker 1932).

Applicable Results

Primary productivity - Aerial

Numerous studies have been done on the productivity of wetlands. Most of these studies have involved the determination of aboveground production of individual vegetative species common in saltwater and brackish systems (Table 1). These studies show a latitudinal variation in productivity with highest values occurring in the southern United States or in the southern range of a particular species. Net production of Spartina alterniflora ranges from 400 g $m^{-2}y^{-1}$ to 3000 g $m^{-2}y^{-1}$ with highest production in Georgia (Reimold 1977).

Primary productivity - Belowground

The scientific assessment of belowground production is a relatively new field. It is not easy to assess belowground production, samples are difficult to retrieve and process, as a result most estimates are

Table 1. Summary of aerial primary production of wetland species

Species	Peak Biomass g m^{-2} Aerial	Net Production g m^{-2} yr^{-1} Aerial	Net Production g m^{-2} yr^{-1} Total	Locale	Source
S. alterniflora		2658		LA	Hopkinson, et al (1978)
	1473		2895	LA	White, et al (1978)
		973		GA	Smalley (1958)
		2000-3300		GA	Odum (1959, 1961)
	259-1320	329-1396		NC	Stroud & Cooper (1969)
	545	650		NC	Williams & Murdoch (1969)
	250-2100	1000		NC	Williams & Murdoch (1966)
	1332			VA	Wass & Wright (1969)
	413	445		DE	Morgan (1961)
		2800		NJ	Smith, et al (1979)
		1487		NJ	Roman & Daiber (1984)
	300			NJ	Good (1965)
		3900-6600		MA	Valiela, et al (1976)
S. patens		6043		LA	Hopkinson, et al (1978)
	2194	1428		LA	White, et al (1978)
	640	1296		NC	Waits (1967)
	805			VA	Wass & Wright (1969)
		1147		NJ	Roman & Daiber (1984)
		993		NY	Harper (1918)
S. cynosuroides		1355		LA	Hopkinson, et al (1978)
	1456			VA	Wass & Wright (1969)
D. spicata		3237		LA	Hopkinson, et al (1978)
	1164	9162		LA	White, et al (1978)
	360			VA	Wass & Wright (1969)
P. australis		2318		LA	Hopkinson, et al (1978)
		2695		NY	Harper (1918)

Table 1. (con't)

Species	Biomass g m^{-2} Aerial	Net Production g $m^{-2} yr^{-1}$ Aerial	Net Production Total	Locale	Source
	1000			UK	Pearsall & Gorham (1956)
	497			UK	Buttery & Lambert (1965)
		2940		NJ	Roman & Daiber (1984)
T. latifolia	684	684		SC	Boyd (1970)
	1527			OK	Penfound (1956)
		1358		NY	Harper (1918)
	1070			UK	Pearsall & Gorham (1956)
	404			ND	McNaughton (1966)
	416			NE	McNaughton (1966)
T. angustifolia	930			VA	Wass & Wright (1969)
		1733		NY	Harper (1918)
Typha community	1380	1905	3205	NJ	Jervis (1964)
L. oryzoides	1545			VA	Wass & Wright (1969)

After Keefe 1972

biomass estimates. Some attempts have been made to estimate production using the Max-Min method (maximum biomass measurement minus minimum biomass measurement), but the accuracy of this method is undetermined. The recent interest in belowground production and the difficulty of obtaining data results in estimates of belowground standing crop that are highly variable (Table 2). De la Cruz and Hackney (1977) estimated belowground production of a _Spartina alterniflora_ marsh in Mississippi to be 22.0 kg m^{-2}, and other Mississippi communities ranged from 9.0 - 16.0 kg m^{-2}(de la Cruz 1974). Estimates from North Carolina appear to be low at 0.6 - 1.3 kg m^{-2}(Cammen 1975) and 1.1 - 5.9 kg m^{-2}(Stroud 1976). Studies conducted in New Jersey have found biomass of 3.3 - 6.5 kg m^{-2}(Roman and Daiber 1984), and 11.2 kg m^{-2}(Smith, _et al._ 1979). Valiela, _et al_ (1976) reported belowground biomass of 3.5 kg $m^{-2}$for a Massachusetts salt marsh. Most of the reported values are for _Spartina alterniflora_.

Loss of dead material from marshes has been determined in several studies using litter bags. A loss of greater than 87 percent was found for all vegetative material by White and Trapani (1982). Kirby and Gosselink (1976) found a loss of 100 percent of _Spartina_ material over a years time with losses as high as 50% in 2.5 months found for that species (White, _et al_. 1978).

Table 2. Summary of belowground productivity of wetland species

Species	Productivity $g\ m^{-2}\ yr^{-1}$	Location	Source
Spartina alterniflora	1600	MS	de la Cruz (1974)
	2100	GA	Gallagher & Plumley (1979)
	500	NC	Stroud (1976)
	110-590	NC	Cammen (1975)
	2900	NJ	Good (1977)
	3300	NJ	Good & Frasco (1979)
	2400	NJ	Good & Walker (1977)
	330-650	NJ	Roman and Daiber (1984)
	1120	NJ	Smith et al. (1979)
	3500	MA	Valiela et al (1976)
	220	ME	Gallagher & Plumley (1979)
Spartina patens	900	MS	de la Cruz (1974)
	310	GA	Gallagher & Plumley (1979)
	470	DE	Gallagher & Plumley (1979)
	3270	NJ	Good & Frasco (1979)
	2500	MA	Valiela et al (1976)
	540	ME	Gallagher & Plumley (1979)
Spartina cynosuroides	2200	MS	de la Cruz & Hackney(1977)
	3560	GA	Gallagher & Plumley (1979)
Distichlis spicata	1070	GA	Gallagher & Plumley (1979)
	3400	DE	Gallagher & Plumley (1979)
	2780	NJ	Good & Frasco (1979)
Phragmites australis	3650	DE	Gallagher & Plumley (1979)
	2810	NJ	Good & Walker (1977)

Sedimentary accretion rates and organic content

Studies of accretion rates using marker beds have shown that accretion tends to be variable and site specific. Ranwell (1964) measured accretion rates varying from 34 to 81 cm y^{-1}. Richard (1978) found accretion rates ranging from 2.0- 45.5 mm y^{-1}. Oenema and DeLaune (1988) found accretion rates for six month intervals ranging from 3.6mm (±4.4 mm) to 32.1mm (±16.2 mm). The percent organic carbon of these sediments ranged from 22 (± 6) to 51 (± 9). An accretion rate of 6.6mm y^{-1} (± 2.2mm), with organic content varying from 20 to 30 percent dry weight was reported by DeLuane, et al. (1983). Hatton, et al. (1983) found organic matter as percent of dry weight ranging from 22 (±3) to 42 (±3) in a brackish Louisiana marsh. DeLaune and Smith (1984) found organic carbon content of 35 (±4) percent. Baumann, et al. (1984) found yearly accretion rates of 15 mm (±0.4). These reported accretion rates were all determined using marker horizons.

Few studies have been done to determine accretion rates in Chesapeake Bay. Those studies most recently conducted all estimated accretion from historical records (pollen identification), ^{137}Cs, or ^{210}Pb dating. Stevenson, et al. (1985) found accretion rates of 1.7 to 3.6mm per year in a Maryland brackish marsh.

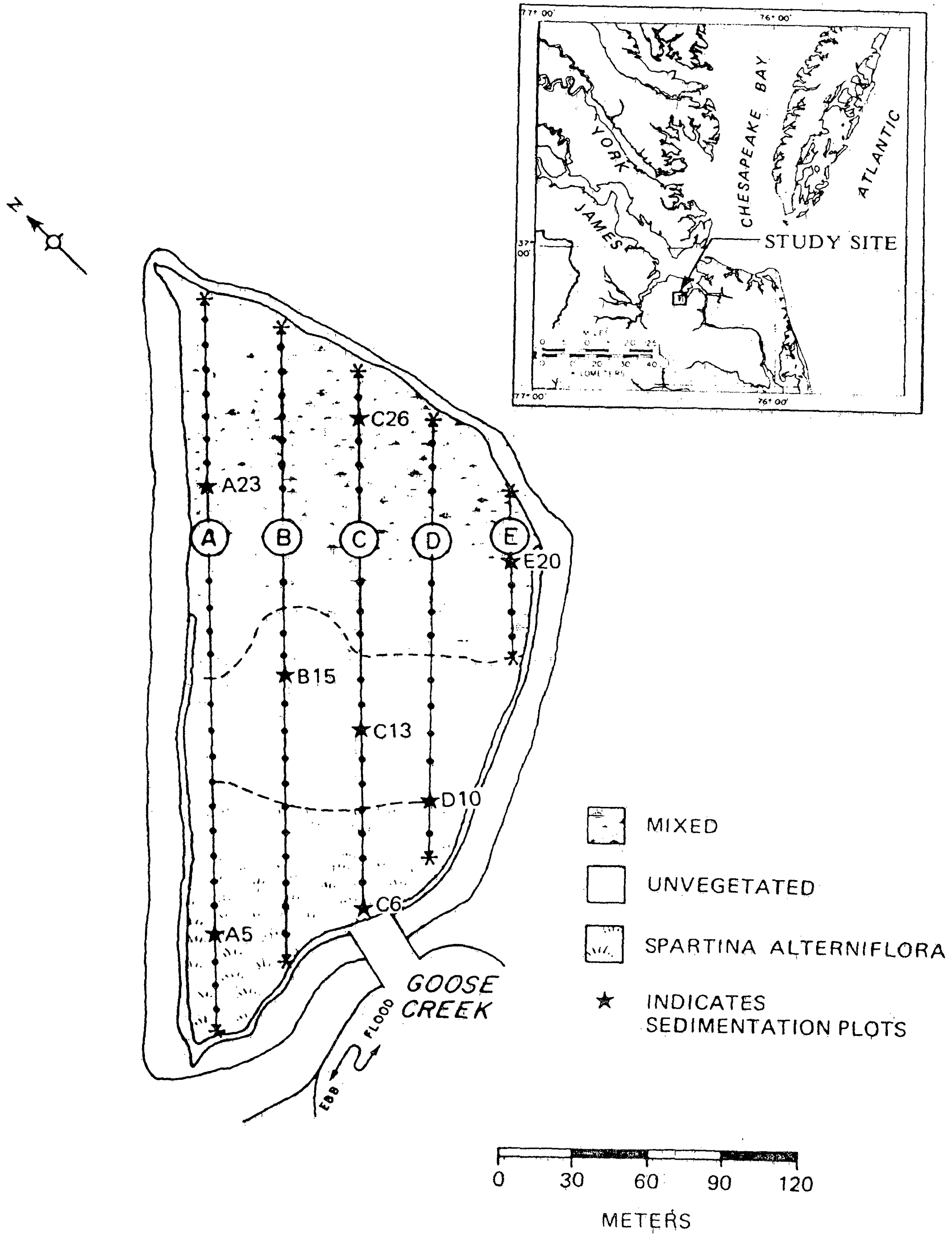
STUDY SITE

The study site is a Virginia Department of Transportation (VDOT) compensation project located in Chesapeake, Virginia (Figure 1). The site is on Goose Creek, a tributary of the Western Branch of the Elizabeth River. The tide measured at the tidal inlet of Goose Creek on August 15, 1984 was 0.7 m. The mean tidal range is 0.8 m at Port Norfolk near the confluence of the Western Elizabeth and the James Rivers -downstream from the study site (NOS tide Tables 1988). Salinities determined from water samples collected at the site are quite variable (Table 3). The vegetative community of neighboring natural wetlands is dominated by *Spartina cynosuroides*.

Construction involved the planting of an approximate 4.32 hectare tidal marsh in an existing borrow pit adjacent to Goose Creek. The borrow pit originnaly was a source for fill material for highway projects. Sediments were inorganic sands. The site was damp with some evidence of groundwater seepage indicated by the presence of cattails (Typha spp.).

The marsh was built with an approximate 3.38 hectare floor and 0.94 hectare transition - embankment area. The embankment of the pit is approximately 3.6 meters high. The area was graded to an elevation

Figure 1. Goose Creek study site on the Western Branch of the Elizabeth River. Site plan indicates location of transects and sedimentation plots.



N
YORK
JAMES
CHESAPEAKE BAY
ATLANTIC
STUDY SITE
A23
C26
E20
B15
C13
D10
C6
A5
A
B
C
D
E
GOOSE CREEK
FLOOD
EBB
MIXED
UNVEGETATED
SPARTINA ALTERNIFLORA
INDICATES SEDIMENTATION PLOTS
0
30
60
90
120
METERS

Table 3. Salinities from tidal inlet - Goose Creek Marsh

July 1983	10 ppt
August 1983	16 ppt
September 1983	17 ppt
July 1984	1 ppt
August 1984	5 ppt
May 1985	14 ppt
July 1985	3 ppt
October 1985	4 ppt
November 1985	5 ppt
June 1986	14 ppt
August 1986	8 ppt
September 1986	11 ppt
October 1986	19 ppt
October 1987	4 ppt
October 1987	7 ppt
May 1988	3 ppt

between 0.5 and 0.6 meters above mean sea level (M.S.L.). The gradient was designed to allow inundation by approximately 0.2 to 0.3 meters of water at mean high tide (Elev. +0.8) and to drain at mean low tide (Elev. -0.3). (Figure 2)

Eight vegetative species were planted in July 1982. The floor of the site was planted with Spartina alterniflora, Spartina cynosuroides, Distichlis spicata, and Spartina patens. Transitional species planted on the slope included Baccharis halimifolia, Iva frutescens, Myrica cerifera, and Ilex glabra.

For this study, five transects were established on the floor of the created marsh. The transects were placed 30 meters apart, and stations were positioned 10 meters apart (Figure 1). Relative elevations were determined in 1984 prior to the beginning of this study to provide information on the status of the site. Elevations were determined each station using a telescopic level and graduated rod. Elevations of established transects A-E are shown in Figure 3. Elevations were referenced to a National Geodetic Vertical Datum 1929 benchmark.

Visual observation indicated a discrepency between actual elevations, vegetative planting and vegetative community establishment. The site plan required the creation of elevations consistent with the planting and establishment of two vegetative communities on the floor of the marsh, S. alterniflora at the lower elevations and S. cynosuroides at the upper elevations. However, at the initiation of the study a large unvegetated area existed in the 'middle' of the site. The lower

Figure 2. Goose Creek site plan for construction of the marsh.

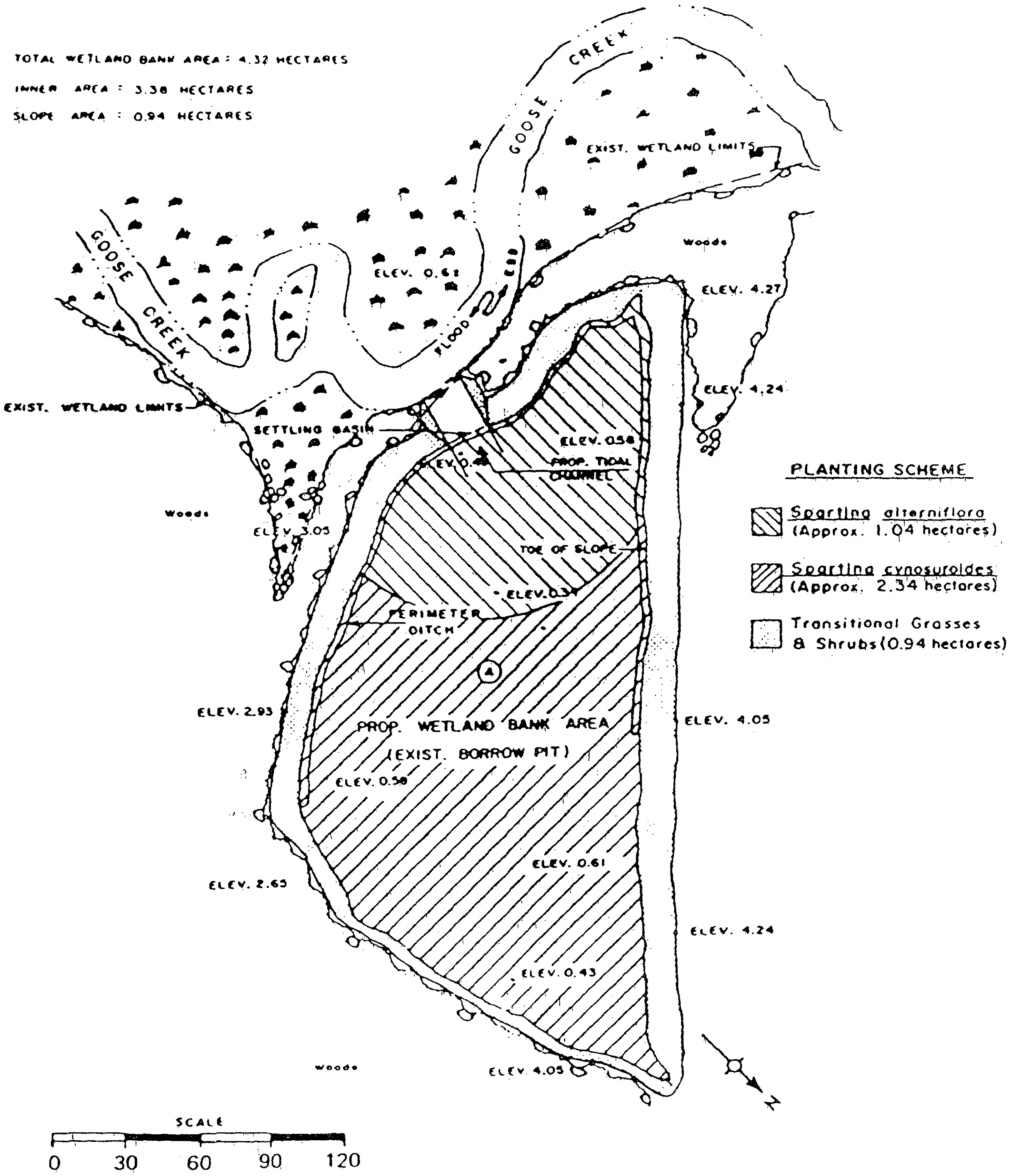
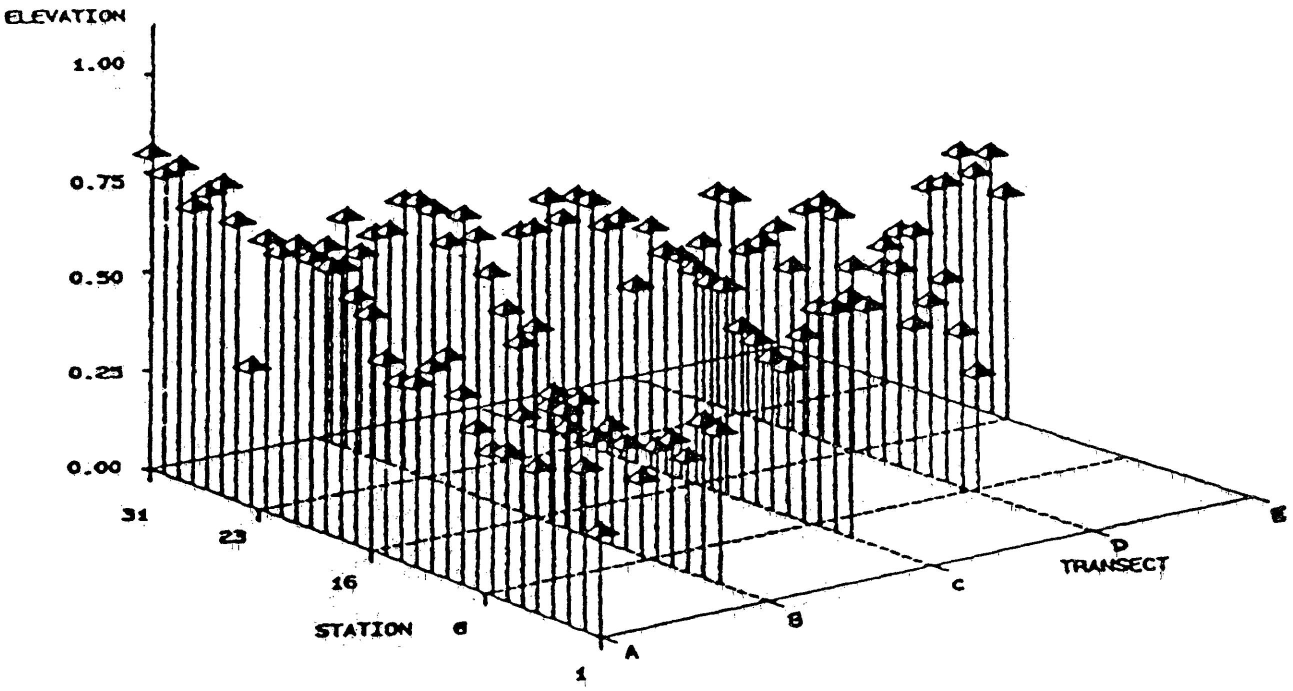

TOTAL WETLAND BANK AREA : 4.32 HECTARES
INNER AREA : 3.38 HECTARES
SLOPE AREA : 0.94 HECTARES
GOOSE CREEK
GOOSE CREEK
EXIST. WETLAND LIMITS
EXIST. WETLAND LIMITS
Woods
ELEV. 0.61
FLOOD
EBB
ELEV. 4.27
ELEV. 4.24
SETTLING BASIN
ELEV. 0.58
PROP. TIDAL CHANNEL
Woods
ELEV. 3.05
TOE OF SLOPE
ELEV. 0.34
PERIMETER DITCH
ELEV. 2.93
PROP. WETLAND BANK AREA
(EXIST. BORROW PIT)
ELEV. 4.05
ELEV. 0.58
ELEV. 0.61
ELEV. 2.65
ELEV. 4.24
ELEV. 0.43
Woods
ELEV. 4.05
N
PLANTING SCHEME
Spartina alterniflora (Approx. 1.04 hectares)
Spartina cynosuroides (Approx. 2.34 hectares)
Transitional Grasses & Shrubs (0.94 hectares)
SCALE
0 30 60 90 120
METERS

Figure 3. Elevations for transects A-E at Goose Creek in 1984.

ELEVATION BY TRANSECT

GOOSE CREEK – 1984



DISTANCE BETWEEN TRANSECTS – 30 M
DISTANCE BETWEEN STATIONS – 10 M

ELEVATION IS IN METERS

elevations, in closest proximity to the tidal inlet, were dominated by a nearly monotypic stand of *Spartina alterniflora*, although *Pluchea purpuracens* was also present. A ubiquitous groundcover of *Eleocharis parvula* co-occured with the *Spartina alterniflora*. The middle area, corresponding to stations 11-15 on transect A, 10-18 on transect B and 8-16 on transects C and D, was unvegetated in 1984. This area remained unvegetated in 1985, with some encroachment of *Spartina alterniflora*. The upper elevations were inhabited by a mixed vegetative community. Table 4 lists vegetative species present at Goose Creek in 1984.

Table 4 Vegetative species observed at Goose Creek in 1984

LM	Spartina alterniflora	S/B
LM	Eleocharis parvula	S/B
LM	Pluchea purpuracens	S/B
HM	Amaranthus cannabinus	S/B/F
HM	Aster tenuifolius	B
HM	Atriplex patula	S/B
HM	Cyperus esculentus	B
HM	Distichlis spicata	S/B
HM	Echinochloa walteri	F
HM	Eleocharis obtusa	S/B/F
HM	Juncus accuminatus	F
HM	Juncus scirpoides	F
HM	Leersia oryzoides	F
HM	Leptochloa uninerva	
HM	Panicum spp.	S/B/F
HM	Phragmites australis	B/F
HM	Polygonum hydropiperoides	F
HM	Polygonum punctatum	F
HM	Ptilimnium capillaceum	B/F
HM	Scirpus robustus	S/B
HM	Scripus validus	B/F
HM	Spartina cynosuroides	B/F
HM/E	Iva frutescens	S/B
HM/E	Scirpus cyperinus	F
HM/E	Typha angustifolia	B/F
HM/E	Typha latifolia	B/F
E	Baccharis halimifolia	S/B/F
E	Cassia fasiculata	
E	Cicuta maculata	B/F
E	Impatiens capensis	F

KEY

Relative location -Goose Creek		Common wetland type	
LM	low marsh	S	Salt
HM	high marsh	B	Brackish
E	edge	F	Fresh

METHODS

This study was designed to determine net aerial primary productivity, peak standing crop, belowground biomass, yearly sedimentation rate, organic content of sediment and sediment density.

Vegetative Production- Aerial

The nature of the vegetative communities at Goose Creek provided for the separate consideration of the low marsh (*Spartina alterniflora*) community and the upper marsh (mixed) community and for the purposes of estimating production, the site was considered as two separate communities. The unvegetated area was excluded from production estimates.

A variation of the ring-toss method was used to locate samples. Starting from the beginning of a transect, a table of random numbers provided distance along and away from transects. Aboveground vegetation samples were delineated with a 0.25 m^2 quadrat and harvested at ground level.

Belowground material was retrieved in cores (10 cm diameter x 30 cm deep) at locations corresponding to aboveground samples.

Thirty aerial and belowground vegetative samples were collected in the *Spartina alterniflora* community in September 1985. Aboveground material was collected four times (seasonally), and belowground material twice, in the mixed community. Aboveground samples were taken in June 1985, October 1985, March 1986, and May 1986. Belowground samples were collected in October 1985 and March 1986.

All samples were brought back to the lab for processing. Aboveground samples were separated into living and dead material. The vegetation was washed, dried at 50 C for 48 hours, and weighed. Belowground cores were washed over a 1 mm sieve. Vegetative material from belowground cores was dried at 50 C for 48 hours and weighed.

A litter bag study accompanied the sampling of primary productivity to correct for the disappearance of dead material. The litter bags contained approximately 150 grams of dried litter material from preceding sampling intervals. Placement and removal of bags coincided with sampling for primary production so that litter removal estimates were on the same time scale as productivity estimates. Litterbags were placed next to each sedimentation plot (see Figure 1).

Smalley's (1959) method was employed to determine productivity for each sampling interval, with a correction for disappearence of dead material according to Weigert and Evans (1964).

Sedimentary Accretion and Organic Content

Sedimentary accretion rates and sediment organic content were determined at eight sites on the marsh. The sites were selected to represent both vegetative communities (3 sites each) and the unvegetated mud flat area (2 sites) (Figure 1). Sedimentation sites were established in May 1985. A meter stick, attached to a wooden stake for stability, was placed at each site. The 0.25 m^2 plots then were marked with two different markers, glitter and spray paint. The stationary meter stake provided a check against any sinking of the marker horizons. Original positions of meter stakes were recorded.

In May 1986, PVC pipe was used to retrieve cores from the sedimentation plots. A second reading on the meter stakes also was taken. The cores were returned to the lab and frozen. Quick heating allowed easy removal of the sediment core from the PVC pipe. The cores were bisected and several measurements of the depth of the marker were taken. The measurements then were averaged.

A Klovan corer was used to retrieve sediment for organic content analysis. A core was taken proximal to each sedimentation plot. In the field these cores were subsampled with a 2 cc syringe, every 3 cm with depth, to the basement inorganic sand. Two subsamples were taken at each depth. The samples were placed in pre-combusted, pre-weighed aluminum pans and returned to the lab. Wet weights were measured and the samples were dried at 50 C for 48 hours and weighed. The samples then were combusted at 550 C for 4 hours and weighed.

RESULTS

Vegetative Production

The estimated, annual, aboveground production of the mixed community at Goose Creek marsh for 1985-1986 is 855 $g\ m^{-2}y^{-1}$(Table 5). Each sample collection on all four sampling dates resulted in one sample without aboveground vegetation. The figures for standing live and standing dead are means of 15 values (one of which was zero for each sampling period) based on 15 samples. The inverse relationship between live standing stock and dead standing stock is shown in Figure 4.

Vegetative material was present in all of the 15 cores collected for belowground biomass estimates (Table 6). These cores were taken to a depth below the organic mud/clay sediment into the inorganic sand basement (30 cm). No vegetative material was present in the sand layer in any of the cores.

Table 6. Belowground primary production for mixed community for May 1985- May 1986. Figures are in $g\ m^{-2}$.

Oct 9	376	(± 43)
March 6	796	(± 101)

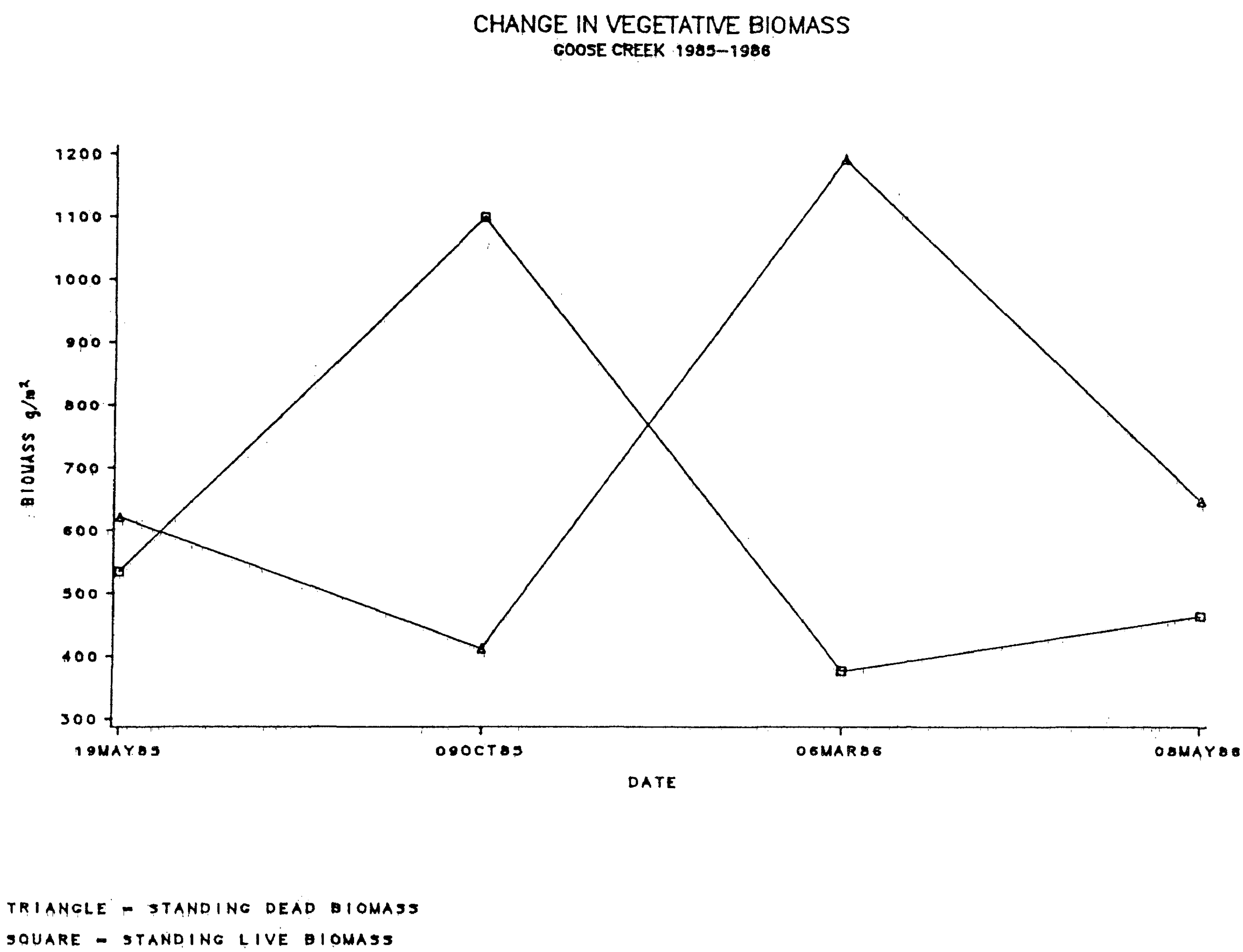
Maximum - Minimum: 796 - 376 = 420

Table 5. Aerial primary productivity of the mixed community, Goose Creek Marsh 1985-1986. Production is in g m^{-2}.

	b	$\hat{b}_i$	a_i	$\hat{a}_i$	r_i	t_i	x_i	d_i	y_i
May 30	534		620						
		565		-209	003	133	205	-4	561
Oct 9	1099		411						
		-722		781	002	147	235	1016	294
March 6	377		1192						
		88		-518	002	75	139	-379	0
May 19	465		674						
								net production	855

b_i - living biomass g m^{-2}
$\hat{b}_i$ - change in living biomass g m^{-2}
a_i - dead biomass g m^{-2}
$\hat{a}_i$ - change in dead biomass g m^{-2}
r_i - daily instantaneous rate of litter loss in mg g^{-1} litter m^{-2}
t_i - time interval between samples days
x_i - litter loss of t_i g m^{-2}
d_i - mortality g m^{-2}
y_i - productivity for t_i

Figure 4. Change in live and dead vegetative material for the year 1985-1986.


CHANGE IN VEGETATIVE BIOMASS
GOOSE CREEK 1985–1986
BIOMASS g/m²
1200
1100
1000
900
800
700
600
500
400
300
19MAY85
09OCT85
06MAR86
08MAY86
DATE
TRIANGLE = STANDING DEAD BIOMASS
SQUARE = STANDING LIVE BIOMASS

The total peak standing crop biomass estimate (above and belowground) of the Spartina alterniflora community at Goose Creek is 1262 g m^{-2} (Table 7). Of the 30 samples collected, one lacked aboveground vegetation. All samples contained belowground vegetation.

Table 7. Peak standing crop of Spartina alterniflora September 15, 1985. Figures are in g m^{-2}.

Aerial:	Living	704	(± 97)
	Dead	229	(± 46)
	Total	933	
Belowground		329	(± 84)
	TOTAL	1262	

Sedimentary accretion and organic analysis

Sedimentary accretion for the time interval May 1985 - May 1986 is shown in Table 8. The mean vertical accretion determined from meter stake readings and marker bed depths at Goose Creek for the year May 1985 - May 1986 was 0.9 cm. Reported marker layer depths are from the glitter marker layer. No evidence of a spray paint marker was found at any of the sites. No glitter marker was present at site C13 which showed erosion. Glitter markers were found at all other sites.

Klovan cores retrieved proximal to the sedimentation sites showed a mean total accumulation, above the native inorganic sediments, of organic mud/clay to be 15 cm (± 3).

Table 8 Sedimentary accretion - May 1985 through May 1986
Measurements are in centimeters

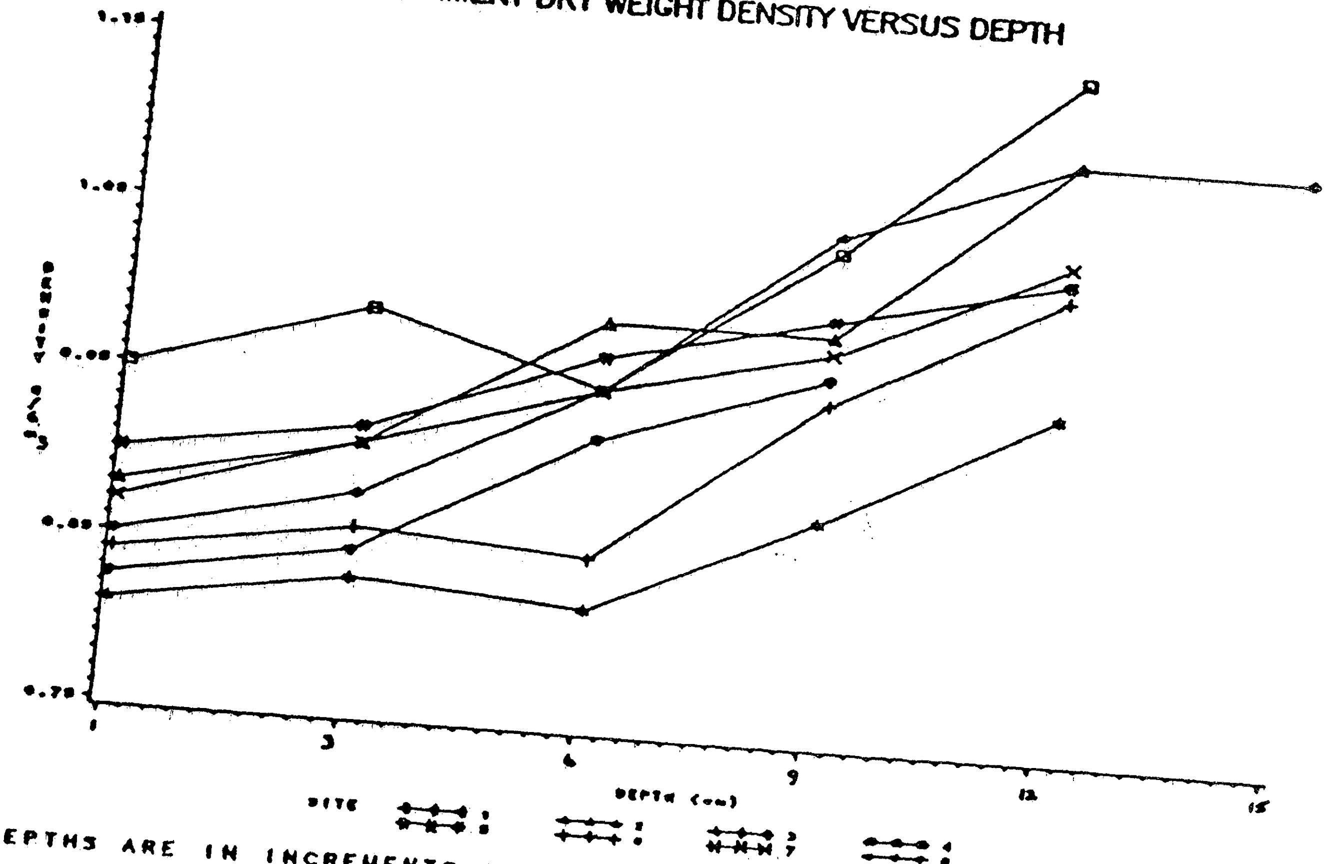
Site	Meter Stake Readings			Marker Bed Depth
	Initial	Final	Difference	
A5	12.4	*stake lost		1.00
A23	8.8	8.8	0[a]	0
B15	9.4	8.4	-1.0[b]	NA
C6	9.4	10.2	1.8	1.85
C13	7.5	9.9	2.4	2.35
C26	8.8	9.8	1.0	1.05
D10			(1cm)[c]	1.10
E20	7.9	8.8	0.9	0.92

a. glitter present on marsh surface
b. unvegetated plot
c. This site had no meter stake, relative change is based on the difference from an original mark made on a wooden stake and the level of the marsh at time of retreval.

Dry weight density and percent organics were determined for all samples and a mean calculated from the replicates to give one value for each depth interval. Figure 5 shows the change in density with depth. Density increased with depth in all cores. There was little change in percent organics with depth at all sites (Figure 6). Figure 7 shows the mean value for percent organics within each core at sites 1-7. Site 8 was excluded because the bottom depth sampled (15 cm) was completely inorganic. The inclusion of the bottom depth in the mean value for site 8 results in an underestimate of the organics at that site. Without including the bottom layer values, site 8 has fewer values contributing to a mean calculation of organics and cannot be compared to the other sites.

Figure 5. The change in dry weight density with depth for eight sample cores collected May 1986. Two subsamples at each depth interval of 3 cm were averaged and one value reported.

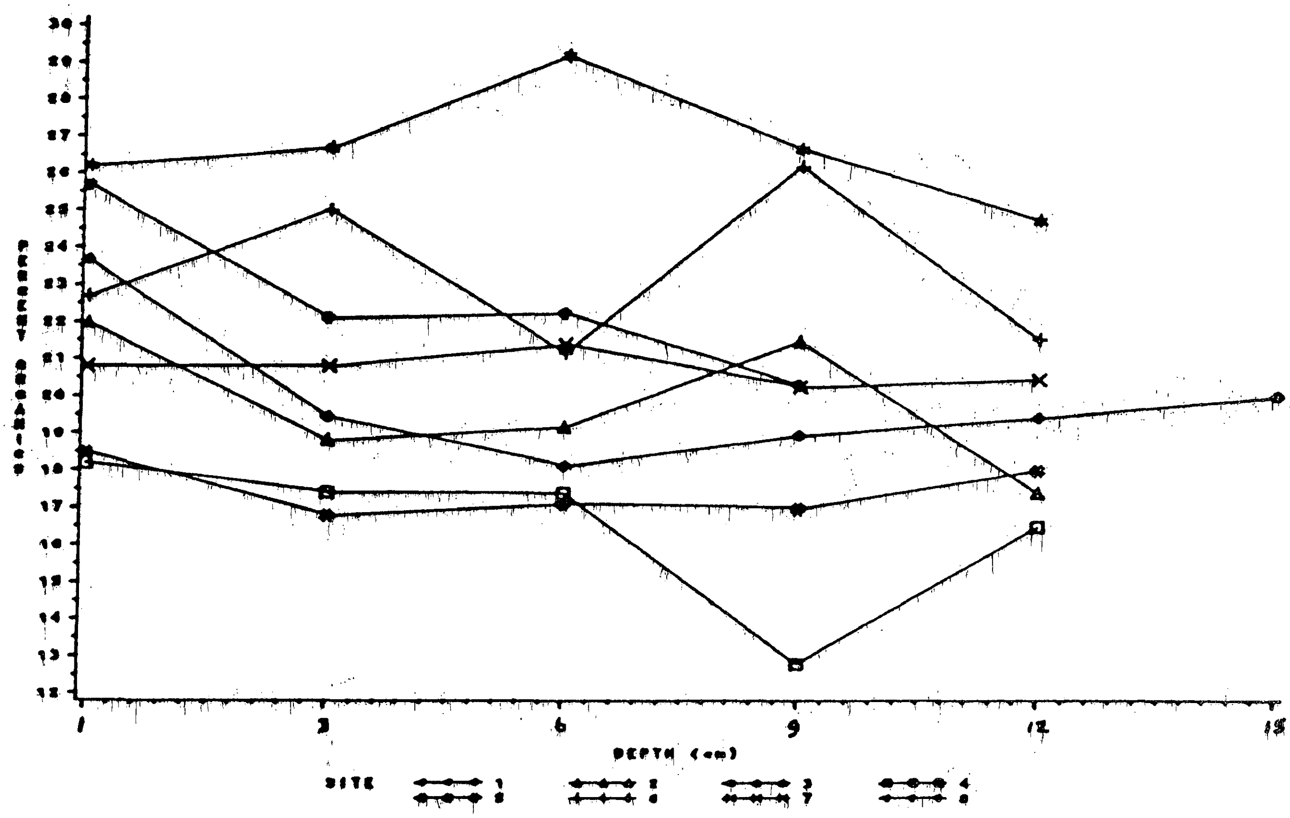
SEDIMENT DRY WEIGHT DENSITY VERSUS DEPTH



DEPTHS ARE IN INCREMENTS OF 3 CM

Figure 6. The change in percent organic content with depth for eight sample cores collected May 1986. Two subsamples at each depth interval of 3 cm were averaged and one value reported.

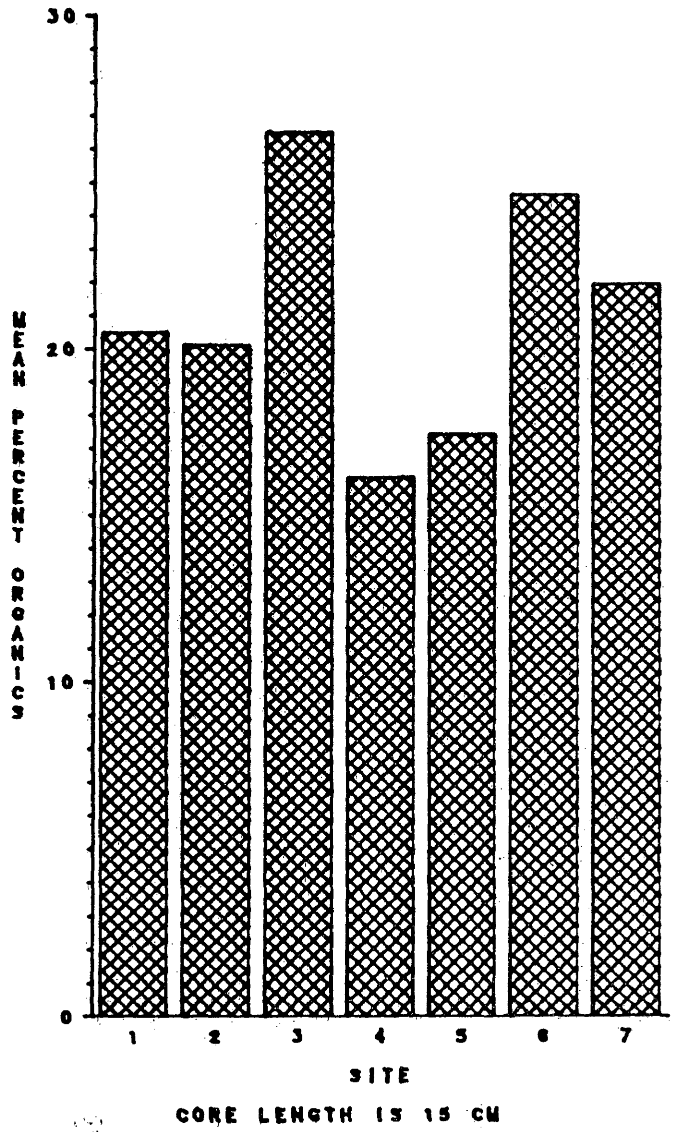
PERCENT ORGANICS VERSUS DEPTH



DEPTHS ARE IN INCREMENTS OF 3 CM

Figure 7. The mean value of percent organics in each of seven cores collected May 1986.

MEAN PERCENT ORGANICS OVER DEPTH



DISCUSSION

Primary production - Aerial

There have been no values of primary production reported for mixed brackish communities in the literature. Most often estimates are determined by species. It would be a very labor intensive task to determine productivity by species at Goose Creek, and if accomplished would be even more difficult to translate into a community production estimate. Cover estimates of each species, to calculate contribution of each species to the whole community, would be required. The mixed community at Goose Creek is quite heterogeneous, and over a period of three years showed much change in species composition. Colonization by many native species, including several freshwater species, was observed. This was also noted by Shisler and Charette (1984) in a study of artificial salt marshes in New Jersey. A estimate of community productivity provides more information about the actual production of organic material in that community.

Although found to be an underestimate of net aerial primary production (Shew et al, 1981), peak standing crop was used to estimate primary productivity in the *Spartina alterniflora* community. This simplified estimate allows for easy comparison to other estimates in the literature. Also, by simplifying the sampling necessary to estimate production in the *Spartina alterniflora* community, it was reasonable to conduct a more intensive study of the mixed community.

Random samples of areas without aerial vegetation were considered as true representation of the absence of production at that site, and were included in a mean estimate of overall aerial productivity. Consistently, there was one zero sample value (absence of vegetation) for each aboveground sampling in the mixed community, and one zero sample in the *S. alterniflora* community.

Litterbags were used to determine litter loss. The paired plot method was not used due to the possibility of non-random movement and removal of detrital material due to the tides. Factors that affect decomposition rates greatly are temperature and tides. The geomorphology of the site provides for a protected environment which would make the effect of storm tides less likely and increase the relative importance of temperature on litter disappearance rates. Litterbags retrieved after the longest time interval (147 days) were virtually empty. Therefore, a loss rate value was difficult to determine from litterbags retrieved after this sampling interval. In order to make a calculation for annual productivity a daily instantaneous rate of litter loss (r) is necessary for each sampling period. After consideration of other disappearance rates determined from this study, rates found in other studies, I assigned a value of 2 mg g^{-1} day^{-1} for that time interval.

The *Spartina alterniflora* community was not sampled to determine a yearly productivity estimate. However, three litterbag sites were located in the area defined as the *S. alterniflora* zone. These litterbags sites corresponded with the sedimentary accretion sites for ease of location. With no prior knowledge of the hydrologic - geochemical functions of the site, the comparison of litter disappearance rates across the surface of the marsh provides information on the natural parameters of the site.

Literature review indicates decomposition rates are highest at streamside. At Goose Creek, rates were similar at all sites. Only one site at Goose Creek could be considered streamside (C6). The tides enter through the inlet and must flood the marsh as sheet flow. At high tide, the site is almost uniformly submerged. However, the lower elevations are submerged for a greater period of time than the higher elevations. Logically, the higher elevations are exposed to greater atmospheric influence and the potential for higher surface temperatures resulting from solar irradiation. An explanation for the similarity in litter decomposition rates at Goose Creek may be found in the balance of litter removal by the tide and thermal vegetative decomposition.

Primary production - Belowground

Although belowground vegetative sampling was done in the same location as aboveground sampling, all samples contained vegetation. Belowground vegetation (roots and rhizomes) cover a larger area than corresponding aboveground parts of the vegetative species at Goose Creek (grasses and reeds). For a community estimate of belowground production, the co-occurence of above and belowground vegetation is not neccessary. However, to consider the production success of an individual species, and the relationship between aerial and subaerial biomass, samples must include both above and belowground vegetation for that species.

The physical limitation of belowground vegetative material to the organic mud/clay layer results in an average limit of 15 cm depth for growth of belowground material. Cores were not separated to estimate production with depth. Studies show a peak in belowground biomass cooresponding to a peak in organic matter at 15-25 cm depth in mature systems. Considering the depth limit of vegetative material and the age of the system, I would not expect great variation of vegetative material with depth. However, the cores generally contained less material toward the bottom of the organic layer which probably results from those factors which are limiting the growth of the roots and rhizomes to the organic layer at the site. It may be simply that the belowground material is not penetrating the sand layer due to lack of nutrients, or some geochemical factor may be preventing growth in the inorganic sand. Clay and silty clay are superior substrate compared to sand for producing maximum vegetational biomass. Sand has the lowest organic content, high porosity and lacks adsorptive surfaces (Smart and Barko 1978). The system is at a stage where the sediment is controlling the extent of belowground growth as opposed to physiological controls of the vegetation.

Some studies of natural systems suggest belowground production comes close to, equals, or is greater than aboveground production (see Tables 1 and 2). The aboveground production estimates are closer to estimates from natural systems than are the belowground estimates. The low belowground estimates of both communities agree with information from other man-made systems (Shisler and Charette 1984). This suggests more time is required for the establishment of belowground biomass. The question concerning belowground biomass is whether or not it will reach levels comparable to natural systems?

Total production of vegetative organics

Aboveground vegetative production estimates from both communities fall within the range reported in the literature (Table 1). The estimate for peak standing crop in the _S. alterniflora_ community, 933 g $m^{-2}yr^{-1}$, is low in comparison to Wass and Wright's (1969) estimate of 1332 g $m^{-2}yr^{-1}$. The belowground standing crop estimate also is smaller than figures reported in the literature; compare the 329 g $m^{-2}yr^{-1}$ of this study to 500 g $m^{-2}yr^{-1}$ reported by Stroud (1976). The productivity estimates of the mixed community are also low in the range of values reported in the literature. An estimate for _S. patens_ productivity in North Carolina (Waits 1967) is 1296 g $m^{-2}yr^{-1}$, the estimate from this study is 855 g $m^{-2}yr^{-1}$. Very few reported values for aerial productivity fall below the productivity estimate determined in this study. The belowground productivity of the mixed community at Goose Creek, 420 g $m^{-2}yr^{-1}$, is greater than only two other estimates reported in the literature (Table 2). However, it is important to remember that the scientific methods for estimating primary production have become more sophisticated, involved, and theoretically more accurate. Older studies relied on simple sampling procedures to estimate production and usually report values lower than the values of more recent studies. In light of that consideration, the production estimates of this study are low in comparison to natural systems in the Mid-Atlantic Region.

A few assumptions can be made about productivity and community size at Goose Creek in order to estimate total vegetative organic production for a growing season based on values determined by this study. Visual observation, coordinated with transect and station positions, divides the vegetative communities at Goose Creek into three zones the mixed community is 13,500 m^2, the unvegetated area is 10,100 m^2, and the S. alterniflora community is also 10,100 m^2. Multiplication of mean production per meter squared by each community area results in vegetative production for that area. The estimates from the areas are added to determine a total for Goose Creek. This calculation is made for above and belowground production. The mixed community produced 172,000 Kg vegetative organics for the year May 1985 - May 1986 (56,700 Kg belowground and 115,000 Kg aboveground). The S. alterniflora community produced 127,000 Kg (above and belowground). The total is

299,000 Kg vegetative organic matter produced at Goose Creek for the year May 1985 - May 1986.

Sedimentary accretion and percent organics

Spatial variations in the rate of accretion at Goose Creek are small. Slight variations often are attributed to differences in hydrodynamic conditions. Under sheet flow conditions, greater tidal energy allows for the transport of sediments and a decrease in energy results in the deposit of sedimentary material. At Goose Creek, sediment laden tidal waters cover the entire site on high tide. The tide enters the site on flood and as the energy decreases, from friction effects, deposits sediment in the higher elevations. However, on ebb tide, sediment is resuspended and carried toward the lower elevations. Ebb-tidal energy is reduced by the constriction at the inlet resulting in the deposit of sediment at the lower elevations and in the inlet. Differences in vegetation density also have an effect on spatial variability of accretion rates. Dense vegetation increases friction, reducing tidal energy and inducing sediment deposition. Bare plots had lower accretion rates or showed erosion of sediments. The plot that had a net loss of sediment, B15, was in an unvegetated area that appeared to be developing into a drainage channel.

It is possible to estimate total accumulation of sedimentary material, and sedimentary organics, for the year May 1985 - May 1986 at Goose Creek. Several assumptions are required to make this determination. A mean accretion rate must be calculated from the eight sampling sites (see Table 8), as well as a mean value for surficial sediment density and organic carbon. The mean accretion rate for May 1985- May 1986 was 0.90 cm. The mean dry weight density of the surficial sediment is 0.85 g cm^{-3}. An accumulation of 7600 g sedimentary material m^{-2} yr^{-1} is the product of the mean accretion rate and the mean sediment density. The mean percent organic content for the surficial sediment at the marsh is 22.2 percent. Therefore, Goose Creek accumulated sedimentary organics at a rate of 1670 g $m^{-2}yr^{-1}$ over an area of 33,800 m^2, for a total of 56,400 kg for the year May 1985 - May 1986.

There was an increase of dry weight density with depth at all sites. The increase in density is due to compaction from the weight of the sediment itself, and the binding ability of the belowground vegetative material.

Young salt marshes are composed of inorganic sediments - older mature marsh sediments have been described as organic peat - anaerobic, waterlogged, with high sulfur levels. Sand allows good percolation of water and retains very little nutrients and organic matter. Natural marsh sediments tend to have high organic and nutrient levels, poor drainage, and an anaerobic environment (Frey and Basan 1978).

There was little change in percent organics with depth at any site. Studies cite the occurrence of an organic peak corresponding to a peak in belowground biomass, but as previously noted, Goose Creek does not have sediment depths of natural systems, nor does there appear to be a peak in belowground biomass. The shallow depth of the organic sediment layer allows for recycling by the vegetative community, bioturbation and mixing via resuspension and redeposition. These factors, with the low belowground biomass, explain the relative uniform distribution of organics with depth. It is interesting to note that site C13, at the inlet, has the highest organic content. The movement of organics through the system on the tides appears to be concentrating organics at the inlet. The ebb tide transports material to the edge of the marsh and deposits the material at the inlet. Conversely, the same location shows lower bulk density than other sites.

Clay and silty clay are superior for the production of vegetative biomass (Smart and Barko 1978). At Goose Creek, there had been a mean accumulation of 15 cm of organic mud/clay in three years. A healthy vegetative community requires nutrient-rich sediment for growth, and likewise the accretion and accumulation of sediment is influenced by vegetation. The decomposing vegetative material provides organics and the standing vegetation increases sedimentation rates by baffling tidal flow, trapping and binding sediment. The nonvegetated sediment plots at Goose Creek had lower accretion rates, or even negative rates, and had lower percent organic content.

Elevation

Relative elevational gradients revealed that sections in the artificial marsh were too low to support adequate growth of the planted vegetational species. This suggests that the marsh surface was at the wrong elevation for the original species planted during construction. In the construction of man-made marshes, care should be taken to avoid overly complicated elevation-vegetation planting schemes.

Although this study does not directly address all issues of wetlands compensation as a management tool, to evaluate the success of Goose Creek wetlands bank, or any other wetlands compensation site, consideration must be given to the original intentions of of compensation as replacement for lost wetlands. For instance, the importance of any given wetland to the watershed in which it is located is poorly understood. Yet, logically, replacement should occur on-site or at least in the same watershed. However, a wetlands bank such as Goose Creek cannot effectively serve as on-site replacement for wetlands throughout the Tidewater area. A parellel to this question is the issue of replacement in-kind with the same vegetative community type(s). While Goose Creek is vegetated with typical tidal species, the community structure is different from many tidal wetlands. There are many vegetative community types and one compensation site cannot function as in-kind replacement for every wetland type.

Goose Creek marsh is a pocket marsh with limited tidal access and is unlikely to function as a flood buffer or provide erosion control benefits. These are two values attributed to wetlands which should be considered when developing a compensation project, and in the assessment of the success of a man-made site in effectively duplicating the ecological functions of the wetlands for which compensation is required.

CONCLUSIONS

Organic Standing Stocks

Total vegetative organics produced at Goose Creek marsh for the year 1985-1986 was 299,000 kg. The rate of production of the mixed community was 1275 g m^{-2}, 855 g m^{-2} in aerial production and 420 g m^{-2} in belowground production. The *Spartina alterniflora* community had an aboveground peak biomass of 933 g m^{-2} and a belowground biomass of 329 g m^{-2} for a total value of 1262 g m^{-2}. These estimates all fall in the low range of reported values of productivity of natural systems. If primary production were used as a factor by which to assess the success of the project, the project is a success.

The accumulated sedimentary organics was 1670 g m^{-2} for a total of 56,400 kg at the site. The mean accumulation of sedimentary material at the site was 0.9 cm. The mean dry weight density and percent organic content of the surficial sediments were 0.85 g cm^{-3} and 22.2 percent, respectively. These values are all comparable to values reported for natural systems. However, primary production and sedimentary organics are just one of many values attributed to wetlands.

The test of whether man-made wetlands are a valid resource management practice is no longer a question of the ability to grow aquatic plants, attract waterfowl, or have the initial appearance of a natural wetland. The question is whether or not the artificial wetland will have a suite of ecological functions similar to those of the natural system it replaces.

Habitat evaluations that are used to determine what type of wetland creation is necessary to replace lost wetland functions assume that created values start at time zero. The time taken to adjust and develop as a functional wetland should be estimated and allowed for in any project design.

The success of any particular project should not be judged solely on the ability to recreate a natural area for compensation as required. Theoretically, concerning wetlands management and the conservation of the resource, the establishment of any wetland type may be perceived as a step in the right direction. However, a project should be judged on the final ability to accomplish the requirements of the project design. If the question of the legitimacy and approval by permitting authorities of a particular project is based on the project design, then it follows that the results should be judged against the same design. For example, if a creation project is designed to compensate for the loss of *Spartina alterniflora* habitat, then the creation project should involve revegetation with *S. alterniflora* and the success of the project is the establishment of *S. alterniflora*.

Post development evaluation should assess:

1) compliance with permit conditions,

2) establishment of artificial marsh vegetation, and

3) determination of problems that need correction.

Important parameters to examine are a) marsh surface elevational changes due to erosion, deposition or sediment compaction, b) groundwater and salinity, c) vegetation (species planted, survival, colonization, succession, response to fertilization and productivity), and d) animal usage.

Goose Creek marsh compensation project is a successful establishment of a wetland system. While my quantitative information addressed only the organic production at the site, visual observations over two years provided much information on changes of the wetland. The original site plan which required the creation of complex vegetational communities dependant on slight elevational changes was complicated and beyond man's present wetlands creation abilities. Yet, toward the end of my study _Spartina alterniflora_ began to invade the unvegetated area and today the area is vegetated. Concurrent studies conducted by Tom Barnard and Walt Priest at the Virginia Institute of Marine Science demonstrate the success of the site as habitat for finfish and crustaceans. Further quantitative research is needed to better understand the processes of development of a man-made marsh. Research should involve studies of other wetland values, comparison to natural systems and continuing monitoring as the site matures.

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