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THE RESPONSE OF DISTICHLIS SPICATA (L.) GREENE AND SPARTINA PATENS
(AIT.) MUHL. TO NITROGEN FERTILIZATION IN HYDROLOGICALLY ALTERED WETLANDS

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ABSTRACT

A fertilization study was conducted to test the hypothesis that substrate moisture content affects nitrogen uptake by plants in brackish wetlands that have been ditched for mosquito control. Spartina patens (Ait.)Muhl. and Distichlis spicata (L.)Greene were the test species. Nitrate fertilizer was applied to plots in an unditched (Control) area and in two areas that had been extensively ditched. Tissue nitrogen concentrations increased significantly in fertilized plots and they were significantly higher in the area where the substrate moisture content had decreased following management. Distichlis had a greater relative response to fertilization but the response did not differ between sites. Spartina, the more shallow rooted species, had the greatest relative response to fertilization in the driest area. The results demonstrate that minimum changes in plant tissue nitrogen concentrations can be achieved in ditched wetlands by maintaining water tables as near to the wetland surface as possible.

INTRODUCTION

Open Marsh Water Management (Ferrigno and Jobbins 1968), hereafter referred to as OMWM, and modifications of the original technique (Meredith *et al.* 1985) are widely used to control mosquito populations in coastal wetlands of the USA (Balling *et al.* 1980; Roman *et al.* 1984). The technique involves ditching the wetlands to destroy the breeding habitat of the mosquitos. OMWM does not appear to have any long-term negative impacts on vegetation (Shisler and Jobbins 1977) or invertebrates (Clarke *et al.* 1984) in frequently flooded coastal wetlands dominated by Spartina alterniflora. There may be negative impacts on birds that feed in salt marsh pools in Spartina alterniflora dominated coastal wetlands but other types of birds are not affected (Clarke *et al.* 1984).

In contrast, OMWM and related types of management can have negative impacts on the vegetation of brackish wetlands which only flood during high spring tides or storm tides if hydrologic conditions are not carefully controlled (Whigham *et al.* 1982; Roman *et al.* 1984). The key to successful implementation of OMWM in infrequently flooded brackish wetlands is to lower the water table enough to drain mosquito breeding depressions, but not far enough to permit the wetland to be invaded

by undesirable shrub species such as Iva frutescens L. and Baccharis halimifolia L. (Meredith *et al.* 1985).

Lowering the water table on infrequently flooded brackish wetlands can also alter the nitrogen status of the vegetation. Whigham *et al.* (1982) found that the nitrogen content of above ground vegetation was significantly higher in areas where the water table had been lowered compared to areas where the water table had been maintained near the wetland surface.

In this paper we report results of an experiment to test the hypothesis that the increased shoot nitrogen concentrations measured by Whigham *et al.* (1982) was positively related to a decrease in the substrate moisture content. The experiment was designed in accordance with two postulates. First, that the addition of nitrogen fertilizer to any area affected by OMWM would result in an increase in shoot nitrogen concentrations. This assumption is based on the fact that plants in tidal wetlands respond positively to nitrogen fertilization (Broome *et al.* 1983; Chalmers 1979; Gallagher 1975; Valiela *et al.* 1982). The second assumption was that the relative response to fertilization would be greatest in areas where the substrate moisture content had been reduced by lowering the groundwater

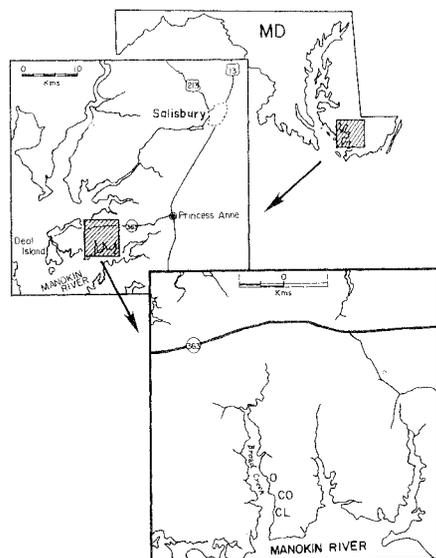


Figure 1. Location of Deal Island study sites. O= Open Site, CL= Closed Site, CO= Control Site.

table. The substrate in those areas should be more oxidized and more nitrogen should be available for assimilation by plants (Linthurst and Seneca 1981; Mendelssohn and Seneca 1980; Morris 1980).

METHODS

Study Location

The study was conducted on the Deal Island Wildlife Management Area on the Eastern Shore of Maryland, USA (Fig. 1). Wetlands within the management area were physically altered in 1979 as part of a study to determine the effects that different ditching and water management procedures had on controlling mosquitoes and on the structure and function of the wetlands (Lesser 1982; Whigham *et al.* 1982 and 1983).

This study was conducted in two of the areas that were ditched in 1979 and an 11.1 ha area, hereafter referred to as the Control Site, that had not been ditched. One of the ditched areas, hereafter referred to as the Open Site, was 20.2 ha in extent and was connected to the estuary by two ditches to permit tidal exchange. The hydrologic modifications at the Open Site resulted in a lowering of the water table and the greatest changes (5 to 10 cm) occurred within 10 meters of the ditches (Lesser 1982). The second ditched site, hereafter referred to as the Closed Site, was 12.1 ha in extent and was similar to the Open Site except that the ditch system was not connected to the estuary.

Because there was no regular tidal exchange between the Closed Site and the estuary, the water table was not lowered. All three areas were dominated by *Distichlis spicata* (L.) Greene and *Spartina patens* (Ait.) Muhl. before ditching began. The species will hereafter be referred to as *Spartina* and *Distichlis*. *Distichlis* and/or *Spartina* dominated both areas after ditching but the Open Site was invaded by *Iva frutescens* L. and *Baccharis halimifolia* L. during the first growing season following the ditching (Whigham *et al.* 1983).

In June 1981, two sets of two plots, each 2 X 10 m, were randomly located at the Closed and Open Sites. One plot of each set was randomly located immediately adjacent to a ditch with the long axis parallel to the ditch edge. The second plot of the set was established with the same orientation but with the 2 meter dimension located between 18 and 20 m away from the side of the first plot. At the Control Site, two separate plots were used; the locations of the two plots were randomly determined. All ten plots were divided into 80 quadrats (0.5 m X 0.5 m) arranged in a 4 X 20 grid.

One set of plots was fertilized at the Open and Closed sites along with one of the plots at the Control Site. The plots were fertilized with $\text{NO}_3\text{-N}$ at a rate of 20 gN m^2 on 11 June (1981), a time of rapid shoot growth. The 100% $\text{NO}_3\text{-N}$ fertilizer (Sudbury Laboratory; Sudbury, Massachusetts) was dissolved in estuarine water prior to application. The loading rate was similar to that used by Gallagher (1975) and falls within the range of nitrogen loading to various estuarine wetlands (Valiela *et al.* 1985).

Shoots of *Distichlis* and *Spartina* were collected from three randomly selected quadrats in each plot after 1, 2, 3, 6, and 9 weeks following addition of the fertilizer. The shoots were dried at 60 °C, ground in a Wiley Mill to pass through a 2 mm screen, and analyzed for nitrogen using Kjeldahl procedures (APHA 1976).

Substrate moisture content was measured on triplicate cores that were collected in June (11, 19, 25), July (9, 22) and August (3). At the Open and Closed sites, samples were collected between 0-2 and 18-20 m from randomly located positions along the ditches. Triplicate random samples were also collected from the Control Site. The aluminum coring tube was 20 cm long and had a diameter of 5 cm. Moisture content, (wet weight-dry weight)/wet weight, was determined by weighing the cores after they were extruded from the sampling tubes and after they had been dried at 60 °C.

The vertical distribution of live belowground biomass (roots and rhizomes) of *Distichlis* and *Spartina* was determined by collecting cores in August from areas which had approximately 50% coverage of both species, the most common situation in all plots. Triplicate cores, 20 cm deep and 5 cm in diameter, were collected from each area. The cores were extruded and cut into 5 cm sections that were processed using the procedures described by Gallagher (1975). Dry weights of root/rhizome material were determined for each species.

Data Analysis

Percent nitrogen data were arcsine and square root transformed and then analyzed in two stages: (1) the Closed and Open Sites were compared to detect differences in plant responses to fertilization, distance from the ditch, and temporal patterns, and (2) comparisons were made between the Control Site and the Closed and Open Sites to investigate differences in responses to fertilization and time.

The analyses were complicated by the lack of true replication (i.e., the quadrats within a single 2 m X 10 m plot are subsamples). To circumvent this problem, sites were treated as blocks. In the first phase of the analysis, the experiment was then analyzed as a split-plot design where the whole plots, distance X fertilizer combinations, were arranged in a randomized complete block design and time was regarded as the split-plot. Interactions involving site X time were tested with sampling error.

For the second part of the analyses, differences between the Control and the Closed and Open sites for percent nitrogen were investigated using Bonferonni t-tests. Pairwise comparisons were made between Open and Control sites and between Closed and Control sites for each fertilizer X distance X time combination.

RESULTS

Spartina patens

There were significant site ($P < .001$) and fertilization ($P < .001$) effects on the nitrogen concentrations of *Spartina* shoots when the Open and Closed Sites were compared. Mean shoot nitrogen concentrations at the Open Site (mean \pm 1 standard error for the four sampling periods: $1.34 \pm 0.03\%$) were significantly higher than at the Closed Site ($1.03 \pm 0.04\%$) and plants in fertilized quadrats had significantly

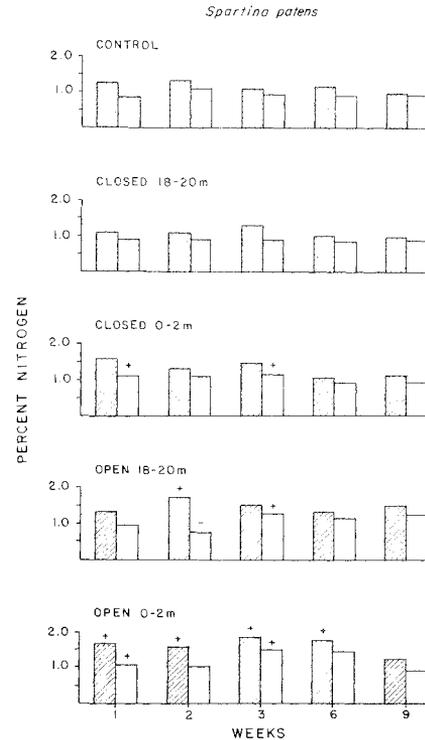


Figure 2. Mean shoot nitrogen concentrations (%) of *S. patens* in fertilized (shaded bars) and unfertilized (unshaded bars) quadrats at the Control, Open, and Closed Sites. Values are means. Means of values at the Open and Closed sites that are significantly different ($P < 0.05$) from means at the Control Site are indicated with either a + (Mean greater than plants from the Control Site) or - (Means less than plants from the Control Site).

higher %N (1.37 ± 0.04) than plants in quadrats that were not fertilized (1.04 ± 0.04). Percent nitrogen in shoots at 0-2 meters (1.23 ± 0.04) was not significantly different from percent N at 18-20 m (1.18 ± 0.04). There were no significant time effects or 2-way interactions. There were significant 3-way interactions among site X time X fertilizer ($P < 0.01$) and site X time X distance ($P < 0.01$), and the 4-way interaction was significant ($P < 0.01$). However, the main features of the data are probably the fertilizer and site effects (mean squares of .0063 and .0048, respectively) since using a conservative degrees of freedom test on all effects involving time (to account for correlation among observations on the same unit over time), showed that the significant time interactions were based on sampling error, which undoubtedly underestimated experimental error.

Figure 2 compares shoot nitrogen

concentrations at the Control Site with those at the two distances at the Open and Closed Sites. In all but one instance (Week 9), %N was significantly ($P < .05$) higher in fertilized quadrats near the ditch at the Open Site than the Control fertilized plots (Fig. 2). In contrast, plants from fertilized quadrats between 18 and 20 m at the Open Site had significantly higher shoot nitrogen concentrations relative to Control fertilized plots only on week 2. Relative to unfertilized Control plots, plants in unfertilized quadrats at the Open site had significantly higher nitrogen concentrations at 0-2 m on week 1 and 3 and at 18-20 m on week 3. There were few significant differences in shoot nitrogen concentrations when the Control and Closed Sites were compared. At the Closed Site, plants in unfertilized quadrats near the ditch had significantly ($P < .05$) higher %N than plants from the unfertilized plots at the Control Site at weeks 1 and 3.

Site differences in the magnitude of the fertilization response of *Spartina* ranged from $38.4 \pm 10.7\%$ at the Open Site to $26.4 \pm 3.5\%$ and $24.8 \pm 7.5\%$ at the Closed and Control sites respectively (Fig. 4)

Distichlis spicata

Site ($P < .001$), fertilization ($P < .001$), and distance ($P < .05$) effects were significant when %N in *Distichlis* shoots was compared at the Open and Closed sites. Nitrogen concentrations at the Open Site ($1.49 \pm 0.04\%$) were significantly higher than those measured at the Closed Site ($1.34 \pm 0.04\%$) and significantly higher near the ditches ($1.45 \pm 0.04\%$) than at 18-20 m ($1.38 \pm 0.04\%$). Shoots collected from fertilized quadrats had significantly higher %N (1.62 ± 0.04) than shoots from quadrats that were not fertilized (1.28 ± 0.04). There were several significant two and three way interactions involving time: time X fertilizer ($P < .01$); time X distance ($P < .001$); site X time ($P < .01$); site X time X fertilizer ($P < .001$); site X time X distance ($P < .001$). The four-way interaction was also significant ($P < .001$). Similar to *Spartina*, the main treatment effects are probably more important than the interactions involving time because the conservative degrees of freedom tests showed that the significant interactions with time were based on sampling rather than experimental error.

Comparisons between the Control Site and two ditched sites for *D. spicata* are shown in Fig. 3. Although there was a tendency for nitrogen concentrations to be elevated in fertilized plots at the Open and Closed Sites relative to fertilized plots at the Control Site,

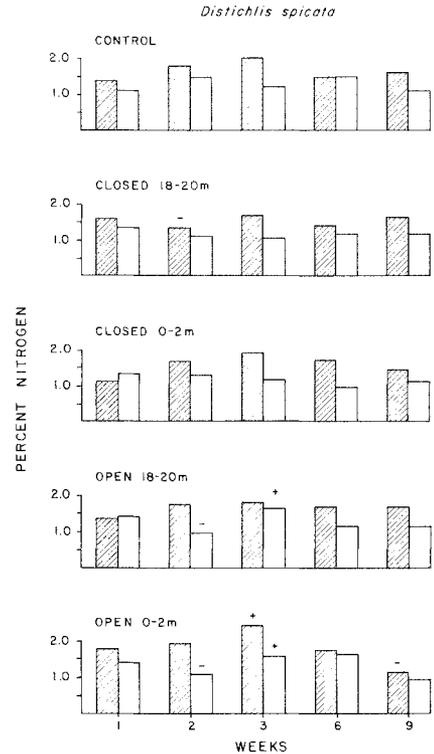


Figure 3. Mean shoot nitrogen concentrations (%) of *D. spicata* in fertilized (shaded bars) and unfertilized (unshaded bars) quadrats at the Control, Open, and Closed Sites. Values are means. Means of values at the Open and Closed sites that are significantly different ($P < 0.05$) from means at the Control Site are indicated with either a + (Mean greater than plants from the Control Site) or - (Means less than plants from the Control Site).

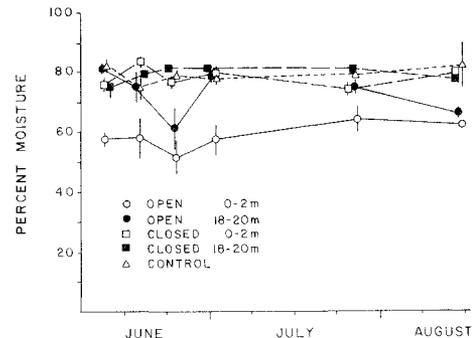


Figure 4. Percent change in the nitrogen concentration of *S. patens* and *D. spicata* shoots at the three study sites. Values are means (± 1 standard error) which were calculated as follows: $(\%N \text{ in fertilized plots} - \%N \text{ in unfertilized plots}) / \%N \text{ in unfertilized plots} \times 100$. Site designations are as in Fig. 1.

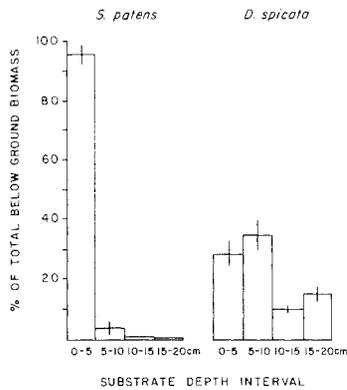


Figure 5. Substrate moisture content at the Open, Closed, and Control Sites. All values are means \pm 1 standard error.

the values were only significantly higher ($P < .05$) than those measured at the Control Site on week 3 at 0-2 m. Shoots in fertilized plots at the Open and Closed sites had significantly lower %N in relation to the fertilized Control Site on two occasions (Closed Site: week 2 at 18-20 m and Open Site: week 9 at 0-2 m). Shoot %N in unfertilized plots at the Open Site on week 2 was significantly lower than the unfertilized plot at the Control Site.

As indicated, *Distichlis* responded positively to fertilization at all three sites (Fig. 4). The percent increase for *Distichlis* was, however, very similar at all three sites.

Substrate Moisture

Substrate moisture content was lowest near the ditch at the Open Site and there were no clear differences between the other sites and distances (Fig. 5). Moisture content ranged from 78.4 ± 0.10 to $83.1 \pm 1.3\%$ at the Control Site and from 75.4 ± 4.6 to $82.1 \pm 1.1\%$ at the Closed Site.

Distribution of Roots and Rhizomes

Most of the below ground biomass ($95.2 \pm 3.5\%$) of *Spartina* occurred within the first 5 cm of substrate (Fig. 6). The distribution of *Distichlis* roots and rhizomes was more uniform with only $27.9 \pm 4.6\%$ of the biomass in the top 5 cm of substrate.

DISCUSSION

The positive responses of *Spartina patens* and *Distichlis spicata* to fertilization are similar to those that have been demonstrated for a more frequently studied estuarine species,

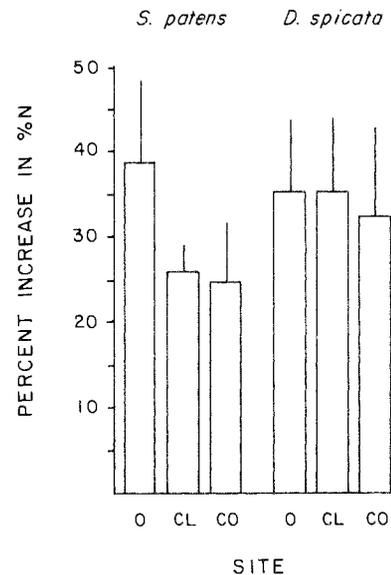


Figure 6. Distribution of roots and rhizomes of *D. spicata* and *S. patens* growing in areas where there is an approximately equal coverage of both species. All values for the 5 cm depth intervals are means of triplicate samples \pm 1 standard error of the mean.

Spartina alterniflora (Sullivan and Daiber 1974; Broome *et al.* 1983; Gallagher 1975; Haines and Dunn 1976; Chalmers 1979; Smart and Barko 1980; Valiela *et al.* 1982 and 1985). The reasons for increased nitrogen utilization under fertilized conditions are complex (Mendelsohn *et al.* 1982) but most results indicate that this may be caused by an increase in the availability of ammonium. Our results indicate that a decrease in substrate moisture content can also result in an increase in the availability of ammonium.

Comparing sites, shoot nitrogen concentrations were significantly higher at the Open Site where the water table had been lowered (Lesser 1982) and where the substrate moisture content had decreased the most, especially near the ditches. That result supports the hypothesis that substrate waterlogging is one of the key factors that controls nitrogen uptake in infrequently flooded brackish wetlands (Mendelsohn *et al.* 1982). A decrease in substrate moisture content could coincide with an increase in substrate oxidation by several mechanisms. First, oxygen could pass from the atmosphere through plant aerenchyma and into the substrate by diffusing out of roots (Teal and Kanwisher 1966; Mendelsohn *et al.* 1982; Howes *et al.* 1981; Mendelsohn and Postek 1982). Plant evapotranspiration and

tidal pumping are two other mechanisms by which oxygen can enter the substrate (Dacey and Howes 1984). Valiela *et al.* (1976) have also shown that diffusion of oxygen into the substrate can be augmented by fertilizer application which can cause increased evapotranspiration. Finally, increasing the rate of movement of interstitial water would also produce the same response as lowering the moisture content of the substrate. Wiegert *et al.* (1983) have shown that short-form *S. alterniflora* production increased when drainage tiles were placed in the substrate to increase the movement of subsurface water. The response measured by Wiegert *et al.* (1983) was, however, most likely caused by a more rapid removal of toxic sulfides and delivery of iron than any change in substrate moisture content (King *et al.* 1982) or alleviation of anaerobiosis in the rhizosphere. In our study, increased water movement within the substrate would have only occurred near the ditches at the Open Site and Lesser (1982) has shown that the groundwater table fluctuated most at those locations. The effects of evapotranspiration and diffusion would have been similar at both sites as there were not any differences in standing live biomass (Whigham *et al.* 1982 and 1983). Both factors would, however, have been augmented at the Open Site by the fact that the groundwater was rarely recharged by surface flooding events and the substrates - especially near ditches - drained during low tide. Drainage could have been primarily responsible for the significantly higher shoot nitrogen concentrations of *Spartina* in fertilized and unfertilized plots near the ditch at the Open Site.

There were also significant differences between the two species in their response to fertilizer addition. While *Distichlis* responded positively to fertilization, the percent increase in shoot nitrogen between fertilized and unfertilized plots was very similar at all three sites. The lack of a clear site effect for *Distichlis* may have been due to the fact that it roots deeper in the substrate where soil moisture levels were higher and similar at all sites. Ditching of the types of wetlands that we have studied would, therefore, have little effect on nitrogen assimilation by *Distichlis* unless the water table was lowered more. Site differences in the magnitude of the fertilization response of *Spartina* were greater at the Open Site, particularly near the ditch. This is consistent with the fact that *Spartina* is much more shallow rooted than *Distichlis* and lowering of the water table by as little as 5 cm could have a positive effect on nitrogen uptake by *Spartina*.

In this study we have demonstrated that wetland management for mosquito control can

have an effect on nutrient cycling if the substrate moisture content is lowered, especially wetlands dominated by *Spartina*. We have shown elsewhere (Whigham *et al.* 1982 and 1983) that lowering the substrate moisture content can also produce dramatic changes in the vegetation. The same types of manipulations did not, however, have any negative impacts on water quality parameters in ditches and ponds nor on patterns of nutrient exchange between the managed wetlands and the estuary (Whigham *et al.* 1983). We agree with Meredith *et al.* (1985) who concluded that proper control of the water table will result in minimum disruption of ecological processes in infrequently flooded tidal wetlands that have been ditched.

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REFERENCES

- American Public Health Association. 1976. Standard Methods for the Examination of Water and Wastewater, 14th edition. American Public Health Association, New York, NY. USA. 1193 p.
- Balling, S.S., Stoehr, T. and Resh, V.H. 1980. The effects of mosquito control recirculation ditches on the fish community of a San Francisco Bay salt marsh. California Fish and Game 66: 25-34.
- Broome S.W., Seneca, E.D. and Woodhouse, W.W. 1983. The effects of source, rate and placement of nitrogen and phosphorus fertilizers on growth of *Spartina alterniflora* transplants in North Carolina. Estuaries 6:212-226.
- Chalmers, A.G. 1979. The effects of fertilization on nitrogen distribution in a *Spartina alterniflora* salt marsh. Estuarine and Coastal Marine Science 8: 327-337.
- Clarke, J.A., Harrington, B.A., Hruby, T. and Wasserman, F.E. 1984. The effect of ditching for mosquito control on salt marsh use by birds in Rowley, Massachusetts. Journal of Field Ornithology 55: 160-180.
- Dacey, J.W.H. and Howes, B.L. 1984. Water uptake by roots controls water table

- movement and sediment oxidation in short *Spartina* marsh. *Science* 224: 487-489.
- Ferrigno, F. and Jobbins, S.M. 1968. Open marsh water management. Proceedings New Jersey Mosquito Extermination Association 55: 104-115.
- Gallagher, J. 1975. Effect of an ammonium nitrate pulse on the growth and elemental composition of natural stands of *Spartina alterniflora* and *Juncus roemerianus*. *American Journal of Botany* 62:644-648.
- Haines, B.L. and Dunn, W.L. 1976. Growth and resource allocation responses of *Spartina alterniflora* Loisel. to three levels of $\text{NH}_4\text{-N}$, Fe and NaCl in solution culture. *Botanical Gazette* 137: 224-230.
- Howes, B.L., Howarth, E.Q., Valiela, I. and Teal, J.M. 1981. Oxidation-reduction potentials in a salt marsh; spatial patterns and interactions with primary production. *Limnology and Oceanography* 26:350-360.
- King, G.M., Klug, M.J., Wiegert, R.G. and Chalmers, A.G. 1982. Relation of soil water movement and sulfide concentration to *Spartina alterniflora* production in a Georgia salt marsh. *Science* 218: 61-63.
- Lesser, C.R., 1982. A Study of the Effects of Three Mosquito Control Marsh Management Techniques on Selected Parameters of the Ecology of a Chesapeake Bay Tidewater Marsh in Maryland. Maryland Department of Natural Resources, Annapolis, MD, USA. 116 p.
- Linthurst, R.A. and Seneca, E.D. 1981. Aeration, nitrogen and salinity as determinants of *Spartina alterniflora* Loisel growth response. *Estuaries* 4: 53-63.
- Mendelssohn, I.A. and Seneca, E.D. 1980. The influence of soil drainage on the growth of salt marsh cordgrass *Spartina alterniflora* in North Carolina. *Estuarine and Coastal Marine Science* 11: 27-40.
- Mendelssohn, I.A. and Postek, M.T. 1982. Elemental analysis of deposits on the roots of *Spartina alterniflora* Loisel. *American Journal of Botany* 69: 904-912.
- Mendelssohn, I.A., McKee, K.L. and Postek, M.T. 1982. Sublethal stresses controlling *Spartina alterniflora* productivity. pp. 223-242. *In* Gopal, B., Turner, R.E., Wetzel, R.E. and Whigham, D.F., eds. *Wetlands: Ecology and Management* International Science Publications, Jaipur, India.
- Meredith, W.H., Saveikis, D.E. and Stachecki, C.J. 1985. Guidelines for "Open Marsh Water Management" in Delaware's salt marshes objectives, system designs, and installation procedures. *Wetlands* 5: 119-133.
- Morris, J.T. 1980. The nitrogen uptake kinetics of *Spartina alterniflora* in culture. *Ecology* 61: 1114-1121.
- Roman, C.T., Niering, W.A. and Warren, R.S. 1984. Salt marsh vegetation change in response to tidal restriction. *Environmental Management* 8: 141-150.
- Shisler, J.K. and Jobbins, D.M. 1977. Salt marsh productivity as effected by the selected ditching technique, Open Marsh Water Management Mosquito News 37: 631-636.
- Smart, R.M. and Barko, J.M. 1980. Nitrogen nutrition and salinity tolerance of *Distichlis spicata* and *Spartina alterniflora*. *Ecology* 61: 630-638.
- Sullivan, M.J. and Daiber, F.C. 1974. Responses in production of cordgrass, *Spartina alterniflora*, to inorganic nitrogen and phosphorus fertilizer. *Chesapeake Science* 15: 121-123.
- Teal, J.M. and Kanwisher, J.W. 1966. Gas transport in the marsh grass, *Spartina alterniflora*. *Journal of Experimental Botany* 17: 355-361.
- Valiela, I., Teal, J.M. and Persson, N.Y. 1976. Production and dynamics of experimentally enriched salt marsh vegetation: Below-ground biomass. *Limnology and Oceanography* 21: 245-252.
- Valiela, I., Howes, B.L., Howarth, R.W., Giblin, A.E., Forman, K., Teal, J.M. and Hobbie, J.M. 1982. Regulation of primary production and decomposition in a salt marsh ecosystem. pp. 245-252 *In* Gopal, B., Turner, R.E., Wetzel, R.G. and Whigham, D.F., eds. *Wetlands: Ecology and Management*. International Science Publications, Jaipur, India.
- Valiela, I., Teal, J.M., Cogswell, C., Hartman, J., Allen, A., Van Etten, R. and Goehring, D. 1985. Some long-term consequences of sewage contamination in a salt marsh ecosystem. pp. 301-306. *In* Godfrey, P.J., Kaynor, E.R. and Pelczarski, S., eds. *Ecological Considerations in Wetlands Treatment of Municipal Wastewater*. Van Nostrand Reinhold Company, New York, NY, USA.
- Wiegert, R.G., Chalmers, A.G. and Randerson, R.F. 1983. Productivity gradients in salt marshes: the response of *Spartina alterniflora* to experimentally manipulated soil water movement. *Oikos* 41: 1-6.
- Whigham, D.F., O'Neill, J. and McWethy, M. 1982. Ecological implications of manipulating wetlands for purposes of mosquito control. pp. 459-476 *In* Gopal, B., Turner, R.E., Wetzel, R.G. and Whigham, D.F. *Wetlands: Ecology and Management*. International Science Publications, Jaipur, India.

Whigham, D.F., O'Neill, J. and McWethy, M.
1983. The Effect of Three Marsh
Management Techniques on the Ecology

of Irregularly Flooded Chesapeake Bay
Wetlands. Maryland Department of
Natural Resources, Annapolis, MD,
USA. 295 p.