1-2004

Below-Ground Biomass in Healthy and Impaired Salt Marshes

R. Eugene Turner
euturne@lsu.edu

Erick M. Swenson
eswenson@lsu.edu

Charles S. Milan

James M. Lee

Thomas A. Oswald

Recommended Citation

Turner, R., Swenson, E. M., Milan, C. S., Lee, J. M., & Oswald, T. A. (2004). Below-Ground Biomass in Healthy and Impaired Salt Marshes., 29-35. Retrieved from https://repository.lsu.edu/oceanography_coastal_pubs/133

Ecological Research (2004) **19**: 29–35

Below-ground biomass in healthy and impaired salt marshes

R. Eugene TURNER,* Erick M. SWENSON, Charles S. MILAN, James M. LEE
and Thomas A. OSWALD

Coastal Ecology Institute, Louisiana State University, Baton Rouge, Louisiana 70803, USA

Twelve salt marshes in south Louisiana (USA) were classified as either 'impaired' or 'healthy' before a summer sample collection of above- and below-ground biomass and determination of sediment accretion rates. The above-ground biomass of plant tissues was the same at both impaired and healthy salt marshes and was not a good predictor of marsh health. However, below-ground root biomass in the upper 30 cm was much lower in the impaired marshes compared to the healthy marshes. Compromises to root production apparently occur before there is an obvious consequence to the above-ground biomass, which may quickly collapse before remedial action can be taken. The subsequent change in vertical position of the marsh surface may be equivalent to many years of accretion, and be irreversible within decades without considerable effort. These results are consistent with the hypothesis that it is the plant's below-ground accumulation of organic matter, not inorganic matter that governs the maintenance of salt marsh ecosystem in the vertical plane. Reversing the precursor conditions leading to marsh stress before the collapse of the above-ground biomass occurs is therefore a prudent management objective and could be easier than restoration.

Key words: accretion; below-ground; restoration; salt marsh; stress.

Introduction

The cover and density of above-ground plant biomass is frequently used to index salt marsh ecosystem health, in part because it is a comparable index of plant productivity and also because of the possibility for remotely sensed data collection over wide areas. Understanding how salt marshes form, survive and degrade, however, also requires a below-ground perspective. Both inorganic and organic matter is deposited at the soil surface, but roots and rhizomes add additional organic mass below-ground. Whether the below-ground processes result in a net gain or deficit in the vertical position of the marsh relative to water level is of significance to the health of the emergent plant biomass. In many cases the erosive forces at the edge may be less influential on wetland loss rates than the stress of increased flooding on the interior of the marsh. If the below-ground accumulation is not sufficient, then a marsh with abundant plant growth might quickly become open water when the plants 'die-back' (Mendelssohn *et al.* 1981). This appears relevant in the recent demise of salt marshes in Louisiana and New York, which is described as a fragmentation of a homogenous landscape of emergent plant biomass that erodes into small ponds that then coalesce, and then enlarge to join the estuarine bay (Turner & Rao 1990; Hartig *et al.* 2002).

Field experiments and the use of fixed-in-place benchmarks to measure seasonal and annual surface elevation changes have been instructive in appreciating the dynamic nature of processes below-ground. Morris *et al.* (2002), for example, documented seasonal lags in surface elevation of several centimeters, which followed fluctuations in sea level, and Harrison (1975) measured the vertical expansion of a Connecticut salt marsh during a tidal cycle. Both Valiela *et al.* (1976) and Morris and Bradley (1999) showed how the below-ground accumulation of organics can be diminished by an addition of nitrogen that simultaneously causes an increase in above-ground biomass. The vertical position upon which the enhanced above-ground production depends is therefore potentially compromised by the loss of organics below-ground. The interdependent parts survive or fail as a unit – the above-ground components may appear healthy while the effects of subsurface stressors accumulate to subsequently lethal levels and the marsh collapses.

An analysis of recent accretion rates for sediment from 141 salt marshes demonstrated that the vertical

---

*Author to whom correspondence should be addressed. Email: euturne@lsu.edu

Received 5 May 2003, Accepted 13 June 2003.

accretion rate is much more influenced by organic than inorganic accumulations (Turner *et al.* 2001). This organic matter might turn over 200–300% in 1 year within the upper 30 cm of a sometimes highly reduced soil layer (Valiela *et al.* 1976; Roman & Daiber 1984), implying that the subsurface metabolic processes are responsive to biological and physical factors influencing anaerobic and aerobic growth. One might expect therefore that the above-ground vegetation and the organisms linked to it are strongly dependent on the below-ground circumstances affecting the net change in organic matter. Salt marsh health, in other words, might be shown to be a soil-dependent condition with both biological and non-biological conditioners. This set of conclusions leads to the testable hypothesis that we considered herein: Sites recognized as 'healthy' will have more accumulated organic matter than comparable sites understood to be under stress.

Methods

Site selection

The sampling occurred in three hydrological basins within the Louisiana coastal zone that is part of the Mississippi River deltaic plain: Terrebonne Basin, Barataria Basin and St Bernard Basin (Fig. 1). These basins were formed by various distributary lobes of the Mississippi River during the past 7000 years. A discussion of various reasons of how and why these wetlands converted over time into open water may be found elsewhere (Turner & Cahoon 1987; Boesch *et al.* 1994; Turner 1997). For interior marshes in the Louisiana deltaic plain, marsh break-up starts with the appearance of numerous small ponds that coalesce into larger ponds (Turner & Rao 1990). A review of the aerial photography for this study showed this process occurring at sample sites in various stages, including the final stage of complete conversion to open water. A marsh in the initial stages of break-up may appear as healthy in larger-scale photography that does not resolve details like the small ponds.

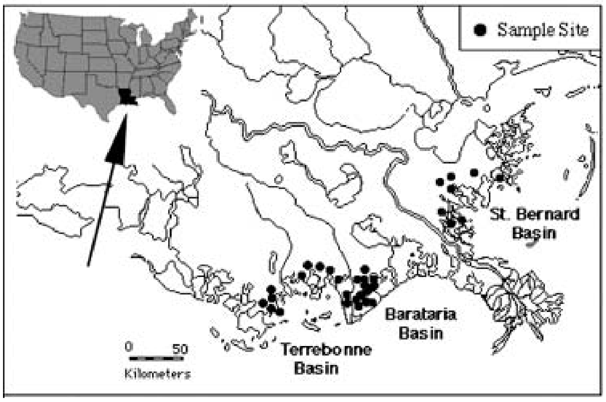

Fig. 1. Location map of sampling in south Louisiana.

The sampling for below-ground biomass in 'healthy' and 'impaired' sites was carried out in the Terrebonne marshes, whereas the sedimentation accretion data and above-ground biomass data were collected from all three basins. The specific details of how sites were classified as either healthy or impaired are described in Turner *et al.* (1995). An abbreviated description of site selection methods is provided here.

Location classification

We chose sampling 'sites' (or plots) from within larger 'locations' that we could classify as either healthy or impaired based on a basin-scale habitat map showing the extent of salt marsh habitats (Chabreck 1972). The classification at a location as impaired or healthy was determined by: (i) the rate of recent land loss; (ii) the presence or absence of obvious internal marsh breakup; and (iii) the degree of alteration of natural hydrology or impoundment by canals and spoil banks. Candidate locations were found using aerial photography, land loss and accretion maps, and aerial inspection at <500 m altitude. We had access to an inventory of the NASA overflights for various time periods within the Louisiana coastal zone. We used recent overflight (1988–1989) and the US Army Corps of Engineers land loss maps (Britsch & Dunbar 1993), which show land loss from 1935 to 1978, to determine areas that have remained stable and areas that are breaking up. Classification was done before field sampling, and then re-checked after field inspection, and before sample processing. It is entirely possible, at the scale that the vegetation plots were sampled, that we sometimes sampled impaired plots within a location that was classified as a healthy marsh or healthy plots in an impaired location.

Sampling date

Sampling for below-ground samples was in September 1993 at three impaired and four healthy locations in Terrebonne Basin, from which a total of 12 sites (or plots) were sampled. No reclassification of sites occurred at these locations as a result of field visits. In 1991, 33 samples were taken to date and measure sediment accumulations.

Sampling scheme

Sampling for above-ground biomass was from a circular cluster of six points located in the inland marsh. The cluster was composed of a center point surrounded by five sampling plots radiating out from the center with a constant distance of 10 m, so that the schematic diagram resembled spokes radiating from a wheel. The center point was 50 m inland to reduce any edge effects (Hatton *et al.* 1983). This distance (50 m) was measured from the back edge of the natural levee or spoil bank and went perpendicular into the marsh to end without consideration of the marsh condition at the end of the transect. The result of the sampling design was that sometimes there were sampling plots in open water devoid of vegetation or plots where the dominant species was not *Spartina alterniflora*, but perhaps *S. patens* or *Juncus roemerianus*.

Plant biomass

Above-ground *S. alterniflora* biomass was harvested from six 0.25 m^2 plots for the 1991 sampling, and at the above-ground plot where the below-ground biomass samples were made in 1993. All standing live and dead culms and litter were removed and placed into prelabeled plastic bags. Twelve below-ground biomass samples were collected at seven locations in the Terrebonne Basin. A 15 cm diameter, 30 cm long core was taken in the middle of the biomass plot after the biomass sample was collected. The core was extruded in the field, sectioned into 10 cm depth intervals, and the sections placed into prelabeled plastic bags. All sample bags holding above- and below-ground biomass samples were kept in an air conditioned room (at the field laboratory) until they were returned to the Louisiana State University laboratory for processing.

The below-ground biomass in the cores was processed by washing sediments through 0.6 mm and 0.3 mm screens. The washing continued until all of the mud and loose organic material was removed, leaving only the root material on the screens. The root material was then sorted into live and dead categories. The standing live portion of the above-ground samples was sorted by species, the standing dead portion was separated into standing dead *S. alterniflora* and standing dead other, and the litter from the surface was rinsed. The sorted root and above-ground vegetation were placed into labeled kraft paper bags then dried at 75°C to a constant weight (~72 h).

Sediment/organic accumulation core analysis

The methods used and rationale for accepting the sediment accumulation rates are described in Milan *et al.* (1995). Some patterns observed between the vertical accretion rate and constituent accumulations of both organic and inorganic constituents are in Turner *et al.* (2001). Briefly stated, after collection, the cores were frozen, subsequently extruded from the core tube using a thawing box, the extruded core measured, and then sectioned at 1 cm intervals. The individual sections were weighted to the nearest 0.1 g, dried, re-weighed, homogenized using a Wiley mill (with a #40 mesh screen) and placed into numbered and labeled containers. A subsample (~ 1.0 g) of each of the homogenized core sections was taken to determine percent organic matter by loss on ignition at 550°C. During core sectioning, the thickness of every fifth subsection was measured with a digital micrometer to ensure the accuracy of the sectioning. The dried and ground samples were then counted for ^{137}Cs using a 40% efficiency germanium detector. ^{137}Cs is a residual of bomb fallout and first appeared in 1954. It peaked in the spring of 1963, with additional large amounts in 1964, and has declined since with minor fluctuations. The activity of ^{137}Cs can be used to locate the 1963–1964 horizon. For this analysis, the data set was restricted to sites with an above-ground biomass consisting of at least 95% *S. alterniflora*. The amount of dry organic or inorganic material above the 1963–1964 horizon is the Σorganic or Σinorganic, respectively.

Statistical analyses

The biomass above- and below-ground at healthy and impaired sites was compared to determine if the means were significantly different (at the 0.05 level) based upon a Duncan's multiple range test. The analysis was carried out using the general linear model procedure (PROC GLM; SAS 1988; SAS Institute Inc., Cary, North Carolina).

Results

Accumulation rate versus organic and inorganic constituents

The vertical accretion rate from the 1963–1964 dating horizon to 1991 for 33 salt marsh soils in the three basins is strongly related to the accumulation of organic material (Fig. 2). A polynomial fit of the data is shown, where,

$$Y = 0.90\ (\Sigma\text{organics}) - 0.19\ (\Sigma\text{organics})^2 - 0.02.$$

The adjusted coefficient of determination, r^2, for the equation is 0.74 ($p = 0.001$). The sites sampled for root biomass fall along the line of best fit, and there is no apparent difference distinguishing the healthy and impaired sites with regard to this data plot. The addition of data on Σinorganic to a stepwise multiple regression analysis showed no statistical improvement ($p = 0.45$), indicating that Σinorganic did not contribute to describing the variance in accretion rate. These results are consistent with the analysis of Turner *et al.* (2001) for a larger data set for the US coastal

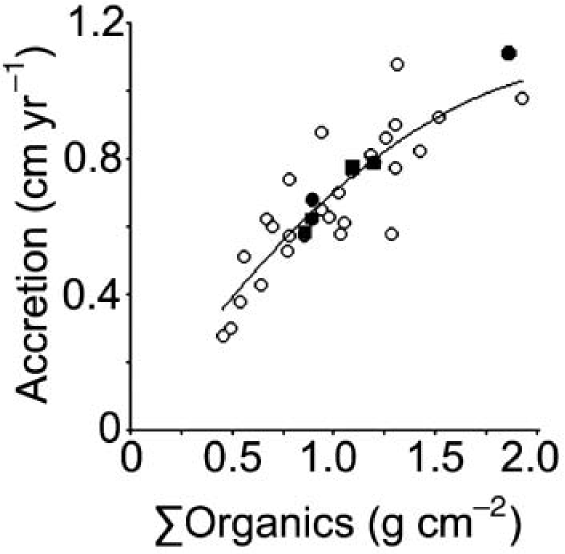

Fig. 2. The relationship between the accumulation of organic matter (Σorganics; g cm^{-2}) and the accretion rate (cm y^{-1}) at the 1963–1964 ^{137}Cs dating horizon. The data are for 33 sediment cores collected in 1991 from salt marshes with ≥50% biomass as *Spartina alterniflora*. A polynomial fit of the data is shown, where, $Y = 0.90\ (\Sigma\text{organics}) - 0.19\ (\Sigma\text{organics})^2 - 0.02$. The adjusted coefficient of determination for the equation is 0.74 ($p = 0.001$). (●) Impaired marsh; (■) healthy marsh.

wetlands, which concluded that it is the amount of accumulated organic matter, not inorganic accumulation that controls the vertical accretion rate in these salt marshes.

Below-ground accumulation of root material

Figure 3 shows the accretion rate, the above-ground live biomass, total root biomass, and live root biomass for the sites sampled in the Terrebonne basin of Louisiana that were classified *a priori* as healthy or impaired before sample analysis. The unfilled bars are from the impaired sites ($n = 5$), and the dark bars are from the healthy sites ($n = 7$). The mean values are indicated above each group of bars. The results of a Duncan's multiple range test at the $p = 0.05$ level indicates that both the accretion rate and the above-ground biomass was not significantly different between healthy and impaired sites, but that the below-ground biomass of live roots and total roots (live + dead) was significantly higher in the healthy sites.

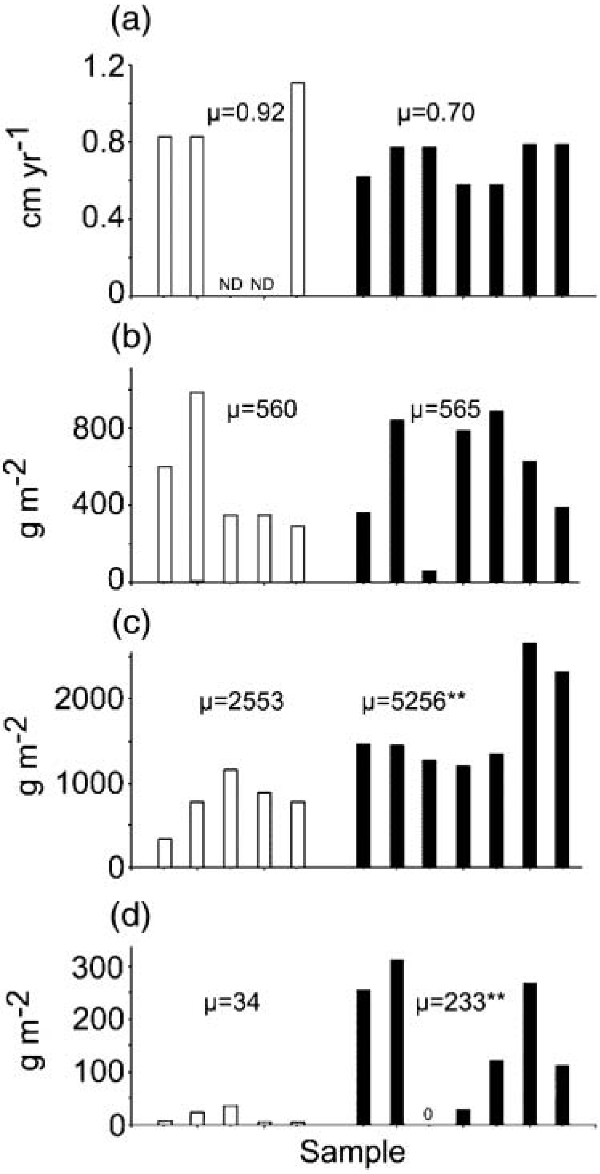

Fig. 3. The (a) accretion rate; (b) above-ground live biomass; (c) below-ground total root biomass; and (d) below-ground live root biomass from sites sampled in the Terrebonne basin in Louisiana that were classified *a priori* as healthy (■; $n = 7$) or impaired (□; $n = 5$) before sample analysis. The mean values are indicated above each group of bars. **, Means are significantly different (between healthy and impaired) at the 0.95 CI; ND, no data; 0, data.

Figure 4 shows the relationship between the dead roots and the total root biomass (live + dead) in marshes that were classified *a priori* as healthy and impaired before sample analysis. The data shown are for the 0–10 cm layer. Only samples above 1500 g m^{-2} had any live roots present in this layer. The total amount of identifiable live + dead root biomass in the 0–30 cm layer ranged from 1612 to 6608 g m^{-2}. Most of the total biomass in the upper 30 cm was in the form of dead roots, not live roots.

Figure 5 shows the percentage of live root biomass of the total root biomass (live + dead) in marshes that were classified a *priori* as healthy or impaired before sample analysis. This data is for the 0–10 cm depth. The total amount of live root material in this layer ranged from 0 to 312 g m^{-2}, representing from 0 to 21.4% of the total root biomass, and increasing with greater

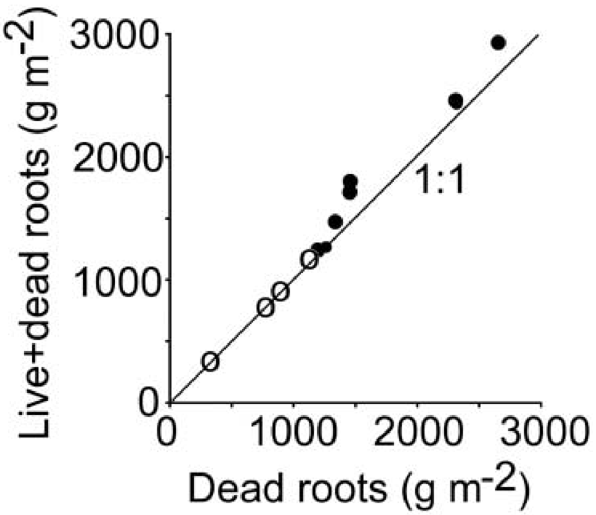

Fig. 4. The relationship between the dead roots and the total root biomass (live + dead) in marshes that were classified *a priori* as (●) healthy and (○) impaired before sample analysis. A 1:1 equivalence between X and Y axis is shown. These data are for the 0–10 cm layer. Only samples above 1500 g m^{-2} had any live roots.

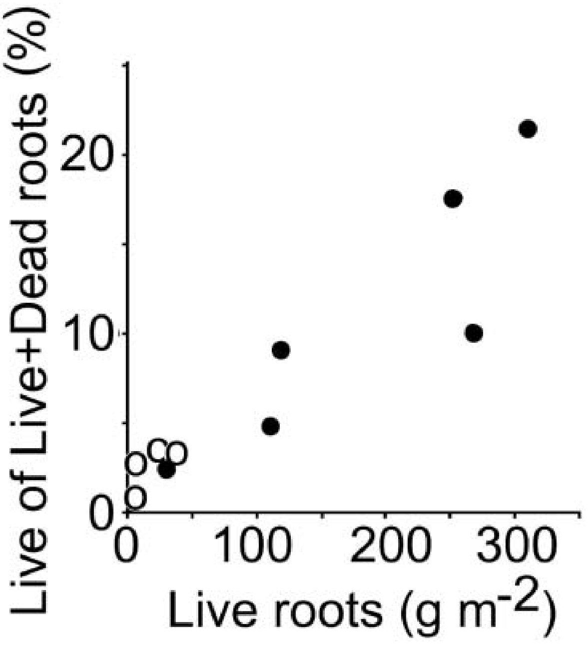

Fig. 5. The percentage of live root biomass of the total root biomass (live + dead) in marshes that were classified *a priori* as (●) healthy or (○) impaired before sample analysis. These data are for the 0–10 cm soil layer.

density of live roots (Fig. 5). One sample had no live roots, even though it was classified as healthy. This is the same site shown in Fig. 3 that had the lowest above-ground biomass.

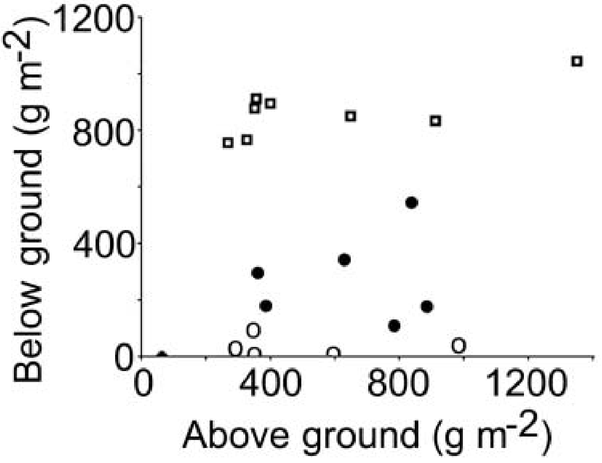

Fig. 6. The relationship between the biomass of above-ground live *Spartina alterniflora* (X; g m^{-2}) and below-ground live root biomass in the 0–30 cm layer (Y; g m^{-2}) at sites identified *a priori* as healthy or impaired sites in Louisiana and along the western Atlantic coast by Gross *et al.* (1991). (●) Healthy (Gulf of Mexico); (○) impaired (Gulf of Mexico); (□) western Atlantic.

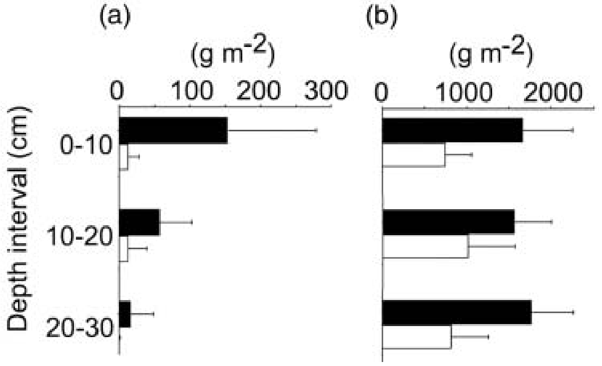

Fig. 7. The vertical profile of below-ground (a) live biomass and (b) dead plant biomass at sites identified *a priori* as (■) healthy or (□) impaired. The mean ± 1 SD is shown for depth intervals 0–10, 10–20 and 20–30.

The relationship between the biomass of above-ground live plants and below-ground live root biomass in the 0–30 cm layer is shown in Fig. 6. The healthy sites had more below-ground biomass of live roots for the same amount of above-ground biomass than occurred in the impaired sites. There was no proportionality between the biomass of live roots and above-ground biomass. These data were compared to the results of Gross *et al.* (1991), who surveyed salt marshes from Nova Scotia to Georgia on the north-western Atlantic seaboard. The separation of data for Atlantic and Gulf of Mexico samples were probably not due to differences in technique, because they used a 16.5-cm core tube to sample, compared to 15-cm core tube for our data, and they sorted roots through a 2-mm sieve size, whereas our sieve size was 0.3 mm Gross *et al.* (1991) found a direct relationship between live and below-ground biomass across a broad range of short form *S. alterniflora* marshes, whereas the samples from Louisiana had far less biomass for the same amount of above-ground biomass.

Figure 7 shows the vertical profile of below-ground live and dead plant biomass at healthy and impaired sites. The mean ± 1 SD is shown for depth intervals 0–10, 10–20, and 20–30 cm. The highest amount of root biomass (live or dead) is in the upper 10 cm of soil. The amount of dead biomass is about equal in each of the three subcore sections. Root biomass was highest in all samples from the healthy marsh compared to the impaired marsh samples.

Discussion

The separation of data on below-ground biomass from healthy and impaired locations is nearly complete (Figs 3–7), thus supporting the basis for the classification procedures. However, the above-ground biomass did not differ between the two location classes (Fig. 3), demonstrating that the relationship between above-ground and below-ground biomass is not proportional at either impaired or healthy marshes (Fig. 6).

The direct relationship between vertical accretion rate and the accumulation of organic matter in these samples was definitive, whereas the statistical effect of including the accumulation of inorganic matter to the analysis was inconclusive. These two results support the hypothesis that the vertical accretion rate is controlled by the accumulation of organic material below-ground. The combined physical volume of organic and inorganic material deposited since the 1963–1964 horizon is <10% of the total volume (Turner *et al.* 2001), but water and air spaces accumulate in association with, or because of, the organic matter. The volumetric contribution of inorganic sediments, dead organic, and live roots will change in vastly different ways over time and extend deep into the soil profile. We found live roots 1 m deep in the soil, which in these marshes represent >100 years of deposition. Living plant roots contain air passages that collapse upon death (DeLaune *et al.* 1994) and so the health of roots and amount of soil organic matter may have a dramatic effect on the vertical position of the marsh surface (Valiela *et al.* 1976; DeLaune *et al.* 1994; Callaway *et al.* 1997; Morris & Bradley 1999). DeLaune *et al.* (1994) provided a particularly robust example when they documented a 15-cm fall in the plant's hummock surface within 2 years after the demise of the plant (intentionally killed by herbicide as part an experiment). This amount of vertical change would be difficult for a *S. alterniflora* plant to adjust to, given its narrow tolerance to flooding in microtidal environments, which could be as low as 10–15 cm in south Louisiana (McKee & Patrick 1988).

The implication is therefore that the total volume of the soil profile (in the upper 1 m, at least) is primarily dependent on the quality and quantity of the organic matter, and not on the inorganic matter. These volumes will be altered downward with the eventual distancing of surface layers to a depth beyond which roots do not penetrate, where only more refractory materials remain, and after the primary effects of compression are expressed.

In summary, root biomass is an indicator of plant health in these marshes and the amount of above-ground biomass is not (within the range of measurements). The hypothesis that was tested survives. The significance of these results for monitoring marsh health is that the above-ground biomass may increase or decrease without apparent immediate consequences to the accumulation of below-ground macroorganic matter. Indeed, if the above-ground biomass declines, it may decline precipitously and be too late for remedial action. Others have suggested, and we agree, that it is important to understand the below-ground live root matrix and microenvironment in order to sustain and restore salt marsh ecosystems.

Acknowledgements

The field portion of this project was funded through the US Environmental Protection Agency, Environmental Research Laboratory in Corvallis Oregon (ERL-C), through a Cooperative Agreement (EPA 818409–01) and the EMAP sampling program, with the oversight of S. Peterson and K. Summers, Contract Officers. The personnel at ManTech, Inc. in Corvallis, Oregon, particularly Ms. Louisa Squires, Ms. Kate Dwire, Ms. Lynne McAllister, Mr. Ted Ernst, and Mr. Richard Novitski, provided many suggestions, constructive criticisms and comments throughout the data collection effort. Additional support was received from the NOAA Coastal Ocean Program MULTISTRESS Award No. NA16OP2670 to complete the analysis. This is a contribution from the 8th INTECOL International Congress of Ecology, Seoul 2002.

References

Boesch D. F., Josselyn M. J., Mehta A. J., Morris J. T., Nuttle W. K., Simenstad C. A. & Swift D. J. P. (1994) Scientific Assessment of Coastal Wetland Loss, Restoration and Management in Louisiana. *Journal of Coastal Research, Special Issue* **20**: 103.

Britsch L. D. & Dunbar J. B. (1993) Land loss rates: Louisiana Coastal Plain. *Journal of Coastal Research* **9**: 324–338.

Callaway J. C., Delaune R. D. & Patrick W. H. Jr (1997) Sediment accretion rates from four coastal wetlands along the Gulf of Mexico. *Journal of Coastal Research* **13**: 181–191.

Chabreck R. H. (1972) Vegetation, water and soil characteristics of the Louisiana coastal region. *Louisiana State University Agricultural Experiment Station Bulletin* **664**.

Delaune R. D., Nyman J. A. & Patrick W. H. Jr (1994) Peat collapse, ponding and wetland loss in a rapidly submerging coastal marsh. *Journal of Coastal Research* **10**: 1021–1030.

Gross M. F., Hardisky M. A., Wolf P. A. & Klemas V. (1991) Relationship between aboveground and belowground biomass of *Spartina alterniflora* (Smooth Cordgrass). *Estuaries* **14**: 180–191.

Harrison E. Z. (1975) Sedimentation rates, shoreline modification, and vegetation changes on tidal marshes along the coast of Connecticut. MSc Thesis. Cornell University, Ithaca, New York, USA.

Hartig E. K., Bornitz V., Kolker A., Mushacke F. & Fallon D. (2002) Anthropogenic and climate-change impacts on salt marshes of Jamaica Bay, New York City. *Wetlands* **22**: 71–89.

Hatton R. S., Delaune R. D. & Patrick W. H. Jr (1983) Sedimentation, accretion and subsidence in marshes of Barataria Basin, Louisiana. *Limnology and Oceanography* **28**: 494–502.

McKee K. L. & Patrick W. H. Jr (1988) The relationship of smooth cordgrass (*Spartina alterniflora*) to tidal datums: a review. *Estuaries* **11**: 143–151.

Mendelssohn I. A., McKee K. L. & Patrick W. H. Jr (1981) Oxygen deficiency in *Spartina alterniflora* roots: metabolic adaptation to anoxia. *Science* **214**: 439–441.

Milan C. S., Swenson E. M., Turner R.E. & Lee J. M. (1995) Accumulation rates estimated from ^{137}Cs activity: Variability in Louisiana salt marshes. *Journal of Coastal Research* **11**: 296–307.

Morris J. M. & Bradley P. (1999) Effects of nutrient loading on the carbon balance of coastal wetland environments. *Limnology and Oceanography* **44**: 699–702.

Morris J. M, Sundareshwar P. V., Nietch C. T., Kjerve B. & Cahoon D. R. (2002) Responses of coastal wetlands to rising sea level. *Ecology* **83**: 2869–2877.

Roman C. T. & Daiber F. C. (1984) Aboveground and belowground primary production dynamics of two Delaware Bay tidal marshes. *Bulletin Torrey Botanical Club* **111**: 34–41.

SAS Institute (1988) *SAS/STAT User's Guide: Release 6.03 Edition*. SAS Publishing, Cary.

Turner R. E. (1997) Wetland loss in the northern Gulf of Mexico: Multiple working hypotheses. *Estuaries* **20**: 1–13.

Turner R. E. & Cahoon D. R., eds. (1987) *Causes of Wetland Loss in the Coastal Central Gulf of Mexico*, **Vol. 1***: Executive Summary, Vol. 2: Technical Narrative, Vol. 3: Appendices. Final report.* Minerals Management Service, New Orleans, Louisiana. Contract no. 14-12-001-30252. OCS Study/MMS 87–0119.

Turner R. E. & Rao Y. S. (1990) Relationships between wetland fragmentation and recent hydrologic changes in a deltaic coast. *Estuaries* **13**: 272–281.

Turner R. E., Swenson E. M. & Milan C. S. (2001) Organic and inorganic contributions to vertical accretion in salt marsh sediments. In: *Concepts and Controversies in Tidal Marsh Ecology* (eds M. Weinstein & K. Kreeger) pp. 583–595. Kluwer Academic Publishing, Dordrecht.

Turner R. E., Swenson E. M. & Summers J. K. (1995) *Coastal Wetlands Indicator Study: EMAP-Estuaries Louisianian Province – 1991*. US Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Gulf Breeze, Florida. EPA/620/R-95/005.

Valiela I., Teal J. M. & Persson N. Y. (1976) Production dynamics of experimentally enriched salt marsh vegetation: Belowground biomass. *Limnology and Oceanography* **21**: 245–252.