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SEWAGE SPRAY IRRIGATION IN A DELAWARE RIVER FRESHWATER TIDAL MARSH

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INTRODUCTION

While it has been demonstrated that several types of ecosystems can efficiently assimilate domestic wastes, until recently most studies have centered on the application of effluent to terrestrial ecosystems (Kardos 1967, 1970, 1972; Sopper 1968, 1971, 1973; Sopper and Kardos 1972 and 1973). Others have examined the effects of domestic wastes on saltmarsh ecosystems (Campbell 1973; Copeland et al. 1972; Kuenzler 1971; Kuenzler and Chestnut 1971a and 1971b; Kuenzler et al. 1973; Marshall 1970; McMahan 1972; McMahan et al. 1972; Odum and Chestnut 1970; Valiela and Teal 1972; Valiela et al. 1973 and 1975) and at a recent symposium in Philadelphia (Tourbier and Pierson 1976), several authors presented papers on the effects of applying domestic wastes to freshwater marsh ecosystems. In a study of a freshwater tidal marsh, Grant and Patrick (1970) examined changes in the quality of water than passed through the polluted Tinicum Marshes near Philadelphia. Water flowing out of the marsh had lower phosphorus concentrations than did the waters which entered and oxygen levels increased as the water passed through the marsh. We have found similar responses in the Hamilton Marshes, a 500 ha freshwater tidal marsh adjacent to the Delaware River near Trenton, N.J. (Whigham and Simpson 1975 and 1976). Based on that earlier work we hypothesized that freshwater tidal marshes could be used for low cost tertiary treatment of domestic sewage effluent and that they might be able to process more effluent than freshwater ecosystems that are not influenced by the tide. In 1975 we began a

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series of experiments to determine the responses of the Hamilton Marshes to the application of chlorinated secondarily treated sewage effluent.

METHODS

Sixteen enclosures were constructed in a section of marsh located near the Hamilton Township Sewage Treatment Plant. The enclosures are three sided, 10m by 20m, with the open end of each facing a drainage channel to insure minimal interference with the movement of tidal water into and out of each enclosure while impeding the lateral movement of water to adjacent units. Effluent is pumped from the sewage treatment plant and sprinkled onto the marsh surface. A second pipe carries potable water to control enclosures. The automated sprinkler control system is coupled to the tide and effluent is applied in the following patterns:

1. Four enclosures receive effluent during a 9 hour period in each 12 hour tide cycle. During that 9 hour period there is no standing water on the marsh surface.
   a. Two receive a high dosage of effluent - 5 inches per day (in/day).
   b. Two receive a low dosage of effluent - 2 inches per day.
2. Effluent is applied continuously to four enclosures.
   a. Two receive a dosage of 5 inches per day.
   b. Two receive a dosage of 2 inches per day.
3. Four enclosures receive effluent when the incoming tidal water begins to flow over the marsh surface. The application covers a 3 hour period during each tide cycle.
   a. Two enclosures receive 5 inches per day.
   b. Two enclosures receive 2 inches per day.
4. The remaining four enclosures serve as controls.
   a. Two receive 5 inches per day of tap water.
   b. Two enclosures do not receive any water.

Three permanent $1m^2$ quadrats were established in each enclosure prior to the onset of the 1975 growing season. The quadrats were sampled for initial vascular plant species composition and checked throughout the growing season. Aboveground components of vascular plants were harvested monthly, 12 quadrats/treatment, for biomass determinations and for tissue analysis of nitrogen and phosphorus (Amer. Soc. Agronomy 1965). Decomposition rates and changes in nitrogen and phosphorus content of decaying litter are being measured for 2 dominant species, arrow arum (*Peltandra virginica*) and bur marigold (*Bidens laevis*), using litter bag techniques.

Monthly water samples are collected at high and low slack water in the enclosures and at 9 sites throughout the adjacent watershed. The samples are analyzed for ammonia plus amino acids, reactive nitrite, and reactive nitrate following the procedures of Strickland and Parson (1968), reactive phosphate following the methods of Murphy and Riley (1962), and total phosphorus using the procedures of Menzel and Corwin (1965). The samples are also analyzed for carbon dioxide, oxygen, and alkalinity following A.P.H.A. (1971) techniques. pH is determined electrometrically.

Duplicate soil cores are collected from each enclosure on a monthly basis and analyzed for nitrate and ammonia nitrogen (Stanford et al. 1973) and total phosphorus (Amer. Soc. Agronomy 1965).

RESULTS

It is still to early to assess long range responses of the vascular plants but there were noticable changes during the first year of effluent application. Populations of most perennials along with wild rice (*Zizania aquatica* var *aquatica*) and waterhemp (*Acnida cannabina*) were apparently not affected but two dominant annuals were sensitive to the chlorinated effluent (Table 1). Touch-me-not (*Impatiens capensis*) was eliminated from all enclosures that received effluent. Bur marigold (*Bidens laevis*) populations were also affected but that species appears to be differentially affected depending on the length of contact with the spray. It was almost completely eliminated from the continuous spray enclosures and minimally affected in areas exposed to two 3-hour spray periods (Table 1). A third annual, halberd tearthumb (*Polygonum arifolium*) increased in importance in all of the noncontrol enclosures. Another impact of spraying was a general depression in the height of the upper canopy. In Delaware River tidal marshes that have been studied (Good and Good 1975; McCormick 1970; McCormick and Ashbaugh 1972) plant height was normally 3-4m late in the growing season. In our enclosures the vegetation averaged 1-2m and the canopy in the tap water control enclosures was less than in the other control areas.

Patterns of aboveground biomass accumulation are shown in Figures

1-3. Except for the August sampling, there were no significant seasonal differences between the two controls. There was, however, less biomass in several enclosures, especially in the continuously sprayed areas that received 5 in/day (Figure 1). For most of the growing season there was less aboveground vegetation in the other continuously sprayed enclosures but the biomass, which increased to 760 g/m^2 by September, was comparable to the tap water control enclosures by the end of the growing season (Figure 1). A similar pattern was observed in enclosures that received effluent distributed over two 9-hour spray periods (Figure 2). In September biomass was 480 g/m^2 in the 5 in/day enclosures and 990 g/m^2 in the 2 in/day areas. The pattern seen in the continuous and 9-hour spray enclosures was reversed in areas that received effluent during two 3-hour spray periods (Figure 3). By September biomass in the 5 in/day enclosures was similar to the tap water control but was less (490 g/m^2) in the 2 in/day sites. The decrease in biomass, especially noticable in August, is due to the normal pattern of biomass accumulation that we have previously documented for vegetation of typical high marsh sites (Whigham and Simpson 1975). Perennials, primarily arrow arum (Peltandra virginica) and sweet flag (Acorus calamus), dominate the marsh early in the growing season. Annuals overtop the perennials by mid-July and then dominated the marsh for the remainder of the growing season. With the exception of areas dominated by cattail (Typha latifolia), the aboveground biomass of perennials decreases in mid-July. Most noticable is the dieback of arrow arum, sweet flag, and spatterdock (Nuphar advena). The perennials, therefore, account for most of the early growing season aboveground biomass while annuals contribute most of the aboveground biomass in August and September. Figure 4 shows biomass data separated into annual and perennial components for one of the experimental enclosures. Perennials accounted for most of the biomass in the June and July samples and, as expected, the perennials began to dieback in July. The decrease in August and September biomass was due to the decline of the perennials and to the partial elimination of bur marigold and the complete elimination of touch-me-not. Halberd tearthumb accounted for most of the annual biomass collected in the August and September samples.

Determinations of nitrogen and phosphorus levels in plant tissues have not been completed but preliminary data show that the nitrogen content has increased slightly in all species with halberd tearthumb having increased more than any other species (Table 2). Similarly, litter decomposition studies have not been completed but preliminary data show that initial decomposition rates were greater in areas receiving sewage effluent (Figure 5).

Representative stream water quality data are presented for nine sites within the watershed that contains the enclosures (Figure 6). The data are for high slack water (hsw) and low slack water (lsw) on three dates during the summer and early fall of 1975.

Dissolved oxygen levels followed expected seasonal patterns and were consistently higher at hsw than at lsw, with downstream sites 11, 12 and 12A typically having 1-3 mg/L more oxygen than upstream sites near the effluent study area. Differences between hsw and lsw oxygen levels were 2-3 mg/L during the summer, but increased to over 8 mg/L in the early fall when the vascular plants were rapidly decomposing. Like dissolved oxygen, nitrate nitrogen levels were consistently higher at hsw than at lsw during the summer with especially dramatic differences appearing at site 12A which drains a marsh region completely isolated from the effluent study site. The picture for October is more mixed with sites 13, 14A and 14B - the latter draining directly from the effluent study area - having more nitrate nitrogen at lsw than at hsw. Ammonia (plus amino acid) nitrogen levels were always low except at sites 13, 14A and 14B where levels in excess of 200 ug·at/L were encountered.

For the same 3 sample dates, water quality data for the experimental enclosures are shown in Figure 7. At hsw the marsh is typically covered with 10-30 cm of water while at lsw the surface is completely drained except for isolated pockets of water. Hsw dissolved oxygen levels followed the same seasonal patterns found for the stream waters of the marsh but were always 2-4 mg/L lower than oxygen levels at site 14 in the stream channel immediately downstream from the study site. In October two hsw values approached zero because the flood tide was extremely low and water did not cover the surface within the enclosures. Lsw surface dissolved oxygen levels ranged from undetectable to 0.3 mg/L. Carbon dioxide levels at hsw were generally less than 20 mg/L and almost always lower than at lsw. The most dramatic differences between hsw and lsw appeared in the enclosures that received effluent when the marsh surface was flooded but no effluent when the tide was off the marsh. In these enclosures, summer carbon dioxide levels in excess of 60 mg/L were recorded at lsw. Little variation in carbon dioxide was found between the hsw and lsw for the tap water controls in August and October. Hsw nitrate nitrogen levels in the enclosures were 20-40 ug·at/L higher than adjacent site 14 levels during the summer. In the enclosures receiving effluent only when the marsh surface was flooded, nitrate nitrogen was undetectable at lsw. Hsw nitrate nitrogen was usually found in the enclosures receiving effluent when the water was drained, but generally levels were substantially lower than hsw values. A notable exception occurred in October for two enclosures receiving 5 inches of effluent per day where lsw nitrate nitrogen levels were exceedingly high, being almost double the hsw levels. Ammonia nitrogen levels on all dates were consistently higher at lsw than at hsw in all enclosures except the two controls where the pattern was reversed. On all dates lsw ammonia nitrogen values in the control bins were from five to ten times lower than in enclosures receiving effluent. Reactive phosphate levels generally showed patterns similar to ammonia nitrogen although the magnitude of difference between hsw and lsw levels was substantially less.

To elucidate the marked differences in water quality between hsw and lsw, time course studies have been started in the experimental enclosures. Changes during one complete tide cycle for two marsh sites beginning with hsw are shown in Figure 8. Dissolved oxygen levels remained relatively constant for the first two hours while the marsh surface was flooded, but as the marsh drained, dissolved oxygen levels began a steady decline with less than 1 mg/L of oxygen being present just before the next flood tide brought water back over the marsh surface. As would be expected, carbon dioxide showed the opposite pattern during the tide cycle. Nitrate nitrogen levels followed a pattern similar to dissolved oxygen, but with a much more dramatic drop to trace levels as the marsh surface drained. Until the next flood tide inundated the marsh, nitrate nitrogen levels remained at this very low level. Reactive phosphate showed the reverse of the nitrate nitrogen pattern with levels being 5-8 ug·at/L when the marsh was flooded and rising quickly to 15-25 ug·at/L as the marsh drained.

DISCUSSION

We are using relatively high application rates of chlorinated effluent and it is obvious that there will be changes in the vascular plant species composition. As we begin the second spray season, it appears that the perennials have not been affected by the chlorine and that the clones of several species including sweet flag, cattail, rice cut grass (Leerisa oryzoides) and arrow arum have increased in aerial extent. We expect that some annuals, particularly touch-me-not and bur marigold, will decline in importance while others, especially halberd tearthumb, will increase in importance. It appears, however, that annual species composition can, in part, be regulated by controlling the spray regimes.

During the summer months nutrient concentrations tended to be lower in the drainage channels (Figure 6). This pattern is more variable in the fall, especially for nitrate nitrogen. Of special interest is the fact that site 14B (see Figure 6) which receives water almost exclusively from the experimental enclosures had higher nitrate levels at lsw than at hsw in October, corresponding to the time of maximum decomposition of vascular plants. While this data are far from complete at this time, it would appear that the vascular plants act as sinks for nutrients during the summer months and that the nutrients are released during the fall and winter. In the enclosures receiving effluent, data from litter bag studies (Figure 5) suggest that most of the nutrients are released within a month after the end of the growing season.

It is, as yet, too early to assess the ultimate fate of the nutrients being added in the effluent.

One obvious effect of the spraying, associated with the decrease in biomass and abundance of certain annuals, was a noticable increase in the amount and coverage of epibenthic algae over what we have previously found for similar habitats (Whigham and Simpson 1975,1976). We hypothesize that the increased algal growth was caused by increased availability of nutrients and by increased incident solar radiation at the marsh surface due to the decline of annuals and the general lowering of the canopy. This summer we will initiate experiments to determine what effects the spraying has on the distribution, abundance, biomass, and production of the algal community.

ACKNOWLEDGEMENTS

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Table 1. Frequency of touch-me-not (*Impatiens capensis*), halberd tearthumb (*Polygonum arifolium*), and bur marigold (*Bidens laevis*). N = 12. For each entry, the first value is the frequency prior to the onset of spray irrigation and the second value is the frequency of occurrence in September.

Treatment Enclosures	Touch-me-not	Halberd tearthumb	Bur marigold
3 hr. - 2 in.	83/33	16/100	100/58
3 hr. - 5 in.	83/8	33/92	100/67
9 hr. - 2 in.	50/0	16/100	100/50
9 hr. - 5 in.	50/0	33/75	100/75
continuous - 2 in.	83/0	33/92	100/33
continuous - 5 in.	50/0	16/92	100/33
water control continuous - 5 in.	83/75	16/92	100/75
control - no spray	100/58	50/100	83/92

Table 2. Nitrogen content of marsh vegetation. Each value is the mean ± 1 standard error. N is given in parenthesis.

Species	1974	1975 - spray area
Bidens laevis	2.22 ± .28 (10)	2.40 ± .29 (18)
Impatiens capensis	2.08 ± .40 (4)	2.33 ± .38 (9)
Sagittaria latifolia	1.91 ± .34 (6)	2.42 ± .39 (8)
Polygonum arifolium	1.93 ± .43 (4)	2.42 ± .40 (7)
Peltandra virginica	2.15 ± .27 (8)	2.54 ± .25 (16)
Acorus calamus	2.06 ± .32 (12)	2.50 ± .33 (8)
Nuphar advena	2.13 ± .28 (9)	
Pontederia cordata	2.11 ± .41 (4)	
Typha latifolia	2.01 ± .30 (7)	
Zizania aquatica	2.12 ± .32 (6)	

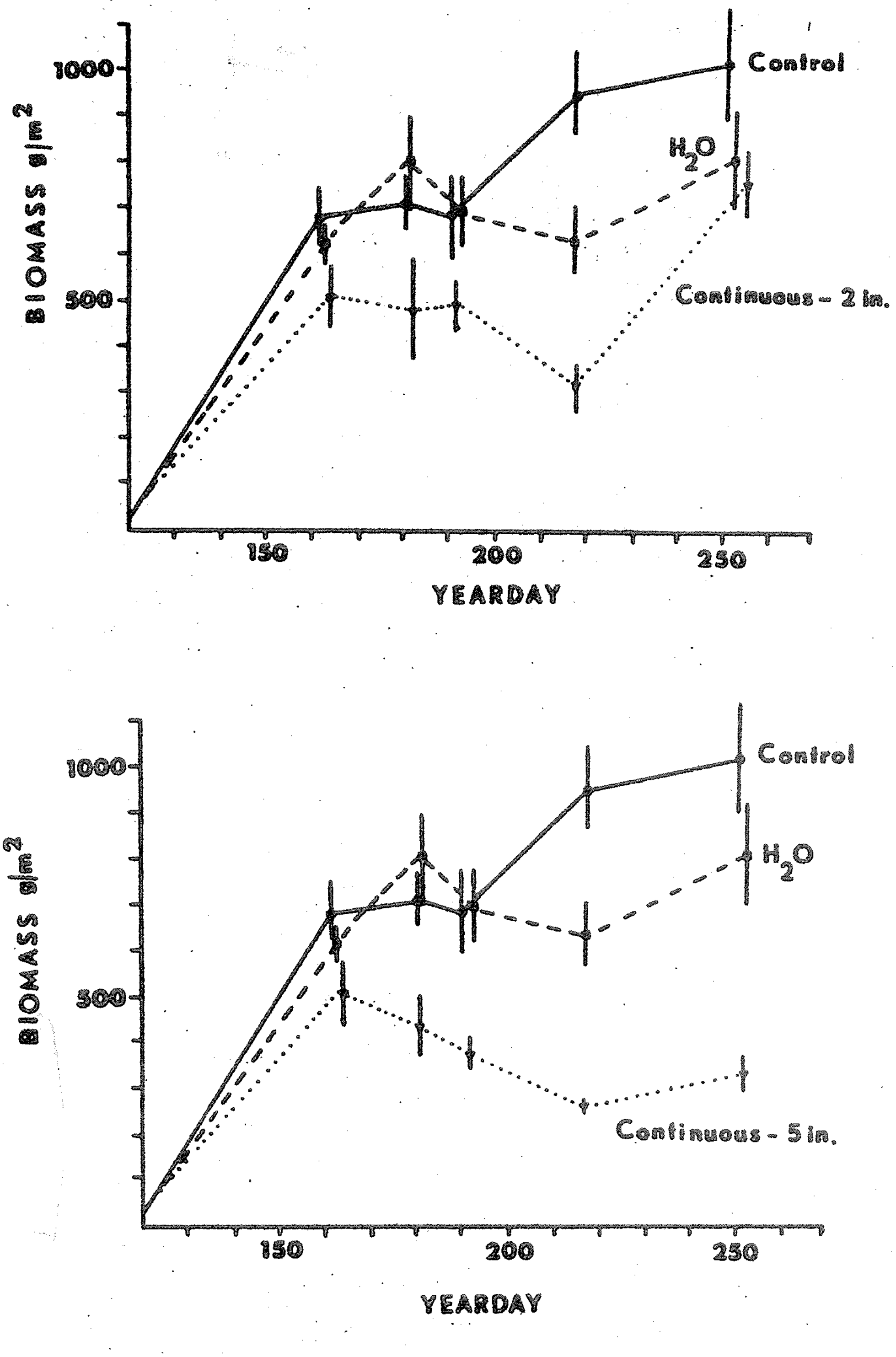


Figure 1. Aboveground biomass in the control sites and enclosures continuously receiving effluent applied at the rates of 2 and 5 inches per day. One control (CONTROL) receives no water and the other control (H_2O) is continuously sprayed with 5 inches of tap water per day. All values are means of 12 quadrats ± 1 standard error.

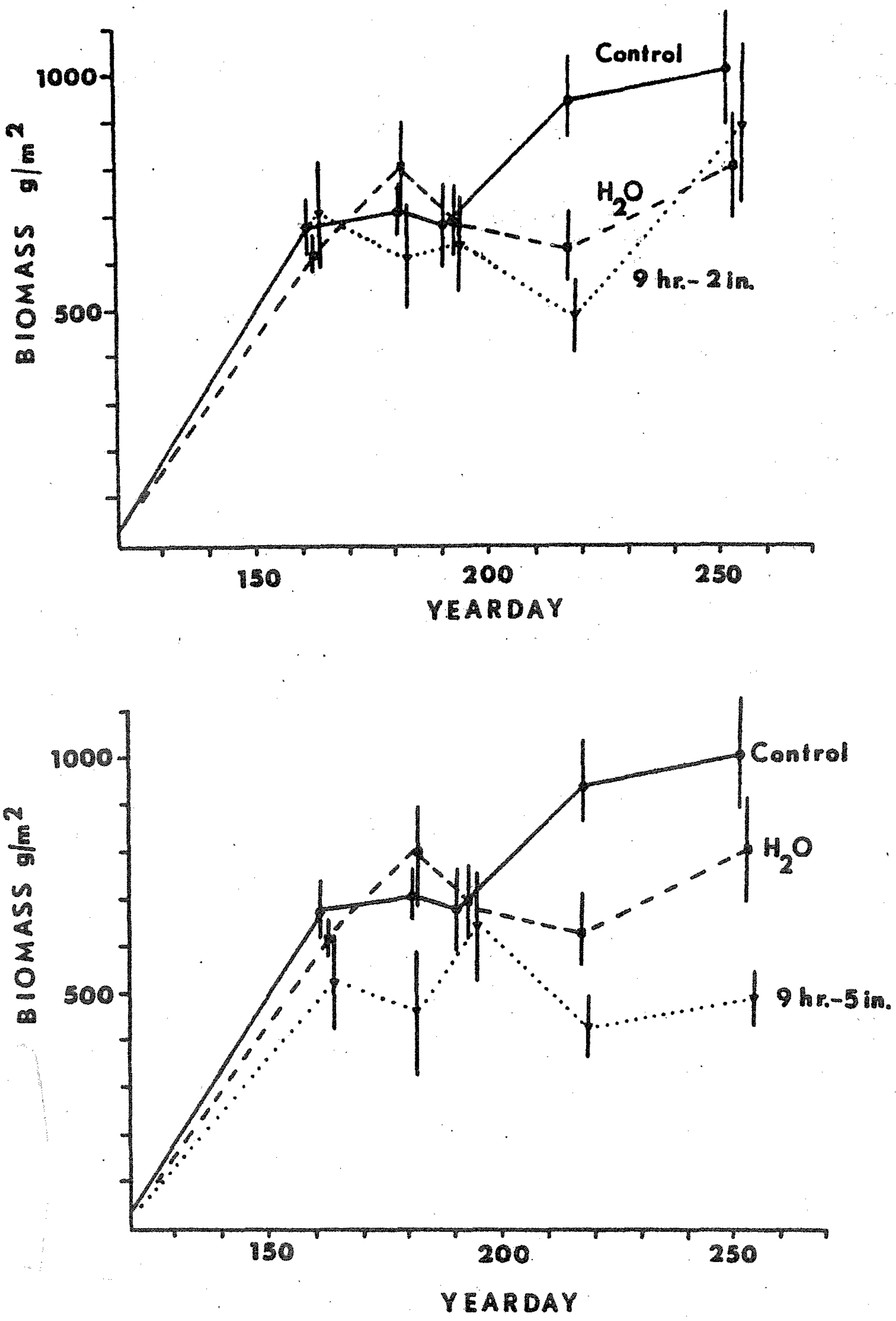


Figure 2. Aboveground biomass in the control sites and enclosures sprayed daily with 2 and 5 inches of effluent during two 9-hour spray periods. One control (CONTROL) receives no water and the other control (H_2O) is continuously sprayed with 5 inches of tap water per day. All values are means of 12 quadrats $\pm$ 1 standard error.

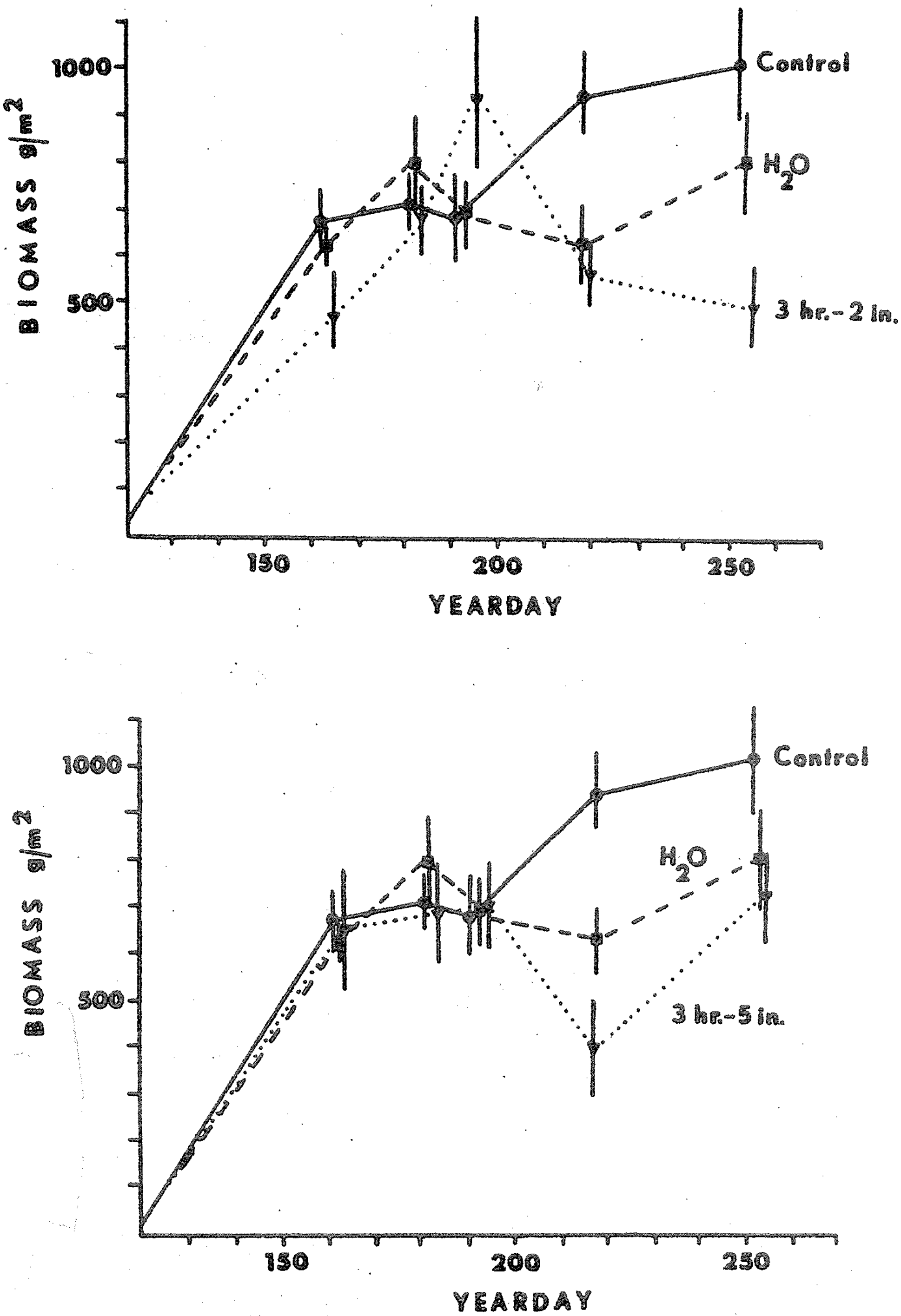


Figure 3. Aboveground biomass in the control sites and enclosures sprayed daily with 2 and 5 inches of effluent during two 3-hour spray periods. One control (CONTROL) receives no water and the other control (H_2O) is continuously sprayed with 5 inches of tap water per day. All values are means of 12 quadrats $\pm$ 1 standard error.

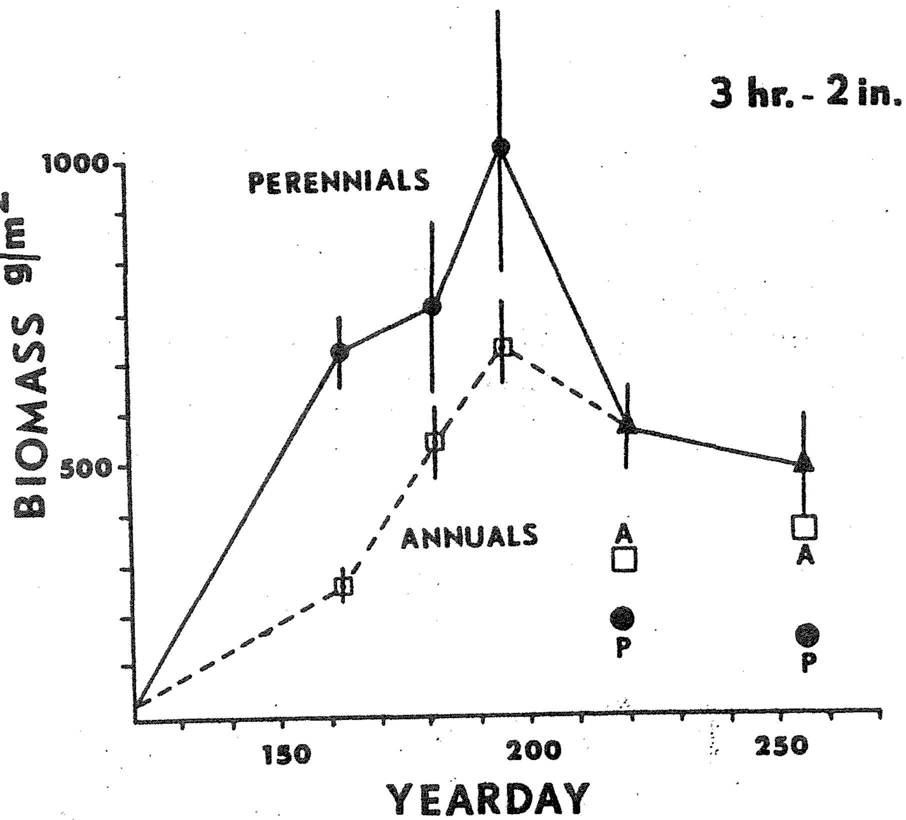


Figure 4. Aboveground biomass data for enclosures receiving 2 inches of effluent daily during two 3-hour periods. The data have been separated into perennials (P) and annuals (A) and also combined for the August and September samples. Values for the first 3 sample periods are means of 6 quadrats ± 1 standard error. August and September combined data are means of 12 quadrats ± 1 standard error.

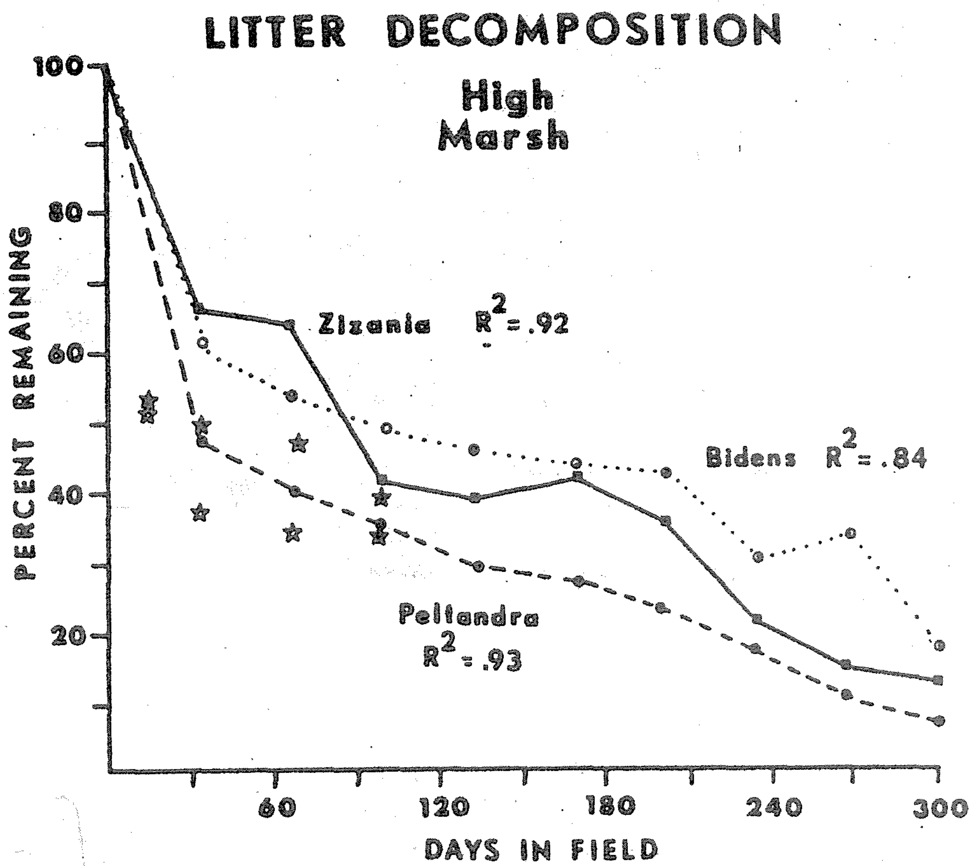


Figure 5. 1974-75 litter decomposition patterns of 3 marsh plants: wild rice (Zizania aquatica var. aquatica), bur marigold (Bidens laevis), and arrow arum (Peltandra virginica). All values are means of duplicate samples. Preliminary data for arrow arum from control enclosures (solid stars) and areas receiving effluent (open stars) are also given.

Figure 6. Dissolved oxygen, nitrate nitrogen, and ammonia (plus amino acid) nitrogen in the effluent study watershed at high slack water (solid bars) and low slack water (open bars) for three sampling dates in 1975.

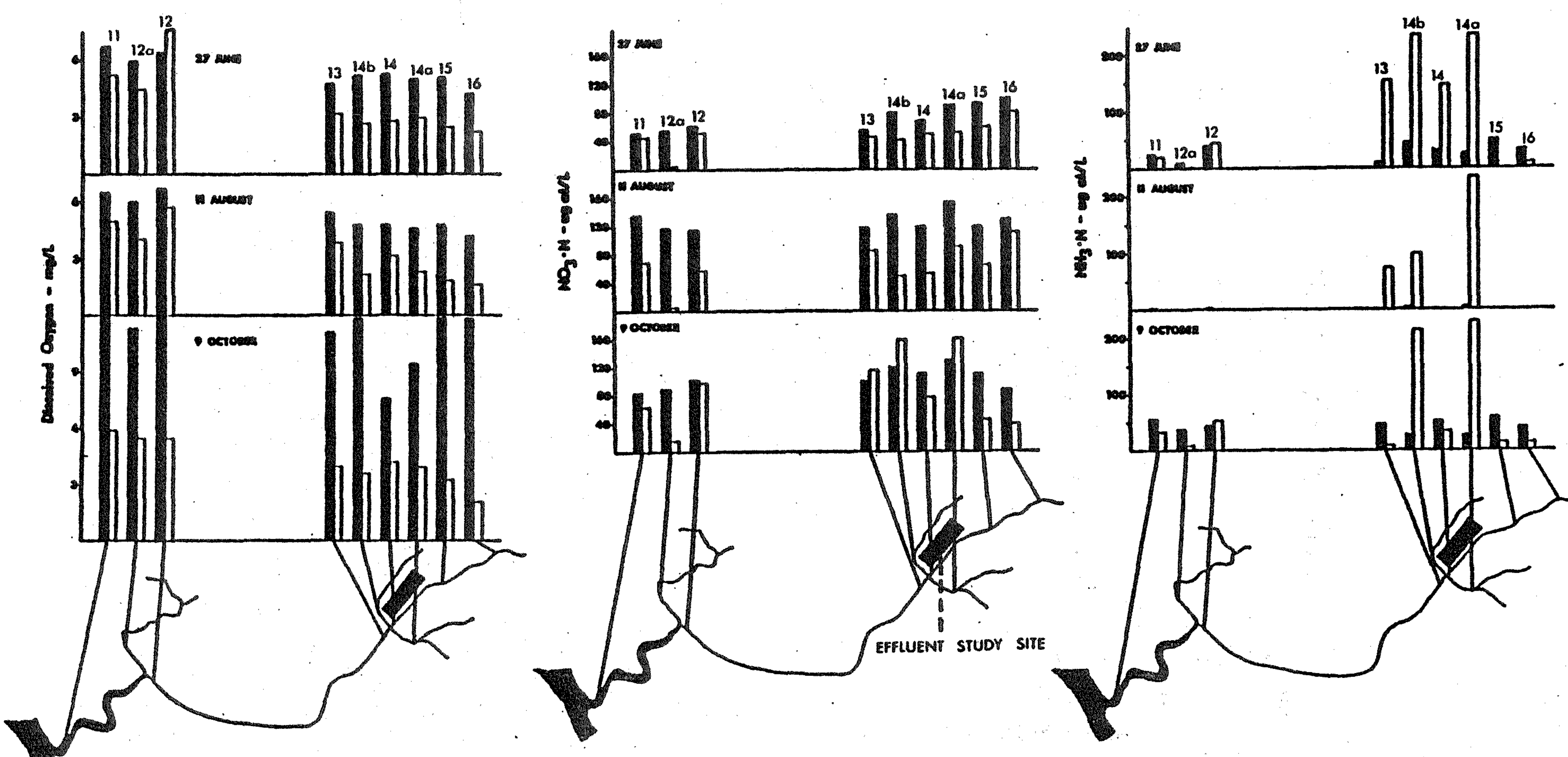
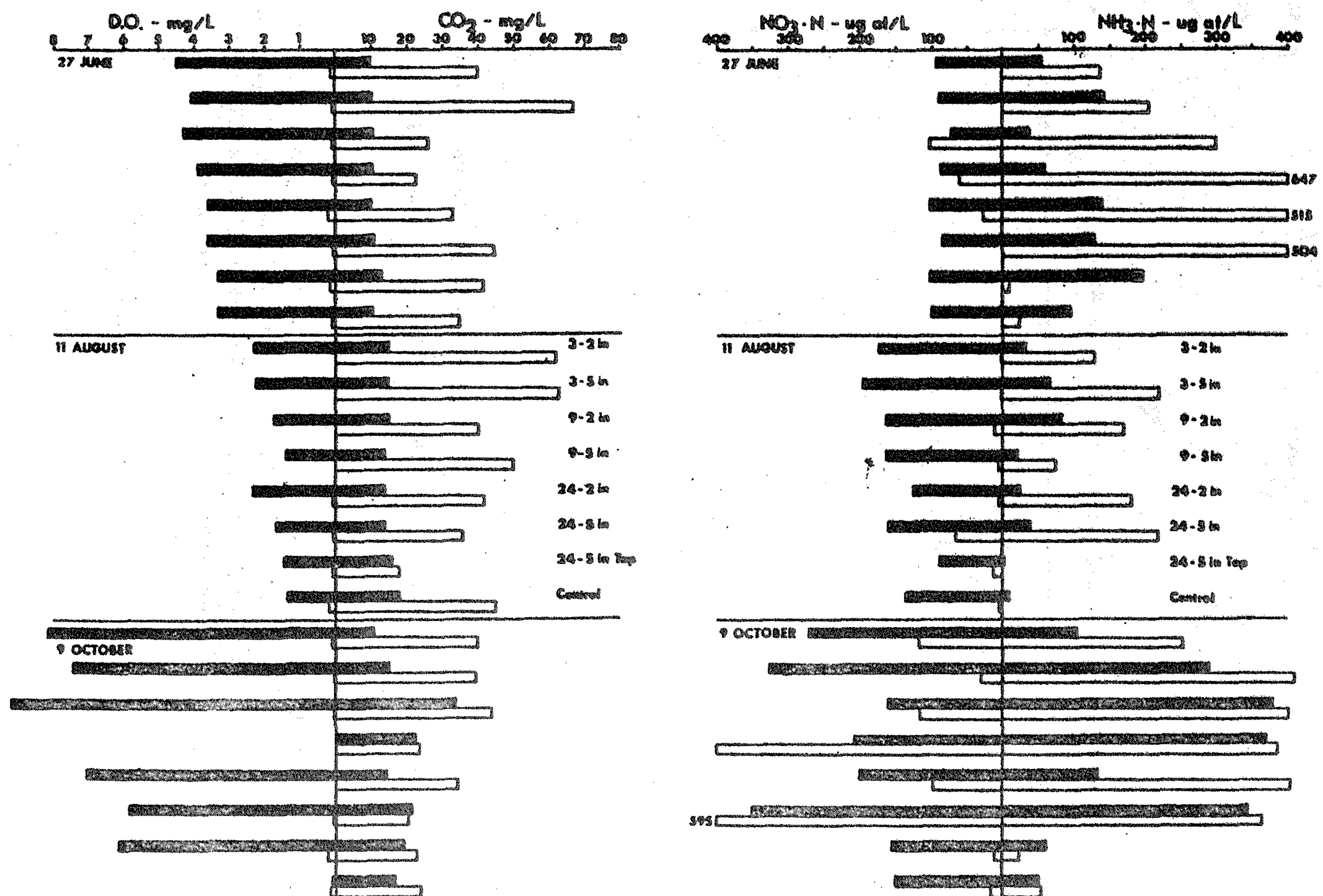


Figure 7. Dissolved oxygen, carbon dioxide, nitrate nitrogen, and ammonia (plus amino acids) nitrogen in the experimental enclosures at high slack water (solid bars) and low slack water (open bars) for three sample dates during 1975. The sequence of enclosures is the same for all diagrams and is presented with the 11 August sampling date. The first number represents hours of application per tide cycle (upper 4 enclosures) or per day (lower 4 enclosures) and the second number represents the daily rate of application.



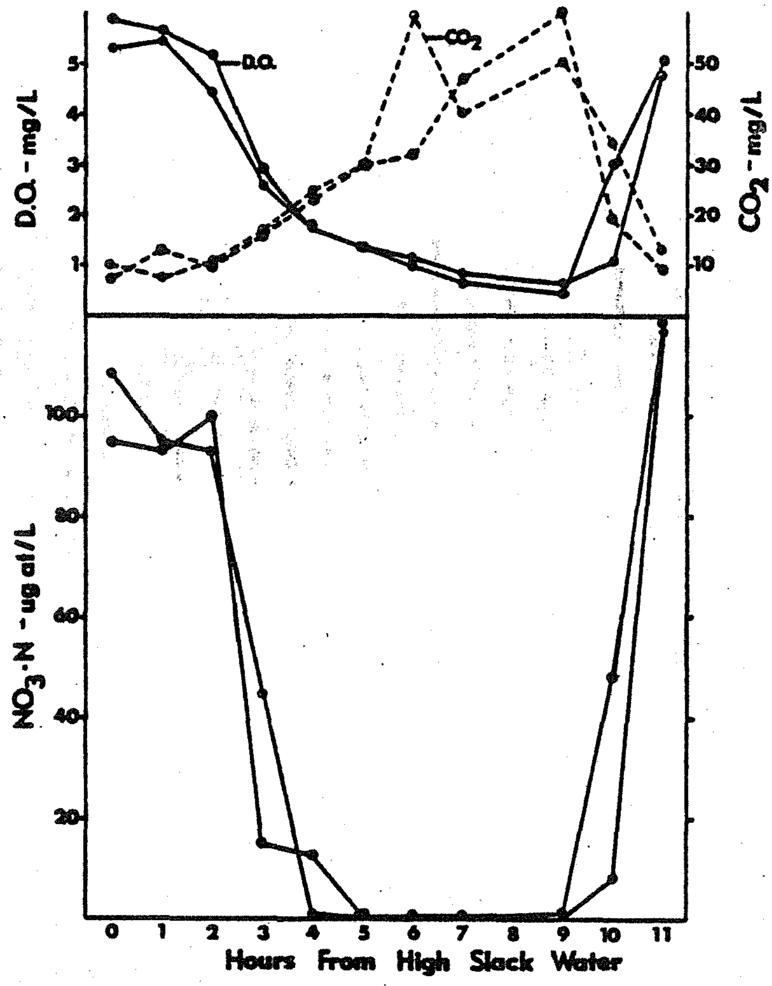


Figure 8. The changes in dissolved oxygen, carbon dioxide, and nitrate nitrogen during one complete tide cycle beginning with high slack water for two marsh sites.