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ECOLOGICAL IMPLICATIONS OF MANIPULATING COASTAL WETLANDS FOR PURPOSES OF MOSQUITO CONTROL

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ABSTRACT

Open Marsh Water Management, a technique to control salt marsh mosquitoes, is being used extensively along the Atlantic Coast of the United States. There are, however, few data to evaluate the ecological implications of OMWM. A large-scale study, using 3 variations of OMWM, was initiated in 1978 to determine effects of the procedure on high marsh wetlands in the Maryland portion of the Chesapeake Bay. Preliminary results have shown that significant changes have occurred in the 3 sites that were manipulated. Vegetation in the Open and Water control sites is now dominated by *Distichlis spicata*, and *Iva frutescens* is becoming more important. The Closed system is now dominated by *Spartina patens*. Within each site, tissue nutrient concentrations of nitrogen and phosphorus were significantly higher. There were significant differences between sites and the most significant effects were near ditches.

There have been no major site differences in water quality parameters and there has been no indication that OMWM has resulted in any deterioration of water quality in the adjacent estuarine streams. Tide cycle studies indicate that the Open system exports all materials that we have been monitoring. Qualitative measurements of surface water, however, indicate that there are no major releases of nutrients duirng flooding events.

INTRODUCTION

It is generally accepted that mosquito control is desirable because of the pestiferous nature of many species as well as their potential as vectors of diseases (e.g., malaria, yellow fever, and encephalitis) to humans and domestic animals. In recent years, many mosquito management programs have been based on the use of larvicides or adulticides which, in addition to having negative impacts on non-target species (Ward and Howes 1974, Ward and Busch 1976, Ward and Ludwig 1976, Fitzpatrick and Sutherland 1978), may have long-term adverse environmental impacts. Insecticide use also produces resistance in the target species and in recent years it has been shown that the use of chemicals is not as cost effective for abatement as methods that control mosquito populations by managing water levels (Provost 1977, Shisler *et al.* 1979). In the United States, there has been a renewed interest in the use of water management techniques which control mosquitoes, reduce the need for insecticides, and do not significantly alter the ecology of the managed wetlands.

The most widely practised mosquito control marsh management technique has been ditching. Smith (1904) recommended ditching as a technique for controlling *Aedes sollicitans* in salt marshes by draining surface water from the marsh so that larvae could not complete development to adulthood (ca. 7-10 days after egg eclosion). Ditching was begun on a small scale in New Jersey in 1906 and by 1912, New Jersey law provided for expansion of a program (Headlee 1945) that consisted of the establishment of ditches that were constructed parallel to one another at a spacing distance of 150-200 feet. Parallel ditching became the principal means of salt marsh mosquito control and its application reached a peak during the Depression years when thousands were employed by state and federal agencies to dig the ditches. It is estimated that by 1938, 90% of the tidewater marshes between Maine and Virginia had been ditched (Bourn and Cottam 1950) with little or no consideration having been given to the ecological consequences. Cottam *et al.* (1938) were first to disagree with the notion of parallel ditching. At about the same time Urner (1935) and Bradbury (1938) reported that many waterfowl and shorebirds were adversely affected by mosquito control projects. Bourn and Cottam (1950) and Cottam and Bourn (1952) advised that parallel ditching caused a decline in the abundance and diversity of salt marsh invertebrates and also caused undesirable changes in the salt marsh plant community structure. Stearns *et al.* (1940) found parallel ditching to be deleterious to muskrat production due to the elimination of choice food plants. Its effectiveness in reducing mosquito production has also been challenged (LaSalle and Knight 1973). Today, it is generally accepted that parallel ditching is not a desirable management technique for mosquito control even though parallel ditching does not always cause the serious ecological consequences attributed to it (Kuenzler and Marshall 1973, and Lesser 1976).

A more recent technique called Open Marsh Water Management (OMWM) has been designed to control mosquito populations by modification of larval habitat based on knowledge of larval requirements (Ferrigno and Jobbins 1968). Several strategies have been proposed to use OMWM to modify larval habitats in coastal wetlands (Meredith and Saveikis 1980) :

1. Marsh surface ditching : Treated areas are ditched so that surface waters drain partially or completely into the adjacent estuary. Mosquito larvae would be stranded in dry areas, soil characteristics needed for oviposition by some species would be altered, and fish predators would have access to the modified wetlands during high tides.
2. Surface pools : Shallow pools of various sizes are created in the wetland. The pools may or may not be connected to ditched areas in the wetland. When there are no connections, the pools only receive water through precipitation and surface flooding during storm and high spring tides. The pools, in addition to creating potential waterfowl habitat, promote biological control of mosquitoes by relying on predation of larvae by fishes.

Previous experience with OMWM, primarily in New Jersey, has shown that mosquitoes can be controlled and the use of insecticides can be eliminated or greatly reduced. Ecological effects of various OMWM procedures are not well known. In some instances, densities of invertebrates (e.g., *Uca*) increased while others (e.g., *Melampus*) declined (Ferrigno 1970, Shisler and Jobbins 1977b). In some instances the wetland plant community has been structurally and functionally altered following OMWM application. Primary production of OMWM managed wetlands that are coupled to the estuary has been shown to increase (Shisler and Jobbins 1977b) although an *Spartina alterniflora* may become less dominant than shrubby species such as *Iva frutescens* and *Baccharis halimifolia*. In managed systems that are not coupled to the estuary, changes in the plant community may not be significant (Burger and Shisler 1978). With the exception of a study of carbon transport in OMWM treated wetlands in New Jersey (Shisler and Jobbins 1977a), there are no data on the impacts that OMWM has on marsh functions such as nutrient export-import dynamics and decomposition processes.

The Deal Island Study

The OMWM techniques that were designed in New Jersey are now being used or proposed for use in other states. In addition to the many ecological questions that remain unanswered, it still must be determined whether or not the techniques will control mosquitoes in other areas. Tidal regimes, salinity patterns and wetland vegetation in the Chesapeake Bay are different than those in New Jersey where the techniques were designed. Particularly striking are differences in the tidal amplitudes. Most of the wetlands in the Chesapeake Bay are irregularly flooded and the average tidal range is much less than those found in Delaware Bay.

In 1978 a joint project between the Maryland Department of Agriculture and the Smithsonian Institution was initiated to determine the management and ecological effects of 3 OMWM techniques on typical irregularly flooded wetlands of the Chesapeake Bay. The research is being conducted on the 10,000 acre Deal Island Wildlife Management Area in Somerset County, Maryland. Wetlands in that area contain many potholes that are used by mosquitoes as primary breeding habitats. In most instances these wetlands are dominated by *Spartina patens* and/or *Distichlis spicata*.

For areas that were similar in topographic and drainage characteristics were located and three were treated as follows with the fourth area serving as a control :

1. *Open Site*— OMWM techniques were used to ditch a 50 acre area. The site was coupled to the adjacent estuary to provide tidal circulation throughout.
2. *Water Control Site*— A 25 acre site was treated similarly to the Open Site but water level control structures were placed on the outlet ditches to permit some tidal water to flood and ebb from the area without allowing complete drainage.
3. *Closed Site*— A 25 acre area was ditched but the site was not connected to the adjacent estuary so that tidal waters exchanged only during spring and/or storm tides.

The ditches and ponds were excavated with an amphibious rotary ditcher that broadcasts for 15 to 20 meters a thin layer of spoil. Ditches are about 0.75 meters wide and from 0.6 to 0.9 m deep. In addition to the ditches, at least one large shallow pond was created within each of the 3 sites. Following completion of the management, a Stevens Type F recorder and 10 water-wells made of 1 meter long (3.8 cm dimeter) plastic pipe were installed at each site to monitor water tables and heights of water in the ditches.

The purpose of this paper is to present preliminary results of one phase of the project that deals with the dynamics of the plant community and qualitative and quantitative studies of selected water quality parameters.

METHODS

Vegetation

Vegetation has been sampled monthly at the 3 treatment and one control sites since May 1979. The sampling design includes harvesting all vegetation in 50×50 cm quadrats that are located at 0, 5, 10, 15 and 20 meters from one of the OMWM ditches. Three quadrats are harvested for each distance. In addition, 5 randomly chosen quadrats are sampled within each site in areas that were not impacted by spoil deposition during the initial management process.

In the laboratory, vegetation was divided into live and dead components with the live biomass being further subdivided by species. Dead biomass included all standing vegetation as well as litter lying on the wetland surface. All plant materials are dried at 60° C, weighed, and ground in a Wiley Mill prior to analysis for nitrogen using micro-Kjeldahl (APHA 1976) and phosphorus using an acid digestion technique (Fiske and Subbarow 1925, King 1932).

Permanent quadrats (25×25 cm) were established along 3 transects at 0, 5, 10, 15 and 20 meters at each site following the initial management. Those plots are monitored monthly and counts are made of the number of live stems of each species and the number of inflorescenses for each species. Height measurements are also obtained for 5 individuals of *D. spicata* and *S. patens* in each permanent quadrat.

Biomass and nutrient data were then used to calculate 13 variables which were tested for site, distance and site-distance interactions using ANOVA techniques. The following variables were considered :

1. Total Biomass (TB)—sum of live and dead biomass
2. Live Biomass (LB)—sum of live biomass of all species
3. Dead Biomass (DB)—including all standing dead material and surface litter
4. Nitrogen concentrations of live biomass (NPL)
5. Nitrogen in live biomass (NLB=NPL×LB)
6. Phosphorus concentrations of live biomass (PPL)
7. Phosphorus in live biomass (PLB=PPL×LB)
8. Nitrogen concentrations of dead biomass (NPD)
9. Nitrogen in dead biomass (NDB=NPD×DB)
10. Phosphorus concentrations of dead biomass (PPD)
11. Phosphorus in dead biomass (PDB=PPD×DB)
12. Total nitrogen in biomass (NT=NLB+NDB)
13. Total phosphorus in biomass (PT=PLB+PDB)

In addition, biomass and nutrient data were used to estimate primary production and its associated nutrients using the following 3 methods as described in Linthurst and Reimold (1978).

METHOD 1—Peak Standing Crop (PSC). Primary production for each site × distance combination was assumed to be equal to the peak standing crop value for the growing season. PSC values for each combination were then used to determine if there were site, distance, and site × distance differences using ANOVA.

METHOD 2—Net Aboveground Primary Production (NAPP). This method is based on the work of Milner and Hughes (1968). Similar to Method 1, NAPP was calculated for each site × distance combination and appropriate ANOVA tests were performed.

METHOD 3—Net Production Smalley (NPS). This method is based on Smalley (1959) and includes harvest data for both live and dead biomass. Statistical analyses were similar to those used for Methods 1 and 2.

Density, height, and inflorescence data for each site × distance combination were also used in ANOVA analyses to determine if there were any site, distance and site × distance effects.

Water Quality Studies

A study was initiated to determine if there were any inter- and intra-site differences in selected water quality parameters. In addition, tide cycle studies have been conducted to determine patterns of exchange between the manipulated areas and the adjacent estuary. Cross-sectional areas of the study ditches and central stream were measured. Flow was measured with a Marsh-McBirney Model 511M electromagnetic current meter. Water flux was determined by combining average height data with average flow data for hourly intervals during the tide cycle. Total nutrient flux was determined for each hourly interval and for each ebb and flood tide by combining average hourly concentration data with hourly water flux data. Water samples were acidified and immediately placed on ice. In the laboratory the following parameters were measured : (1) dissolved and total phosphorus, (2) total and dissolved nitrogen, (3) ammonia nitrogen, (4) nitrate nitrogen. Phosphorus and nitrogen parameters were analyzed with standard procedures found in APHA (1976), King (1932), Strickland and Parsons (1965), and Richards and Kletsch (1964).

RESULTS

Biomass

There were significant site, distance, and time effects for most of the biomass variables. Because a detailed presentation of data is not possible in this paper, we have chosen examples that document the types of changes that have occurred.

Figure 1 shows temporal and distance changes that occurred at the Open Site during the first growing season. Following the OMWM manipulations, there was very little live biomass at 0 and 10 meters (Yearday 130). By Yearday 158, live biomass at 10 and 20 meters was significantly greater than biomass in the 5 random plots, while little recovery had occurred at 0 meters. Production at 0 meters was very high between Yeardays 158 and 184 and by Yearday 184 the amount of biomass at 0 meters was greater than at the other distances. The pattern of larger biomass near the ditches continued throughout the remainder of the growing season.

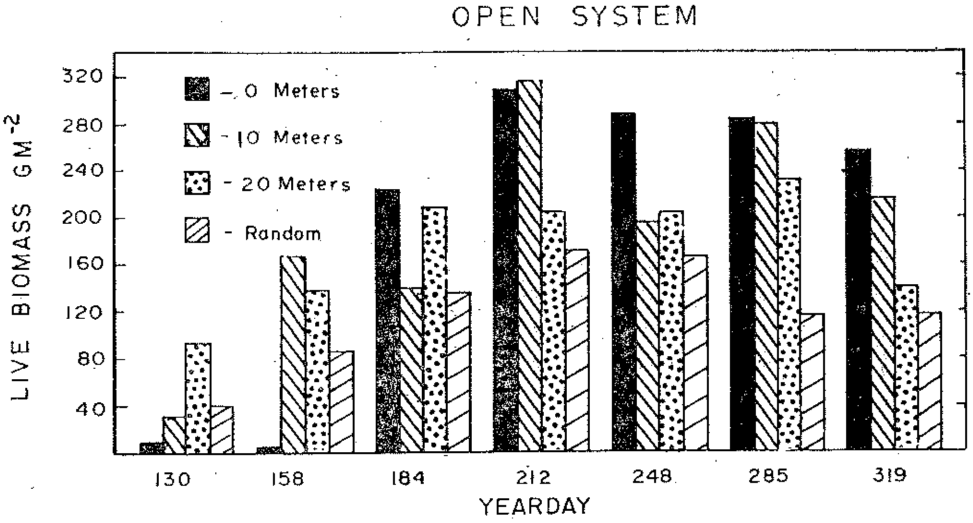

FIG. 1. Seasonal patterns of aboveground biomass at 0, 10 and 20 meters from a ditch compared to random plots that were not affected by spoil. Data are means of triplicate samples.

Although the same patterns occurred at the other treated sites, there were significant site differences for most biomass variables. Figure 2 shows the pattern of total live biomass (LB) recovery at 2 of the treated sites and the control. Total biomass, combining all distances, was significantly higher at the Open and Closed Sites by September and these differences persisted throughout the remainder of the growing season. There were, however, significant inter-site differences. Most of the live biomass at the Open Site was due to a dominance of *Distichlis spicata* over *Spartina patens* (Fig. 3), while the reverse was true at the Closed Site. The species differences were also apparent when comparisons were

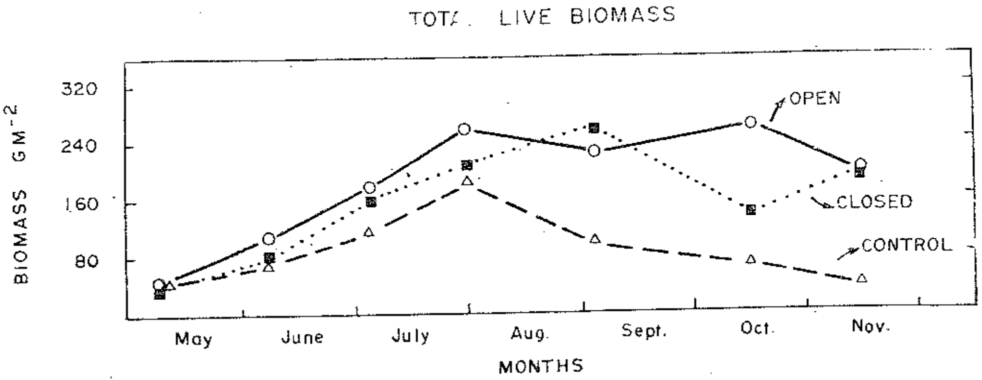

FIG. 2. Seasonal patterns of live aboveground biomass at two treatment sites and the Control site. All values are means of 15 samples.

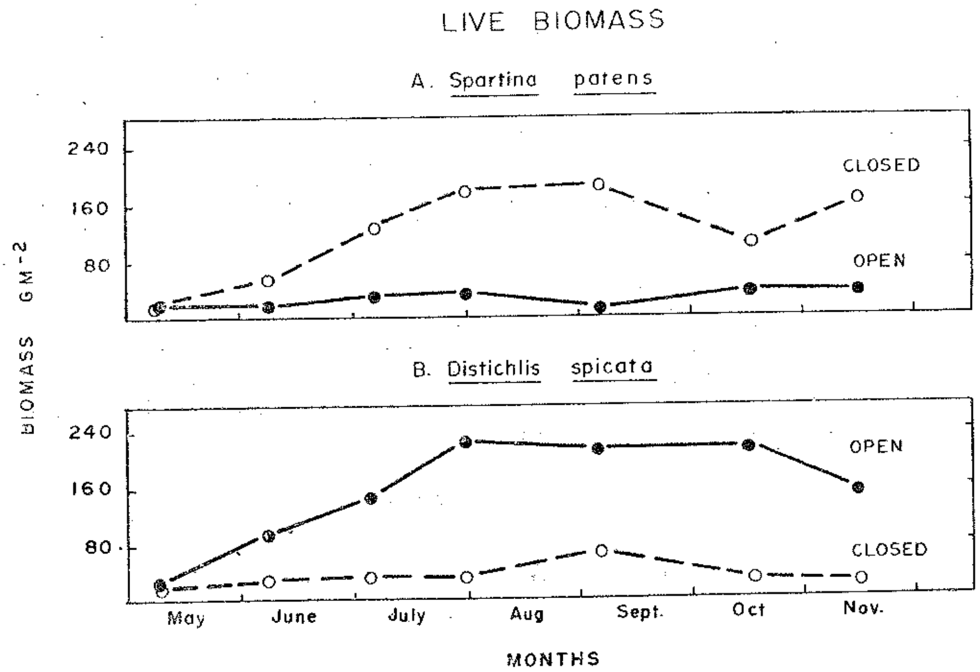

FIG. 3. Seasonal patterns of live aboveground biomass of two dominant species at two treatment sites. All values are means of 15 samples.

made of plant densities (Fig. 4). *Spartina* densities were significantly greater at the Closed Site while *Distichlis* densities were significantly greater at the Open Site. Although live biomass had completely recovered by the end of the first growing season, recovery of dead biomass (*i.e.*, recovery of the litter compartment) was not as complete (Fig. 5). The decline in live stem densities in October and November (Fig. 4) resulted in an increase in the dead biomass component but the standing stock values were still significantly lower at the 0 and 10 meter distances.

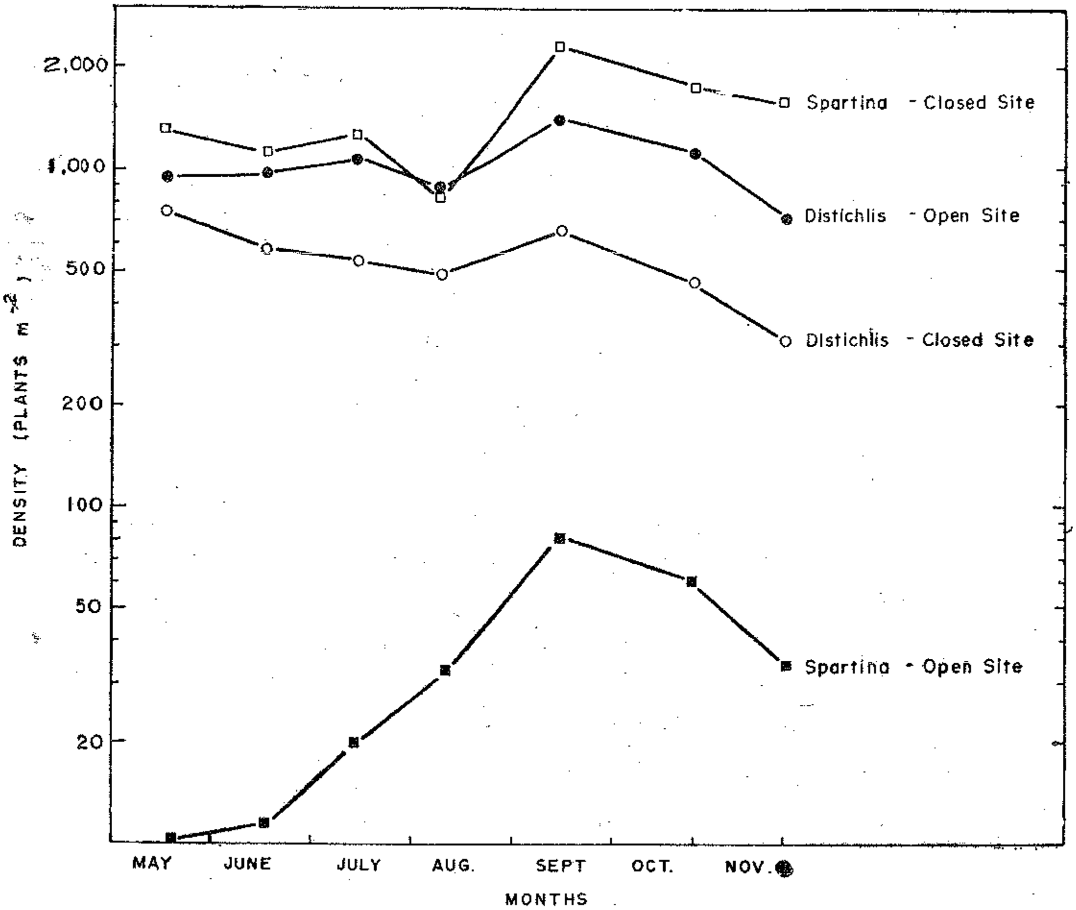

FIG. 4. Seasonal patterns of stem density for two dominant species at two treatment sites. All values aremeans of 15 samples.

There were also significant site, distance and time effects on nutrient concentrations on live tissues as well as total nutrient standing stocks. Concentrations of nitrogen, combining all distances and times, averaged 1.14% at the Open Site and 1.18 at the Water Control Site. Those values were significantly greater ($\propto = .05$) than those measured at the Closed (0.88%) and Control (1.01%) Sites.

Temporal trends in nutrient concentrations were similar at all sites and are demonstrated for the Open Site in Figure 6. Nitrogen concentrations were elevated significantly at all distances as compared to the random plots and the differences were most pronounced early in the growing season. Tissue N concentrations declined throughout the growing season but significant distance differences remained for several months. The same patterns were found for phosphorus concentrations in the live biomass (Fig. 7) although the differences were not as striking as those for nitrogen nor did they remain as long.

When concentration (N and P) data were combined with biomass data to calculate total nutrient standing stocks, there were significant differences between and within sites. Figure 8 demonstrates that total nitrogen standing stock was significantly less near the ditches for the first 3 sample periods, and with one exception, there were no distance differences

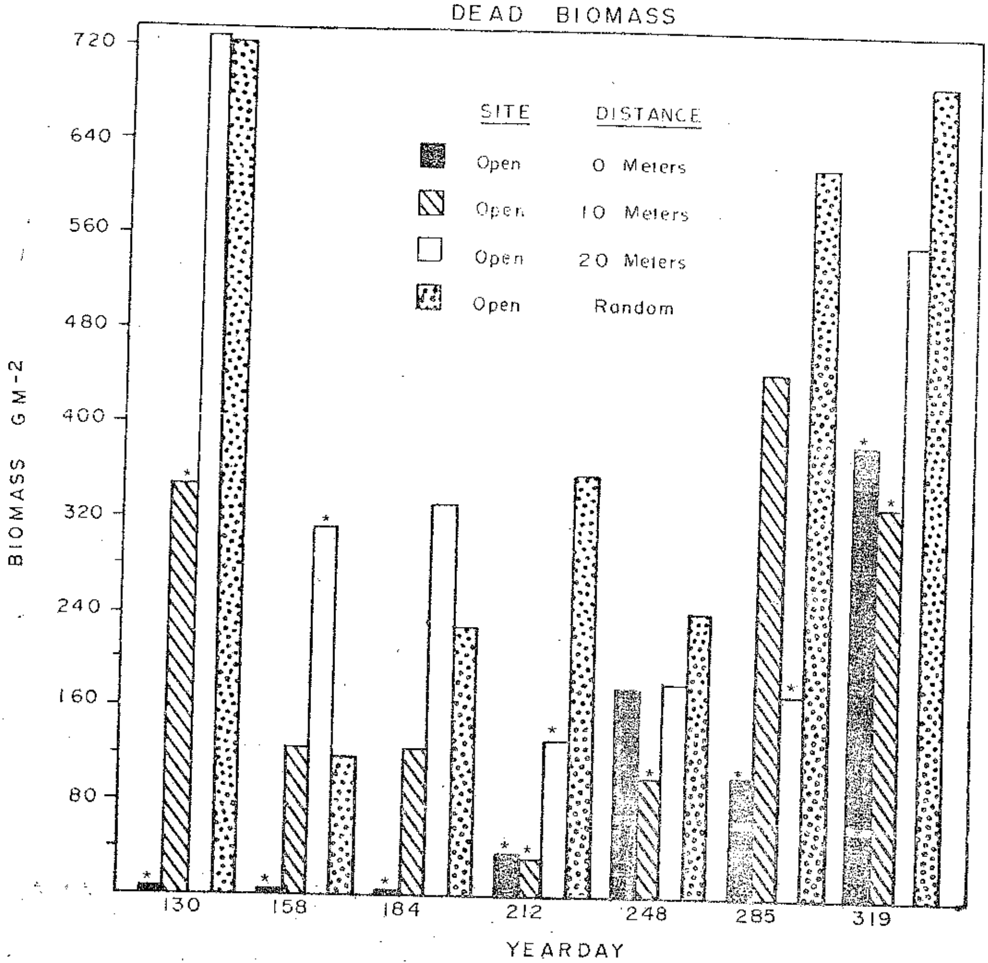

FIG. 5: Seasonal patterns of dead biomass at the Open Site at 0, 10 and 20 metres from a ditch compared to data from 5 random plots that were not affected by spoil deposition. Values for each distance are means of triplicate samples. Means that are significantly different from the random plots ($\alpha = .05$) are indicated with an *.

thereafter. Although the same temporal trend occurred at the other treated sites, there were significant site differences as shown by analysis of variance tests. Total nitrogen, combining all distances and time, was significantly greater at the Open Site ($\bar{X} = 2.80$ g m^{-2}) than at the other sites.

Phosphorus standing stocks showed the same temporal pattern as those found for nitrogen but the distance effects were not as pronounced (Fig. 9). Recovery of the phosphorus total standing stock was not as complete as that for nitrogen and the analyses of variance tests showed that combining all times, the total standing stock of P was significantly less at 0 (0.15 g m^{-2}) and 5 (0.16 g m^{-2}) meters ($\alpha = .05$) compared to 20 meters (0.22 g m^{-2}). Similar to nitrogen, the average P standing stock at the Open Site (0.23 g m^{-2}) was significantly greater than the Control Site (0.15 g m^{-2}). The P standing stock at the Water Control Site (0.20 g m^{-2}) was also significantly greater than at the Control Site.

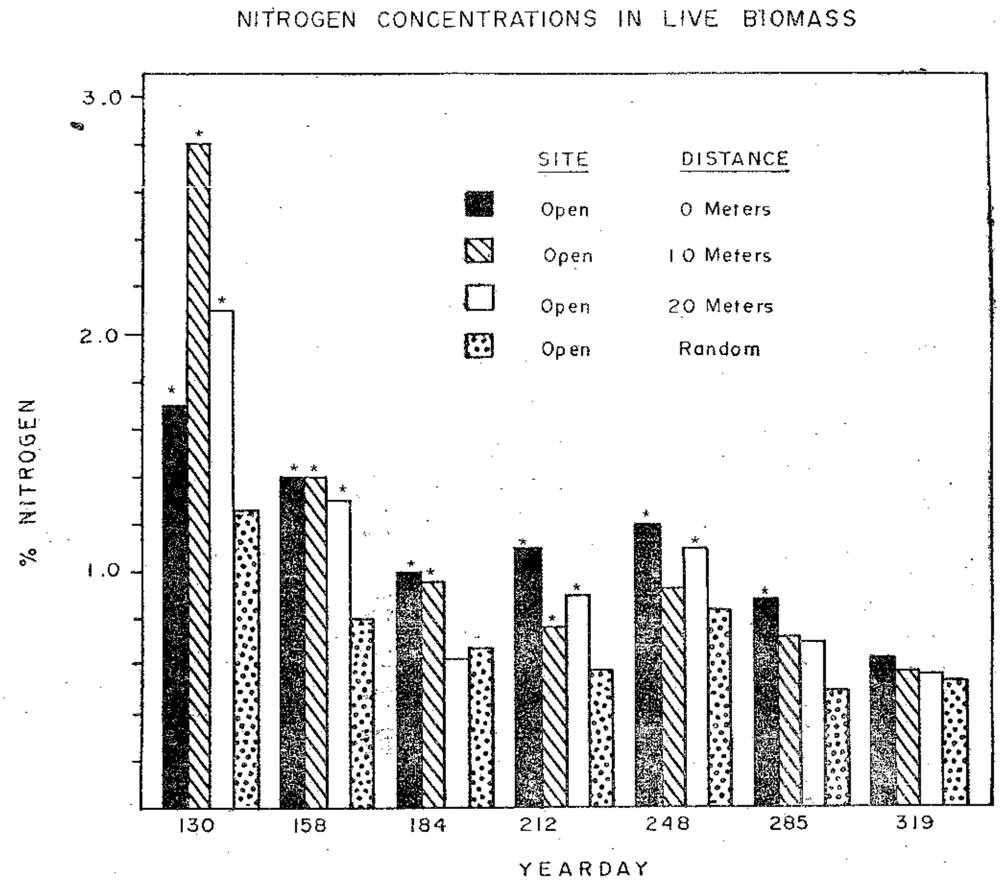

FIG. 6. Seasonal patterns in nitrogen concentrations of live tissues at the Open Site at 0, 10 and 20 meters from a ditch compared to data from 5 random plots that were not affected by spoil deposition. Values for each distance are means of triplicate samples. Means that are significantly different from the random plots ($\alpha = .05$) are indicated with an*.

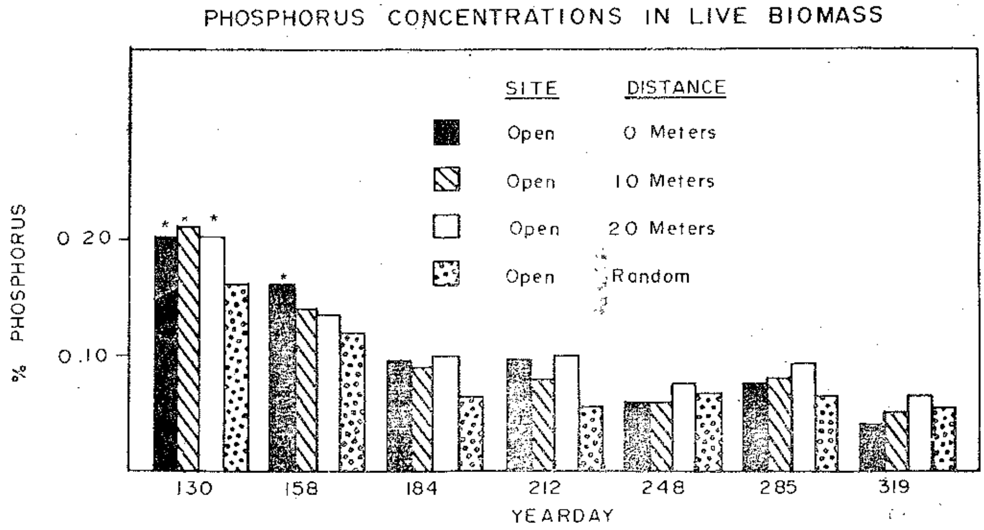

FIG. 7. Seasonal patterns in phosphorus at the Open Site at 0, 10 and 20 meters from a ditch compared to data from 5 random plots that were not affected by spoil deposition. Values for each distance are means of triplicate samples. Means that are significantly different from the random plots ($\alpha = .05$) are indicated with an*.

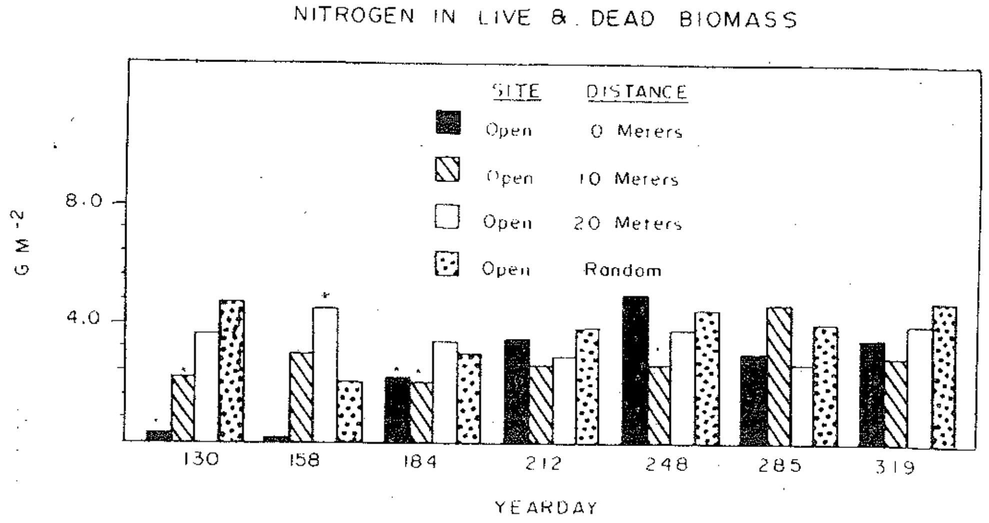

FIG. 8. Seasonal patterns in nitrogen standing stock in aboveground vegetation at the Open Site at 0, 10 and 20 meters from a ditch compared to data from 5 random plots that were not affected by spoil deposition. Values for each distance are means of triplicate samples. Means that are significantly different from the random plots ($\alpha = .05$) are indicated with an*.

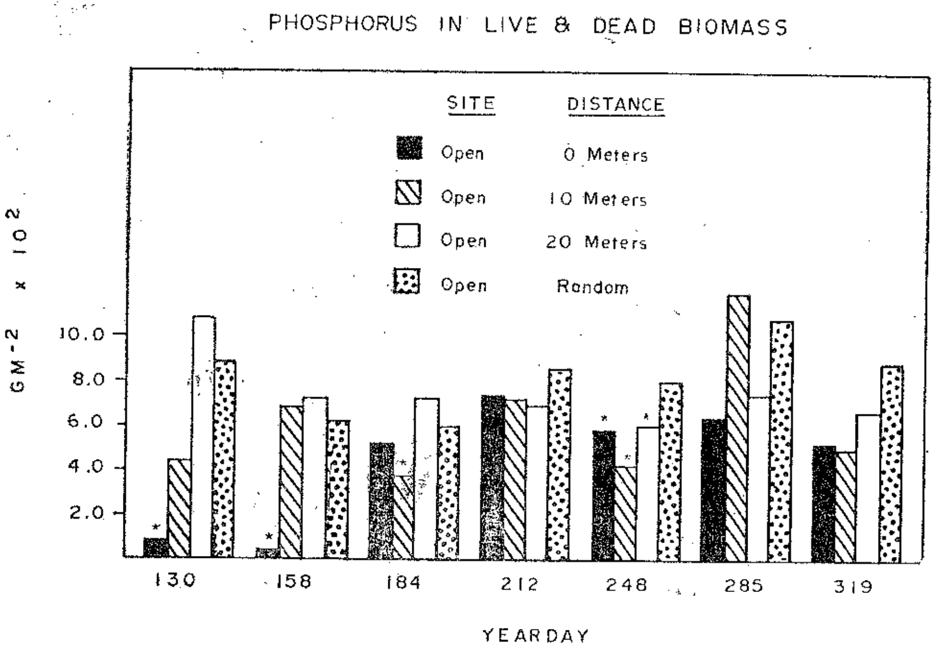

FIG. 9. Seasonal patterns in phosphorus standing stock in aboveground vegetation at the Open Site at 0, 10 and 20 meters from a ditch compared to data from 5 random plots that were not affected by spoil deposition. Values for each distance are means of triplicate samples. Means that are significantly different from the random plots ($\alpha = .05$) are indicated with an*.

Estimates of aboveground primary production and associated uptake of nitrogen and phosphorus are shown in Table 1. The 3 treated sites had higher estimated primary production than the Control Site for each of the calculation techniques. With one exception the treated sites were similar and ranged between 313.6 and 898.8 g m^{-2}. There were also differences in nitrogen and phosphorus uptake estimates. Nitrogen values were always significantly higher at the Open and Water Control Sites which reflects the higher tissue nutrient concentrations in the live biomass. The same pattern was found for phosphorus. In all instances, there were no significant differences between estimated N and P assimilation at the Closed and Control Sites even though aboveground production was significantly greater at the Closed Site.

TABLE 1. *Estimated net aboveground primary production and associated N and P assimilation.* See the text for an explanation of the 3 computational methods. All values are g m^{-2} and means that are not significantly different ($\alpha = .05$) share the same superscript.

Site	Primary production			Nitrogen			Phosphorus		
	PSC	NAPP	NPS	PSC	NAPP	NPS	PSC	NAPP	NPS
Open	353.6^{A}	421.6^{AB}	898.8^{A}	3.08^{A}	3.12	5.12^{A}	0.32^{A}	0.36^{A}	0.44^{A}
Closed	313.6^{A}	362.8^{B}	881.2^{A}	1.88^{B}	1.76^{A}	4.20^{A}	0.20	0.20	0.47^{AB}
Water Control	364.0^{A}	498.4^{A}	859.2^{A}	3.24^{A}	4.56	7.24	0.32^{A}	0.36^{A}	2.52^{A}
Control	225.2	233.2	599.6	1.64^{B}	1.60^{A}	4.72^{A}	0.16	0.12	0.32^{B}

Water Quality

There were no major differences for water quality parameters when three types of comparisons were made : (1) inter-site comparisons, (2) intra-site comparisons of temporal changes in water quality parameters during tide cycles, and (3) intra-site comparisons of nutrient flux during tide cycles. Similar to the biomass data, it is not possible to present all of the information that has been obtained and we have chosen to present data that demonstrate major temporal and spatial patterns.

Table 2 and 3 demonstrate temporal changes in selected water quality parameters at the Open and Control Sites. Dissolved and particulate total phosphorus concentrations are almost always low and minimum values (0.01-0.02 mg l^{-1}) occur during the summer months (Tables 2 and 3). There have been no distinct differences between ponds and ditches at either site and site differences have also been minimal. Most important, the data show that there have been no temporal trends and that phosphorus concentrations immediately after the management, with the exception of June 1979, were not any higher than concentrations that have been measured in 1980.

Concentrations of dissolved and total Kjeldahl-nitrogen have, with few exceptions, been consistently higher in ponds at the Open Site (Table 2). Within the Control Site (Table 3), there has been much more temporal variation as well as differences between natural potholes (ponds) and the natural channel (ditch). Nitrogen concentrations at the Control Site have usually been slightly higher than those measured at the Open Site. The temporal variation as well as higher concentrations of nitrogen at the Control Site are most likely due to more frequent flooding of potholes at that site plus the fact that

TABLE 2. *Temporal trends in water quality parameters for ponds and ditches at the Open Site.* All values are mg l^{-1}.

	Dissolved Phosphorus		Total Phosphorus		Dissolved Kjeldahl-Nitrogen		Total Kjeldahl-Nitrogen		Nitrate-Nitrite Nitrogen		Ammonia Nitrogen	
	Pond	Ditch	Pond	Ditch	Pond	Ditch	Pond	Ditch	Pond	Ditch	Pond	Ditch
Apr 1979	..	0.01	..	0.06	..	0.38	..	0.87	..	0.07	..	0.13
May 1979	..	0.00	0.08	0.04	1.50	0.85	2.24	1.24	..	0.00	0.39	0.13
Jun 1979	0.06	0.06	0.13	0.12	1.28	0.86	1.56	0.99	0.01	0.01	0.45	0.04
Jul 1979	0.01	0.01	0.03	0.06	0.83	0.54	0.97	0.87	0.00	0.00	0.20	0.10
Aug 1979	0.01	0.01	0.06	0.05	0.79	0.59	1.14	0.87	0.01	0.00	0.04	0.02
Sep 1979	0.00	0.01	0.02	0.01	0.70	0.70	0.97	1.11	0.01	0.01	0.12	0.10
Nov 1979	0.00	0.02	0.03	0.03	0.70	0.70	0.81	1.13	0.01	0.03	0.19	0.10
Dec 1979	0.00	0.01	0.02	0.03	1.35	0.50	1.57	1.06	0.02	0.13	0.39	0.19
Jan 1980	0.01	0.01	0.04	0.08	0.86	0.56	0.98	0.68	0.07	0.12	0.20	0.08
Feb 1980	0.01	0.01	0.04	0.05	1.11	0.55	1.38	..	0.13	0.16	0.35	0.06
Mar 1980	0.02	0.02	0.05	0.08	0.71	0.35	0.93	0.74	0.05	0.19	0.20	0.08
Apr 1980	0.02	0.01	0.07	0.07	0.49	0.63	1.51	0.82	0.00	0.17	0.06	0.05
May 1980	0.02	0.02	0.07	0.06	1.53	0.64	1.91	0.84	0.00	0.01	0.52	0.28
Jun 1980	0.00	0.03	0.03	0.07	0.93	0.37	1.23	0.80	0.00	0.00	0.22	0.00

TABLE 3. *Temporal trends in water quality parameters for natural potholes (ponds) and a natural tidal channel (ditch) at the Control Site.* All values are mg l^{-1}.

	Dissolved Phosphorus		Total Phosphorus		Dissolved Kjeldahl-Nitrogen		Total Kjeldahl-Nitrogen		Nitrate-Nitrite Nitrogen		Ammonia Nitrogen	
	Pond	Ditch	Pond	Ditch	Pond	Ditch	Pond	Ditch	Pond	Ditch	Pond	Ditch
Apr 1979	..	..	..	..	0.68	..	1.09	..	0.01	..	0.15	..
May 1979	0.01	0.01	0.03	0.13	0.88	0.75	1.05	0.95	0.02	0.12	0.09	0.13
Jun 1979	0.07	0.07	0.07	0.17	1.09	1.02	1.11	1.55	0.01	0.03	0.02	0.09
Jul 1979	0.02	0.00	0.07	0.04	1.08	0.68	1.42	0.99	0.00	0.00	0.18	0.03
Aug 1979	0.00	0.01	0.04	0.06	0.91	0.71	1.09	1.03	0.01	0.00	0.03	0.05
Sep 1979	0.01	0.01	0.01	0.10	0.92	1.31	1.31	1.71	0.01	0.01	0.10	0.15
Nov 1979	0.02	0.01	0.05	0.06	0.49	1.08	1.11	1.20	0.01	0.01	0.08	0.08
Dec 1979	0.05	0.03	0.09	0.03	1.99	0.82	2.50	0.97	0.00	0.05	0.29	0.19
Jan 1980	0.02	0.01	0.05	0.06	0.52	0.55	0.56	0.61	0.05	0.09	0.05	0.07
Feb 1980	0.02	..	0.05	..	2.58	..	2.64	..	0.01	..	0.54	..
Mar 1980	0.02	0.05	0.06	0.15	0.82	0.51	1.17	1.89	0.01	0.08	0.06	0.08
Apr 1980	0.02	0.01	0.06	0.16	0.88	1.07	1.07	0.88	0.00	0.01	0.09	0.20
May 1980	0.01	0.02	0.04	0.07	0.98	0.76	1.16	0.97	0.00	0.05	0.04	0.19
Jun 1980	0.01	0.01	0.17	0.04	1.68	0.63	2.10	0.81	0.00	0.00	0.14	0.05

the natural stream is bordered by mudflats and a narrow band of *Spartina alterniflora* vegetation. These areas are much more biologically active than the ditches at the treated sites. For example, fiddler crabs (*Uca*) and snails (*Littorina*) are very abundant along the Control stream while few have invaded the treated sites. In addition, bioturbation of the soft sediments and resuspension of materials during tidal cycles probably accounts for the higher nitrogen values measured at the Control Site.

Nitrate nitrogen concentrations have been consistently low, usually less than 0.02 mg l^{-1}, except between December and April when values as high as 0.19 mg l^{-1} were measured (Tables 2 and 3). Nitrate concentrations have almost always been lower in ponds that are not as frequently coupled to tidal activity as are the ditches. Except during summer months, water from the Control Site stream almost always had lower nitrate concentrations than did water from the ditch at the Open Site. Similar to dissolved and total nitrogen, these differences are most likely due to site differences in biological activity. Ammonia concentrations have been consistently higher in the pond at the Open Site (Table 2) where there has also been a temporal pattern with the lowest concentrations occurring between June and November. Although not as pronounced, a similar pattern occurred in the ditch at the Open Site. Ammonia concentrations at the Control Site have been variable as those described for nitrate.

Table 4 and 5 contain representative data from one of the tide cycle studies. Only dissolved and total Kjeldahl nitrogen have shown any consistent concentration effect during the tide cycles with the highest concentrations occurring near low slack tide (Table 4). Comparing the Open Site to the Control Site (Table 4), total phosphorus and total

TABLE 4. *Nutrient concentrations during the May* 1980 *tide cycle study.* All values are mg l^{-1}. Data presented for the Open and Control Sites are means of 2 samples for the time intervals shown.

Time since Low Slack Tide (Hours)	Dissolved Phosphorus	Total Phosphorus	Dissolved Kjeldahl-Nitrogen	Total Kjeldahl-Nitrogen	Nitrate-Nitrite Nitrogen	Ammonia Nitrogen
			OPEN SITE			
Low Slack Tide						
0.0—2.2	0.02	0.06	0.64	0.82	0.02	0.19
2.2—4.2	0.02	0.08	0.60	0.79	0.02	0.19
4.2—4.7	0.02	0.09	0.60	0.74	0.03	0.19
High Slack Tide						
4.7—6.8	0.02	0.09	0.30	0.75	0.04	0.18
6.8—8.6	0.02	0.11	0.63	0.79	0.04	0.14
8.6—10.7	0.03	0.10	0.60	0.82	0.04	0.14
10.7—12.6	0.04	0.07	0.72	0.83	0.03	0.08
Low Slack Tide						
			CONTROL STIE			
Low Slack Tide						
0.0—1.1	0.03	0.08	0.93	1.26	0.00	0.30
1.1—3.3	0.03	0.07	0.68	0.85	0.01	0.23
3.3—5.3	0.02	0.07	0.51	0.72	0.02	0.18
High Slack Tide						
5.3—7.5	0.02	0.05	0.54	0.69	0.03	0.19
7.5—9.3	0.02	0.05	0.58	0.73	0.03	0.20
9.3—11.7	0.02	0.05	0.68	0.76	0.02	0.22
11.7—13.5	0.02	0.03	0.74	0.76	0.01	0.24
Low Slack Tide						

TABLE 5. *Nutrient flux data for the Open and Control Sites for the May* 1980 *tide cycle study.* Net flux is indicated as import (+) or export (—) for the time intervals shown as well as the net flux for the tide cycle. All values are grams of material.

Time Since Low Slack Tide (Hours)	Dissolved Phosphorus	Total Phosphorus	Dissolved Kjeldahl-Nitrogen	Total Kjeldahl-Nitrogen	Nitrate-Nitrite	Ammonia-N
			OPEN SITE			
Low Slack Tide						
0.0—2.2	+10.5	+31.3	+360.2	+502.9	+8.2	+115.9
2.2—4.2	+18.7	+52.0	+471.6	+592.2	+15.9	+156.6
4.2—4.7	+1.3	+4.0	+30.1	+43.6	+1.7	+10.6
High Slack Tide						
4.7—6.8	—15.4	—41.1	—417.2	—531.0	—32.3	—145.3
6.8—8.6	—11.3	—31.0	—346.6	—433.7	—23.9	—118.2
8.6—10.7	—8.4	—22.3	—290.0	—334.1	—16.1	—95.7
10.7—12.6	—4.0	—7.1	—154.3	—158.2	—6.1	—50.4
Low Slack Tide						
Net Flux	—8.6	—14.2	—346.2	—318.3	—54.6	—126.5
			CONTROL SITE			
Low Slack Tide						
0.0—1.1	+0.7	+2.2	+21.6	+27.5	+0.0	+ 6.4
1.1—3.3	+7.2	+32.5	+240.4	+316.4	+2.6	+79.6
3.3—5.3	+6.6	+30.9	+219.3	+270.3	+7.3	+68.1
High Slack Tide						
5.3— 7.5	—6.2	—26.4	—158.9	—226.6	—8.3	—53.2
7.5— 9.3	—4.0	—18.9	—112.2	—141.2	—5.3	—24.7
9.3—11.7	—5.6	—18.9	—121.8	—150.9	—3.8	—20.1
11.7—13.5	—0.9	—1.7	—17.3	—19.8	—0.2	— 3.0
Low Slack Tide						
Net Flux	—2.2	—0.3	+44.1	+75.7	—7.7	+48.1

Kjeldahl nitrogen concentrations were somewhat higher in ebbing water from the Control Site. Concentrations of the dissolved components for both elements are not that different which suggests that the higher total concentrations are due to nitrogen and phosphorus associated with particulate matter. Nitrate concentrations (Table 4) have been slightly lower in ebbing water at both sites while ammonia concentrations have been lower in ebbing water only at the Open Site.

Typical tide cycle flux data are shown in Table 5. There has been a net export of all measured materials from the Open Site since the initiation of our sampling in June, 1979. Almost all of the nitrogen and usually between 50 and 75% of the phosphorus has been in the dissolved form. The magnitudes of fluxes into and from the Control Site are much less (Table 5) because a smaller amount of water fluxes through that site. There has usually been a small net flux of phosphorus from the Control Site while nitrogen has been more variable with a net export occurring during many non-growing season months and a net import, especially of ammonia, occurring during the growing season.

DISCUSSION

While it is still too early to draw any final conclusions from these studies, several interesting patterns have developed. Data from the water wells demonstrate that there has been a drop in the water table at all sites and that there are site differences (Fig. 10) with the water table in the Open and Water Control Sites being the lowest. Recovery of the plant community was almost complete by the end of the first growing season. The Open Site is, however, still undergoing dramatic shifts in plant community organization and *Iva frutescens* is rapidly colonizing that area. The Water Control and Closed Sites are not being invaded by *Iva* although ruderal species such as *Pluchea camphorata* and *Atriplex patula* are common throughout the Water Control Site. Net aboveground primary production was significantly greater at the 3 treated sites. Shisler and Jobbins (1977b) found that site production increased following OMWM application and suggested that the increase was due to enhanced tidal circulation and greater availability of nitrogen. Our data, however, suggests that the tidal circulation hypothesis still needs further testing as no differences were found in estimated production between the Open and Closed Sites which are at extreme opposites in terms of tidal circulation.

Increased aboveground production may, in part, be due to increased availability of nutrients from spoil deposited on the surface or from increased availability of nutrients in the substrate due to increased aeration of the sediments. The significant, yet differential, changes that have been monitored in N and P tissue levels would suggest that the latter hypothesis may be the most important. Sites (Open and Water Control) that had the lowest water tables had the highest N and P uptake and, in addition, we have found lateral

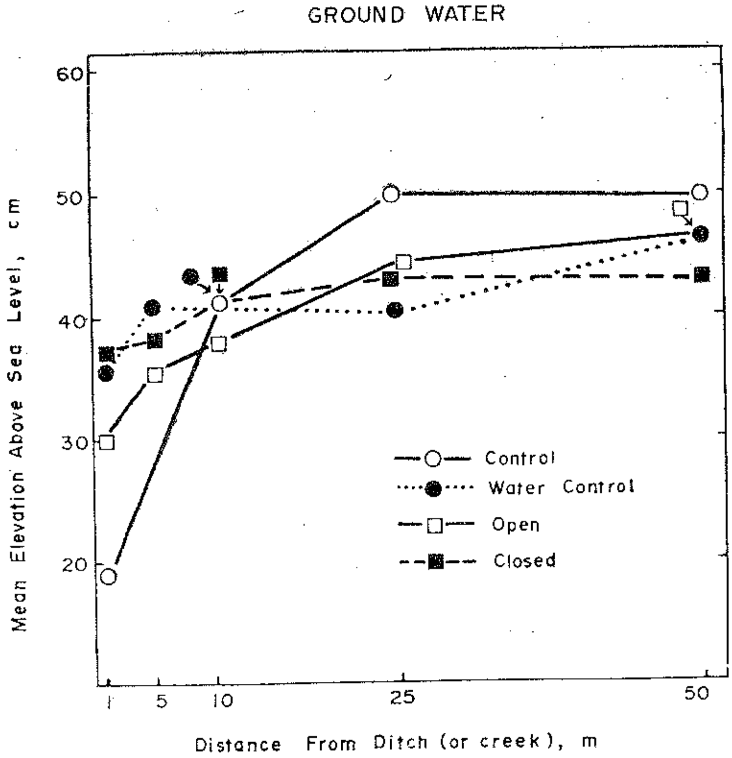
GROUND WATER

FIG. 10. Water well data for the three treated sites and the Control Site.

trends with the highest N and P concentrations occurring near the ditches where the water table is the lowest. These results would be expected if, as Mendelssohn (1979) has suggested, lower production rates on the high marsh are due to stresses associated with anaerobic conditions rather than lack of nutrients. Any drop in the water table could alter substrate conditions, perhaps by introducing oxygen, which would result in increased nutrient availability. Wiegert *et al.* (1980) have found that short form *Spartina alterniflora* wetlands in Georgia can be converted to tall-form plants as a result of modifying subsurface drainage by placing drain tile in the wetland. Preliminary data from the second growing season show that the elevated tissue N and P concentrations have persisted which suggests that the changes are not ephemeral. In addition, we are conducting fertilization studies during the second growing season and expanding our sampling to include N and P data for belowground materials as well as monitoring NO_3 and NH_3 in interstitial water.

There have been very few studies of the nutrient dynamics of irregularly flooded brackish wetlands in the Chesapeake Bay (Axelrad 1974, Blum 1969, Heinle and Flemer 1976, Stevenson *et al.* 1977, Correll 1978). It is still not clear whether they are sources or sinks for nutrients on an annual basis, but it is clear that one does not find the distinct seasonal import patterns found in other estuaries (Nixon 1981, In press). The modifications that were performed on the Deal Island wetlands apparently did not create any major changes in import-export dynamics. Nutrient concentrations were not elevated immediately after completion of the treatments and there appear to be no major quantitative differences between the Control Site and the Open Site except that the magnitude of the net fluxes have been greater at the Open Site where there has been a consistent pattern of net export for all materials being monitored. Export-import dynamics at the Control Site have been more variable.

As stated in the Introduction, only a small portion of the overall study is reported in this paper. Mosquito populations were effectively controlled during the first year and the 3 sites are being used by 15 species of fish. Stable fish population have become established in the sites with permanent standing water and fish freely move into and out of the Open Site.

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