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PRELIMINARY IDENTIFICATION, ANALYSIS, AND CLASSIFICATION OF ODOR-CAUSING MECHANISMS INFLUENCED BY DECREASING SALINITY OF THE GREAT SALT LAKE

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INTRODUCTION

The rising level of the Great Salt Lake has received a great deal of attention because of the resulting physical damage to adjoining properties, threatened disruption of major transportation facilities, and environmental damage to feeding and resting areas for migratory waterfowl. Another problem of growing concern is that some zones of the lake are producing odors that are objectionable to nearby populated areas. These odors are most offensive during the warm summer months and appear to be increasing with the rising levels and decreasing salinity of the lake water.

This report presents the approach taken and the findings of a short-term investigation completed by the Utah Water Research Laboratory to determine the sources and mechanisms causing the odor. At the outset of the study, it was hypothesized that the odors come from one or more of the following sources: 1) bottom sediments which contain municipal and agricultural sewage residues and industrial wastes; 2) decay of algal blooms and the organic material produced by the algae; 3) decaying vegetative matter on land areas that have only recently been inundated by the rising water of the lake; and 4) decaying pupae cases of brine flies. The first three of these were investigated briefly in the laboratory using lake water and sediment samples. Information on brine flies was derived from the literature from numerous studies that have been made during recent years.

BACKGROUND

Sewage and Sediment

At one time virtually the entire Farmington Bay (Figure 1) was a dense brine, but the Antelope Island causeway has radically changed that by preventing the mixing of highly saline water in the lake with freshwater from tributary streams. Currently the salinity varies from "fresh water" conditions at the stream entrances to those approaching ocean water adjacent to the causeway, and a dense brine wedge underlies the less saline surface water throughout much of the bay (Coburn and Eckhoff 1972). Recent significant rises of the lake level have further complicated the situation by completely inundating the Antelope Island causeway, as well as many of the dikes in the Farmington Bay waterfowl management area, and further freshening the water. Concern was expressed by Coburn and Eckhoff (1972) that the man-made conditions in the bay might lead to extremely undesirable consequences. A host of organisms, which could not have survived in the Great Salt Lake at the time of their study, had invaded the bay. It was Coburn and Eckhoff's (1972) contention that continued disregard for the ultimate water quality of Farmington Bay might lead to the development of a tremendously large mismanaged waste lagoon, upwind from metropolitan Salt Lake City. Since sulfate levels were high in all incoming streams, they concluded that should extensive anaerobic conditions develop in any of the streams due to low flows or sedimentation, or should extensive anaerobic conditions develop in the bay, the potential for odor problems inherent in the anaerobic reduction of sulfate was high.

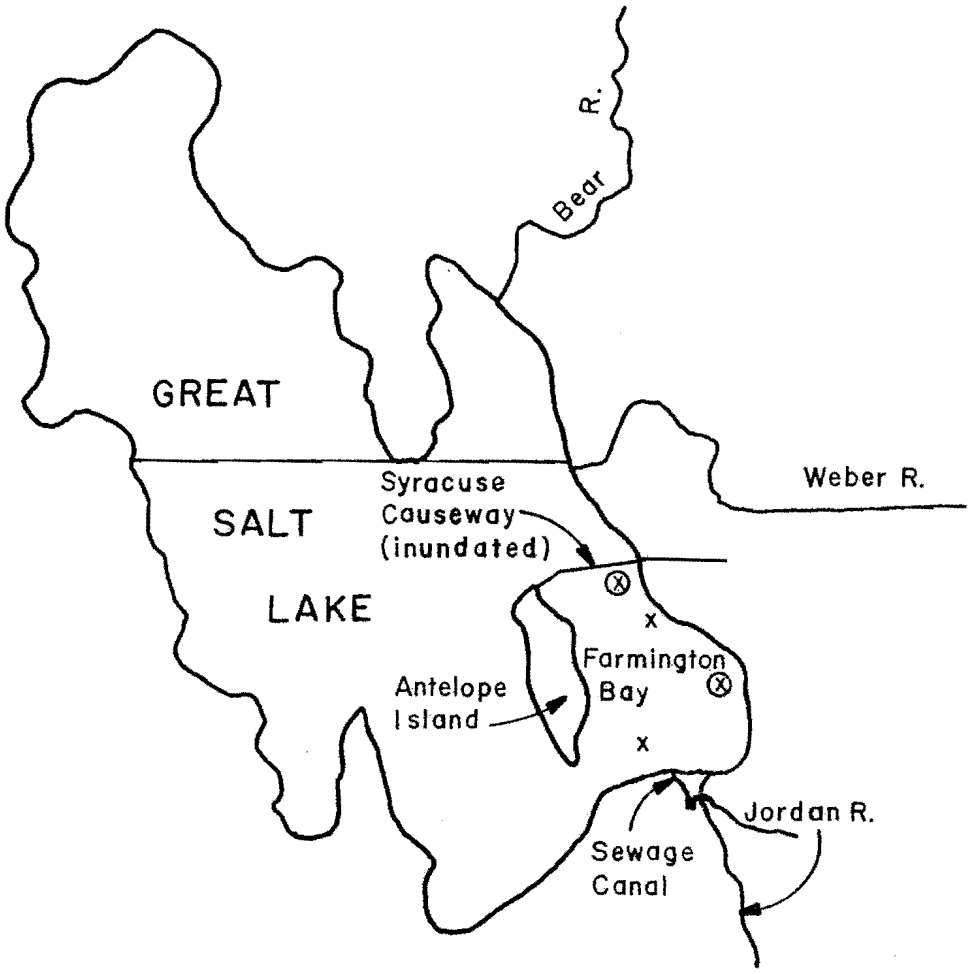

Figure 1. Farmington Bay study area of the Great Salt Lake.

Noticeable amounts of hydrogen sulfide (H_2S) gas are apparent and were found on the surface of the Farmington Bay in previous studies. Carter et al. (1971) collected 6 foot (1.8 m) sediment cores from Farmington Bay when its maximum depth was 12 feet (3.7 m) and the lake water level was at 4198.5 feet (1280 m) above sea level. With the lake at that level, more than 50 percent of the bay was under less than 5 feet (1.5 m) of water. Most of the sediment samples were taken from cores collected in the north end of the bay, and determinations of pH, conductivity, and particle size analyses were made on each sample. Volatile solids determinations were made on 24 of the samples, and bacteria cultures were prepared on 12 samples. Every sample tested showed some level of organics, the highest being 37 percent. In the surficial sediments these organics were decaying in the freshening water. Sediments also harbored coliform bacteria. In lower horizons the organics underwent an anaerobic fermentation, producing methane and hydrogen sulfide.

For many years the liquid refuse of Salt Lake City, industrial wastes of various kinds, and irrigation return flows from farms were dumped into the Farmington Bay. Also for a long period the entire liquid sewage refuse of the Wasatch Front towns and cities from Layton on the north to the towns of the southern Utah Valley, where collection systems existed, was deposited untreated in the bay. This practice has resulted in a sewage delta of rather large proportions in a very localized area (Van der Meide and Nicholes 1972). In their study, Van der Meide and Nicholes (1972) indicated also that the greatest number of coliforms found in the bay were in the area nearest the mouth of the Salt Lake sewage canal, and the greatest concentration was in bottom sludge. They also conducted

studies of the inhibitory effect of various concentrations of Great Salt Lake water on coliform organisms isolated from the bay. When 6 percent bay water was used to make the medium, lactose fermentation by the coliforms was completely inhibited and growth was inhibited in a large percentage of the tubes. They proposed that the accumulated raw sewage deposits sequester gastrointestinal bacteria and viruses; that the organic matter of the accumulated deposit will support the growth of these bacteria, and that these microorganisms may seed the waters of the bay for several years to come, contributing to possible health hazards and detracting from the aesthetic quality of the area.

McDonald and Garifin (1965) studied the effects of pollution on the Great Salt Lake and reported that while for the lake as a whole areas of less salt concentration usually showed greater numbers and variety of organisms, an exception existed in the East Bay area near the outlet of the Salt Lake sewage canal. Contrary to the situation found in many freshwater environments, where addition of organic pollutants results in an increased biomass, the East Bay area was a virtual biological desert, a habitat unsuitable for either the biota of the lake or for species normally found in undiluted sewage. They did not conduct any studies to determine the cause of this phenomenon.

Great Salt Lake Brine

The first comprehensive study of Great Salt Lake brines was completed by Hahl and Handy (1969) who reported the chemical and physical variations of the lake brines for the period 1963-1966. They pointed out that the concentration of dissolved solids in the Great Salt Lake brine varied from place to place and with depth. Inflow, evaporation, currents, wind, and

density differences resulted in brine stratification in the deep parts and brine concentration in the shallow isolated parts of the lake. Completion of the railroad causeway by the Southern Pacific Co. in 1957 divided the lake and altered the movement of brine. The southern two-thirds of the lake receives over 90 percent of the surface inflow and since 1957 has rarely reached salt saturation.

The shallow zone of brine in the southern part of the lake varies in concentration of dissolved solids from season to season because of the interplay between inflow and evaporation, and brine in this zone is usually the most dilute of any brine in the lake (Hahl and Handy 1969).

Whelan and Petersen (1973) examined the chemical and physical variations of Great Salt Lake brines, and determined that south arm brines were continuing to freshen. Whelan and Petersen (1977) determined from available data of dissolved gases of the Great Salt Lake that south arm deep brines contained 16 to 25 ppm hydrogen sulfide.

Studies performed by students at the University of Utah (1971) determined that, since the construction of the Syracuse-Antelope Island causeway, the rate of exchange and mixing of salt water from the Great Salt Lake with fresh water entering Farmington Bay east of the island had decreased.

Carter et al. (1971) found that the bay had a stream cut channel running along the eastern shore of Antelope Island, flanked on each side by mud flats which were seasonally inundated and intermittently exposed. A logical and very consistent current pattern existed in the bay, east of Antelope Island. The denser brine flowed south under the causeway bridge to a point about 3000 feet (910 m) south of the causeway where it became the dominant layer and carried the upper south brine layer south with it.

This occurred generally on the west side of the channel. The northward-moving water was driven by the freshwater inflow in the southeastern corner of the bay and flowed mainly on the east side of the channel. In general, the northward moving currents consisted of less dense brines in shallower areas of the bay.

Studies conducted on Farmington Bay by Bott and Shipman (1971) determined that it was an area showing great variance in salinity, both vertically and horizontally, ranging from a low of 0.5 percent to a high of 12 percent. The temperature of the bay was also shown to vary almost daily as a function of air temperature.

Algae and Bacteria

The northern arm of Great Salt Lake supports a very simple ecosystem consisting basically of the alga, Dunaliella salina Teodoresco, several protozoa and bacteria. The less saline south arm supports two basic biotic systems: a plankton system consisting of the alga Dunaliella viridis Teodoresco, brine shrimp Artemia salina (L.), and several protozoa and bacteria; and a benthic sequence consisting of the blue-green alga Coccochloris elebans Drout and Daily, detritis, and the brine flies Ephydra spp. The two systems are linked in that brine fly larvae will feed on detritis consisting of dead Dunaliella and Artemia, and Artemia will feed on the blue-green alga and shrimp fecal pellets when Dunaliella populations decline (Stephens and Gillespie 1972).

Porcella and Holman (1972) determined from algal bioassays that inorganic nitrogen is apparently the limiting factor for growth in samples of Great Salt Lake water. Carbon may also have been limiting. Phosphorus, iron, and other trace elements seemed to be in abundant supply.

Porcella and Holman (1972) fed brine shrimp several concentrations of Dunaliella sp. as well as yeast cells and found that their growth and reproduction when fed only algae were superior to that when fed yeast alone. Production of algae and brine shrimp in lake enclosures may be increased by the addition of specific nutrients. Stube et al. (1976) determined from lake and microcosm studies that algae and bacteria appeared to depend on each other for nutrients. The bacteria appeared to use organic matter produced by the algae and the algae used ammonia produced by the bacteria and possibly the brine shrimp. They determined also from aquarium studies that the potential for biomass production of algae and bacteria in the north arm of Great Salt Lake was much higher than that actually observed. Consequently, they postulated two additional factors as controlling population: 1) the grazing of algae by the invertebrates with the excretion of compounds rich in nitrogen, and 2) the reduction of bacterial metabolic activity by winter cold.

Bott and Shipman (1971) concluded that the limiting factors to algal growth in Farmington Bay were the concentration of phosphate in the water and the high salinity. They noted in comparing the algae growth and the phosphate levels in a longitudinal cross section of the bay, that a lag existed between the maximum nutrient load where the sewage effluent was dumped into the bay and the maximum algal concentrations as measured by algal counts. They suggested that some sewage breakdown must take place before the nutrients were available to stimulate the algae blooms. They also found a definite positive correlation between algae growth and dissolved oxygen level, principally because the oxygen is a product of photosynthesis.

Schulze (1971) found that the number of protozoans and the number of protozoan species in Farmington Bay increases as the water freshens. Hayes (1971) determined that populations and species diversity of phytoplankton and zooplankton also increased as salinity in the bay decreased.

Brine Flies

Reports written by Fremont (1845) and Stansbury (1852) indicated great numbers of brine flies at the Great Salt Lake even in their time. Jorgensen (1956) reported that 69 species representing 24 genera of the brine fly family Ephydridae occur in Utah, but only two of these are produced in the Great Salt Lake, Ephydra cinerea Jones which is the smallest and most abundant, and Ephydra hians Say. Winget, Rees, and Collett (1969) reported finding adults of both species in great numbers on the surface of the water and along the shores of the lake. They appeared to be widely distributed in the lake but more concentrated in certain areas, and weather conditions seemed to have some effect on their distribution. They first appeared in April and continued until late September, with a population peak during July and August.

Jorgensen (1969), quoting John Silver of Silver Sands Beach, stated that brine flies seemed to come in cycles due to the rise and fall of the lake. In Mr. Silver's opinion the wind blew the flies from the lake onto the beaches, or they developed on the lake and drifted in seeking fresh water. It was his opinion that the fly was definitely the cause of the beach odor.

The tremendous number of brine flies produced in Great Salt Lake was attributed to a simple ecological law: abundance of food consisting basically of a few species but great numbers of algae and bacteria,

competition of a limited number of species (one brine shrimp and two brine flies), reproduction unhindered by competition from other animals competing for food or living space, and few natural enemies (Wirth 1970).

Winget, Rees, and Collett (1970) stated that the brine fly larvae were responsible for consuming vast quantities of algae and decaying organic matter in the lake. The pupae and adult flies are a very important part of the overall food chain of many animals associated with Great Salt Lake, including birds, rodents, lizards, snakes, and many species of insects and other anthropods. It is impossible to comprehend the long-range effects that eradication or wide-spread reduction in the numbers of brine flies would have on the ecology of the lake. Winget et al. (1969) expressed that "without the removal of algae and other organic matter by the brine fly larvae the Great Salt Lake would resemble a bowl of split pea soup."

Numerous attempts have been made to control the flies. Nabrotsky, Rosay, and Sadler (1973) applied chemicals to a shoreline area and reported that the proportions of young flies in the treated and untreated groups were about the same. Apparently, with or without chemical control, the influx of new flies was fairly constant at any location along the shoreline from a large population on the lake as the primary source of adults.

Hansen (1969) gave the following account related to him by Mr. John Silver, proprietor of Silver Sands Beach:

> The millions of flies we kill daily create a thick and heavy layered mass of rotting brine flies which runs like a wide black band along the water's edge of our beach extending for miles east and west of our facility. Each day, almost all day long, it requires the full time services of two beach boys

> just to rake and shovel up the piles of decaying flies and haul them off the beach and bury them. Not only do the bodies of the fallen insects we kill blacken our entire beach by the water's edge, but likewise the very much alive brine flies cover the Great Salt Lake waters for a good block or so out from the shore and oftentimes sweep over the higher beach areas and spread out like a huge brown blanket for miles around the south end of the lake.

Hansen (1969) further stated that chemicals applied to beaches had been effective in destroying adult flies, but none had succeeded in eliminating or even materially reducing the nuisance. New movements of flies to the treated areas had quickly recreated the problem of living flies, and the bodies of the dead flies had created still another nuisance by producing an extremely offensive odor and serving as a larval habitat for house flies.

UDNR Division of Wildlife publication no. 74-13 summarizes what is known about the brine fly in the following manner:

> The brine fly adults living and dead accumulate in the water and on the beaches in such great numbers that it is impossible to avoid and difficult to endure them. The pupae cases of these flies wash up on the beaches forming windrows of decaying animal matter that emit a repulsive odor and in which other fly larvae develop.
>
> The abundance of these flies is reported as variable from year to year and by some is considered cyclic. Undoubtedly their numbers are influenced by changes in the water chemistry and variation in the population of other organisms in the lake which in turn is determined in part by the influence of man on this environment.
>
> In the water of the lake they remove as food great quantities of algae, bacteria and organic refuse from brine shrimp and their own life processes that could become more abundant and objectionable in the lake than the brine flies, if the brine flies were completely destroyed. The brine flies are also a major source of food for bird life associated with the lake and many land animals inhabiting the shores of the lake.
>
> The larvae do not need access to atmospheric oxygen to breathe. They obtain oxygen from the water by diffusion through their skin. The larvae remain free swimming for awhile after emergence from the eggs. During this period they are

dispersed by movement of the water. It appears that when they find a suitable habitat such as algal bioherms, or other stationary objects, they remain close to the bottom in this protective covering and food supply. Larvae and pupae have been found in such habitats on the bottom of the lake in water 1 to 20 feet (0.3 to 6.1 m) deep. According to Cohenour (1966) 10 percent of the lake bottom is covered with algal bioherms thus providing widely distributed and extensive areas in the lake for larval and pupal development. In warm weather larvae are also reported to live and pupate in great numbers on the surface of the lake in floating masses of algae.

The last larval instar attaches to the algal bioherm or other stationary object on the lake bottom and pupates. The larvae on the surface attach themselves to each other forming large floating pupal rafts.

The pupae cases split open on the backs and the fully developed adult flies emerge in about equal numbers of males and females. The flies emerging from the pupae attached on the bottom of the lake come to the surface in a bubble of air which forms in the pupa case.

It has been reported that the life cycle of the brine fly, under favorable conditions can be completed in 21 to 30 days. At lower temperatures it may require several months. The flies survive the winter in immature stages.

All shoreline areas on the south and east sides of the lake seemed to be affected by the flies, including the west shore of Antelope Island (Nielsen 1967). Since great abundance of the brine fly was reported as early as 1848, there is little evidence that any sewage pollution of the lake has perpetuated its presence.

Ephydra cinerea possesses an exceptional ability to regulate its ionic balance and osmotic pressure. It posseses the highest internal osmotic pressure ever reported for an insect (Nemenz 1960). In a study reported by Welker and Havertz (1973), it appeared that as salinity increased, so did E. cinerea's ability to compete (i.e., reproduce and survive), and E. cinerea dominated accordingly; but as salinity decreased, E. cinerea appeared to lose its physiological competitive edge, and its dominance decreased. They also reported that salinity may be an important

factor in determining the fluctuating populations of brine flies, although it is most likely there are other factors controlling as well.

Ephydra larvae, according to Winget, Rees, and Collett (1969), exhibited an ability to adjust to varying salt concentrations. It was observed that when larvae were taken from water with a 16 percent salt concentration and placed in water having a 25 percent salt content, they did not submerge below the surface of the water until approximately 8 hours later when they began to descend with some effort. After about 12 hours they were able to descend and remain on the bottom of the containers.

Salt tolerance of the larvae was studied by placing 50 larvae in each of seven one quart bottles having various salt concentrations. The dead larvae were counted and removed periodically. Counts were totaled after 4 weeks and again after 8 weeks. Their results are shown in Table 1.

Ephydra larvae appeared to have a high salt tolerance, but the mortality was highest when the concentration was higher than 12 percent and less than 1 percent. It seems that these brine fly species prefer (or

Table 1. Percent mortality of Ephydra larvae in various salt concentrations (Winget, Rees, and Collett 1969).

Percent NaCl	Percent Mortality		End of 8 Weeks	
	4 Weeks	8 Weeks	No. Pupae	No. Adults
29.4	48	100	0	0
*25.6	72	100	0	0
*22.2	44	94	1	0
*12.6	32	68	2	1
* 8.4	8	30	9	5
* 3.4	0	26	7	6
0.2 (Distilled H_2O)	76	100	0	0

*These concentrations are within the range found in the waters of the Great Salt Lake.

are adapted to) a lower concentration of salt than is frequently found in much of the Great Salt Lake but are nevertheless very successful in higher concentrations, probably due to a lack of competitors and predators in the lake. In the present study, Farmington Bay salinity in the fall of 1984 was about 5 percent; a level near optimum for Ephydra larvae survival.

Winget, Rees, and Collett (1969) reported that adult flies brought into the laboratory from Antelope Island completed egg laying in three days and most adults were dead at the end of the fourth day. Adults which emerged from pupae brought into the lab, mated and completed egg laying within six days after emergence. Eggs were laid three to five days after emergence of these adults, and from seven to ten days were required for the eggs to hatch.

During the fall, Welker and Hawertz (1973) noted a definite increase in the E. hians population at a study site of lower salinity, perhaps to the point where a definite reversal of dominance (E. hians over E. cinerea) occurred.

LABORATORY INVESTIGATIONS

Materials and Methods

Sampling

The water samples for the study were taken from the surface of the water in Farmington Bay using wide-mouth 4-liter polypropylene bottles and 15-liter buckets. Sample bottles and buckets had been detergent washed and rinsed with 6 N HCl followed by several rinses with deionized water.

Sediment samples in water deeper than 1 m were collected with a 30 x 30 cm Ekman grab (dredge). This sampler collects only fine surficial sediments. In shallow water, sediments were collected with a garden spade to a depth of 10-15 cm below the sediment surface.

Sample locations are shown in Figure 1. Sediments from two locations were selected for study; one from the recently inundated West Layton Marshes, and the other in 2.4 to 3.7 m of water (i.e., sediments at about 4200 feet (1280 m) elevation above sea level) north of the Salt Lake Sewage Canal outfall in Farmington Bay. It was felt that these two sediments would help resolve the question of whether "polluted" sediments (i.e., those influenced by wastewaters) or newly inundated sediments were more important in producing odors.

Chemical Analyses

Most of the analytical procedures used are described in Standard Methods for the Examination of Water and Wastewater (APHA 1981) and are listed in Table 2. Since the high salinity of the Great Salt Lake could interfere with some analyses, all samples were spiked with known quantities of the analyte whenever possible to assure that there were no matrix interferences.

Odor Microcosms

To investigate the interaction of salinity with the sediments in the production of odorous compounds, microcosms were constructed in 20 ℓ, narrow mouthed glass bottles using "polluted" and marsh sediments. Duplicate microcosms with Farmington Bay (FB) water, FB water plus 5% salts (approximately double current salinity), FB water diluted with

Table 2. Analytical methods.

Parameter	Method	References
Physical Properties:		
pH	Potentiometric	APHA 1981, pp. 402-409; EPA 1979, Method 150.1
Specific Conductance	Conductivity Meter, Wheatstone Bridge	APHA 1981, pp. 70-73; EPA 1979, Method 120.1
Solids--		
Total Dissolved (Total Filterable)	Gravimetric, Dried at 180°C	APHA 1981, pp. 92-94; EPA 1979, Method 160.1
Suspended (Total Nonfilterable)	Gravimetric, Dried at 103°C	APHA 1981, pp. 94-95; EPA 1979, Method 160.2
Volatile Suspended	Gravimetric, Ignition at 550°C	APHA 1981, pp. 95-96; EPA 1979, Method 160.4
Major Anions and Cations:		
Alkalinity, Total	Titrimetric with Potentiometric Endpoint	APHA 1981, pp. 253-257; EPA 1979, Method 310.1
Chloride, Cl	Titrimetric, Mercuric Nitrate	APHA 1981, pp. 271-273; EPA 1979, Method 325.3
Calcium, Ca	ICAP	
Magnesium, Mg	ICAP	
Potassium, K	ICAP	
Sodium, Na	ICAP	
Sulfate, SO_4	Turbidimetric	APHA 1981, pp. 439-440; EPA 1979, Method 375.4
Nutrients:		
Nitrogen--		
Ammonia, NH_3-N	Colorimetric, Indophenol with Nitroprusside, Manual	APHA 1981, pp. 363-366; EPA 1979, Method 350.1; Solorzano 1969
Nitrate, NO_3-N	Colorimetric, Cadmium Reduction and Diazotization, Automated	APHA 1981, pp. 376-379; EPA 1979, Method 353.2
Nitrite, NO_3-N	Colorimetric, Cadmium Reduction and Diazotization, Automated	APHA 1981, pp. 376-379; EPA 1979, Method 353.2
Total	Colorimetric, Persulfate Digestion and Automated Cadmium Reduction and Diazotization	Solorzano, L., and J. H. Sharp (1980)
Phosphorus--		
Orthophosphate, PO_4-P	Colorimetric, Ascorbic Acid	APHA 1981, pp. 420-421; EPA 1979, Method 365.2
Total	Colorimetric, Ascorbic Acid with Persulfate Digestion	APHA 1981, pp. 15, 420-421; EPA 1979, Method 365.2
Organics:		
Carbon, Total Organic, TOC	Infrared, with Persulfate and Heat Digestion	APHA 1981, 471-475; OIC 1977
Algal Assay	Printz Bottle Test for Nutrient Limitation	Miller et al. 1978
Chlorophylls *a* and *b*	Spectrofluorometric	Loftus and Carpenter 1971
Threshold Odor Number, TON	Sensory Odor Panel	APHA 1981, pp. 78-85

deionized water to half strength, and FB water diluted to quarter strength were constructed to make a total of 8 microcosms for each sediment. Each microcosm contained about 8 cm of sediment under about 25 cm of water. The odor microcosms were incubated in the dark at 25 $\pm$ 2°C for 27 days; conditions which probably lead to anaerobiosis in the water and sediments. Samples were withdrawn from the microcosm water at about mid depth on a weekly basis for odor analysis. After the second sampling, the water in the microcosms was gently stirred to dispel salinity stratification and evenly disperse odorous compounds throughout the water column.

Odor Analysis

Because of the complex nature of odor perception, and the lack of sensitive chemical procedures that can be correlated with odor, the production of odors was evaluated using a panel of odor judges to determine odor thresholds (APHA 1981). A panel of 15 judges was selected from 25 candidates for their sensitivity to odors in water exposed to FB sediments. Potential panelists evaluated 6 sets of sample dilutions with 8 dilutions/set. Within each set, 2 of the flasks contained deionized water (blanks) while the remaining 6 flasks contained increasing concentrations of odorous water. Selection of panelists was based on a combination of ability to correctly identify the pure water and sensitivity of odor detection. Data expressed as the threshold odor numbers (TON) were compiled and the 15 best panelists were selected for the panel.

Threshold odor number (TON) was calculated as the reciprocal of the dilution of the sample at which odor could be detected. For example, if no dilution of the sample is made the TON is 1, but if a 1:10,000 dilution is made of the sample and the odor is first recognized at that

APHA 1981, pp. 78-85
Sensory Odor Panel

dilution, the TON is 10,000. Six increasing dilutions of the sample surrounding the estimated odor threshold, along with two randomly positioned unidentified blanks and a known reference blank, were presented to the panelists in glass stoppered 500 ml flasks at room temperature. Panelists swirled each sample, removed the stopper, sniffed the vapors and then noted if the sample smelled like pure water (-) or if it had any other detectable odor (+). They were also asked to describe the odor. Panelists were not made aware of the origins of the samples. Samples within each set were evaluated in order of increasing concentration. Eight sets of samples were evaluated during each panel session. In order to alleviate olfactory fatigue, samples were evaluated in two different room locations. Asking the panelists for a written description of the odor detected also served to reduce fatigue. Water over marsh sediment was evaluated for 5 weeks and water over polluted area sediment for 4 weeks. During the last panel session, panelists evaluated 12 sets of samples from the three phase microcosms.

Individual threshold values were tabulated and the percentage of panelists who could correctly smell an off-odor at each concentration was calculated. The percent correct was plotted against the TON values for each concentration. The point where 50 percent of the panelists could detect an odor was considered the threshold for that sample.

Three-Phase Microcosms

The construction of the three-phase microcosms is shown in Figure 2. These mini ecosystems were used in the present study to evaluate the effect of salinity and sediment type on the production of algae, and to observe the dynamics of mineral nitrogen and phosphorus in relation to

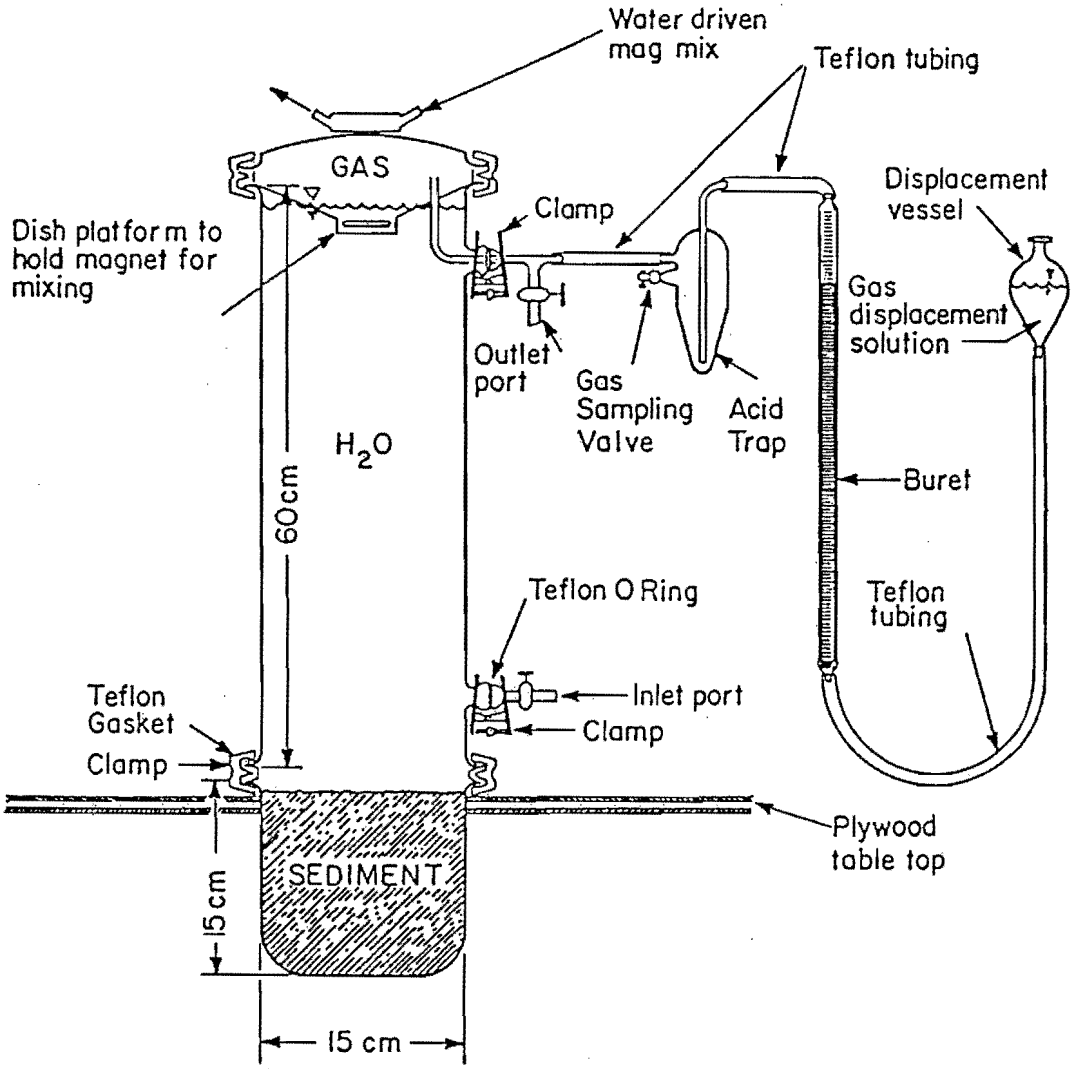

Figure 2. Schematic of microcosm (Dickson et al. 1982).

algal productivity under these conditions. Artificial FB water at current salinity, half and quarter current salinity was placed over "polluted" and marsh sediments in duplicate microcosms for each treatment. Composition of the full strength artificial FB water is shown in Table 3. Ammonium and nitrate nitrogen, and orthophosphate were added to all of the media in concentrations high enough to assure that mineral nutrients would not limit algal productivity.

The three-phase microcosms were operated at 25 ± 2°C under a 16 hr light 8 hr dark diurnal cycle. Approximately 1 ℓ of medium was exchanged in each microcosm, every other day creating a semicontinuous culture condition with a mean residence time for the liquid medium of 20 days. The exchanged medium was analyzed occasionally for chlorophylls *a* and *b*, as indicators of algal crop, and phaeophytin *a*, the initial decomposition product of chlorophyll *a*, as an indicator of vitality of the algal community. Analyses were made also for total and dissolved nitrogen and phosphorus.

Table 3. Components of full strength artificial Farmington Bay medium.

Salt	Concentration (g/l)
NaCl	44.93
$MgSO_4 \cdot 7H_2O$	9.16
$MgCl_2 \cdot 6H_2O$	4.82
KCl	2.10
$CaCl_2 \cdot 2H_2O$	0.543
$NaHCO_3$	0.390
K_2CO_3	∿0.16*
Nutrients: (mg/l)**	
NH_4-N	0.4
NO_3-N	1.7
PO_4-P	1.5

*K_2CO_3 added as needed to achieve pH 9.0 ± 0.2.
**Nutrient concentration in microcosm media of all strengths was kept the same.

Algal Bioassay

Attempts to isolate algae from three-phase microcosm samples or to obtain algae that are indigenous to the Great Salt Lake from stock cultures were unsuccessful. So to ascertain the effect of salinity on algal growth in FB water, a mixed culture algal bioassay was performed. Farmington Bay water collected December 10, 1984 from the state park causeway was either diluted or amended with salts to achieve salinity ranging from 1.4 to 14.4 percent. Nutrients were added to all of the resulting media to achieve the concentration used in the three-phase microcosms (Table 3). An inoculum was prepared from a highly productive three-phase microcosm that contained about 10^5 cells or trichomes of Nodularia sp./ml as well as much smaller numbers of Dunalliela sp. and other algae. Assay cultures were prepared by preparing triplicate 500 ml Erlenmeyer flasks with 100 ml of medium and inoculating with 1 ml of the above inoculum. Assay flasks were incubated at 20 $\pm$ 5°C under continuous illumination of 2000 $\pm$ 200 lux for 7 days. On the seventh day, biomass production in each flask was estimated by determining the volatile suspended solids content of the medium.

Statistical Procedures

Odor data from the anaerobic sediment microcosms were analyzed for significant effects of salinity treatments within each sediment type using one way analysis of variance and determining the least significant difference (LSD) between treatments for each sampling date. Logarithms of threshold odor numbers were used in this analysis (APHA 1981). The significance of differences between ultimate cumulative gas production

in the three-phase microcosms was also determined in this way, but without logarithmic transformation of the data.

Logarithmically transformed odor data from the three-phase microcosms were analyzed for significant effects of sediment type and salinity treatments using two way analysis of variance. Computerized statistical procedures (SPSS Inc. 1983) were used throughout. Error bars drawn in figures are plus and minus one standard deviation, except where noted.

Results and Discussion

Chemical Quality of Farmington Bay

Results of chemical analyses of water samples from Farmington Bay and the Jordan River are shown in Table 4. The composition of the sample near the North Davis wastewater treatment plant was used as the guide for major cation and anion composition and pH of synthetic media used during the project. As expected, salinity decreases in the bay toward the south where major freshwater inputs are present. Nutrient levels were apparently lower in November and December than is typical for summer months. Summer concentrations of NH_4-N and NO_3-N average 0.4 and 2.0 mg/l respectively, while PO_4-P averages 0.7 mg/l (Russ Hinshaw, Utah Bureau of Water Pollution Control, Personal communication 1984); values similar to the Jordan River sample taken December 6. However, levels of ortho and total phosphorus in the Bay samples shown in Table 4 certainly are high enough to support dense algal blooms.

Odor Production from Sediments

Figure 3 shows the results of the sediment odor production experiment for the "polluted" sediment. As the experiment progressed it was observed

Table 4. Water quality data from Great Salt Lake samples and the Jordan River.

Sample Site	Sample Date	Conductivity mmhos/cm	Solids g/l	Ca g/l	Mg g/l	Na g/l	K g/l	Alkalinity mg $CaCO_3$/l	pH	Cl g/l	Nitrogen µg NH_4-N/l	Nitrogen mg NO_3-N/l	Nitrogen µg NO_2-N/l	Nitrogen mg N/l	Phosphorus µg PO_4-P/l	Phosphorus µg P/l	Sulfate µg SO_4/l
Farmington Bird Refuge	1 Nov 84	7.65	4.41	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Farm near Farmington	1 Nov 84	45.9	42.1	0.126	1.48	13.3	0.864	335.	9.18	22.3	-	-	-	-	-	-	2.45
Near Central Davis WWTP	1 Nov 84	58.5	43.0	0.136	1.53	13.5	0.882	352.	9.16	24.2	-	-	-	-	-	-	2.72
Near North Davis WWTP	1 Nov 84	51.1	53.9	0.148	1.97	16.9	1.10	397.	8.95	31.2	-	-	-	-	-	-	3.57
W. Layton Marsh	7 Nov 84	-	56.6	-	-	-	-	385.	-	30.7	18.	<0.04	2.	-	100.	--	4.47
Near Sewage Canal	7 Nov 84	-	37.6	-	-	-	-	352.	-	18.4	14.	0.20	30.	-	316.	-	3.44
Causeway	6 Dec 84	-	53.7	-	-	-	-	-	-	-	10.	0.05	2.	1.78	42.	206.	-
Jordan River 100 yds below South Davis, South WWTP	6 Dec 84	-	0.763	-	-	-	-	-	-	-	959.	1.28	37.	2.05	504.	644.	-

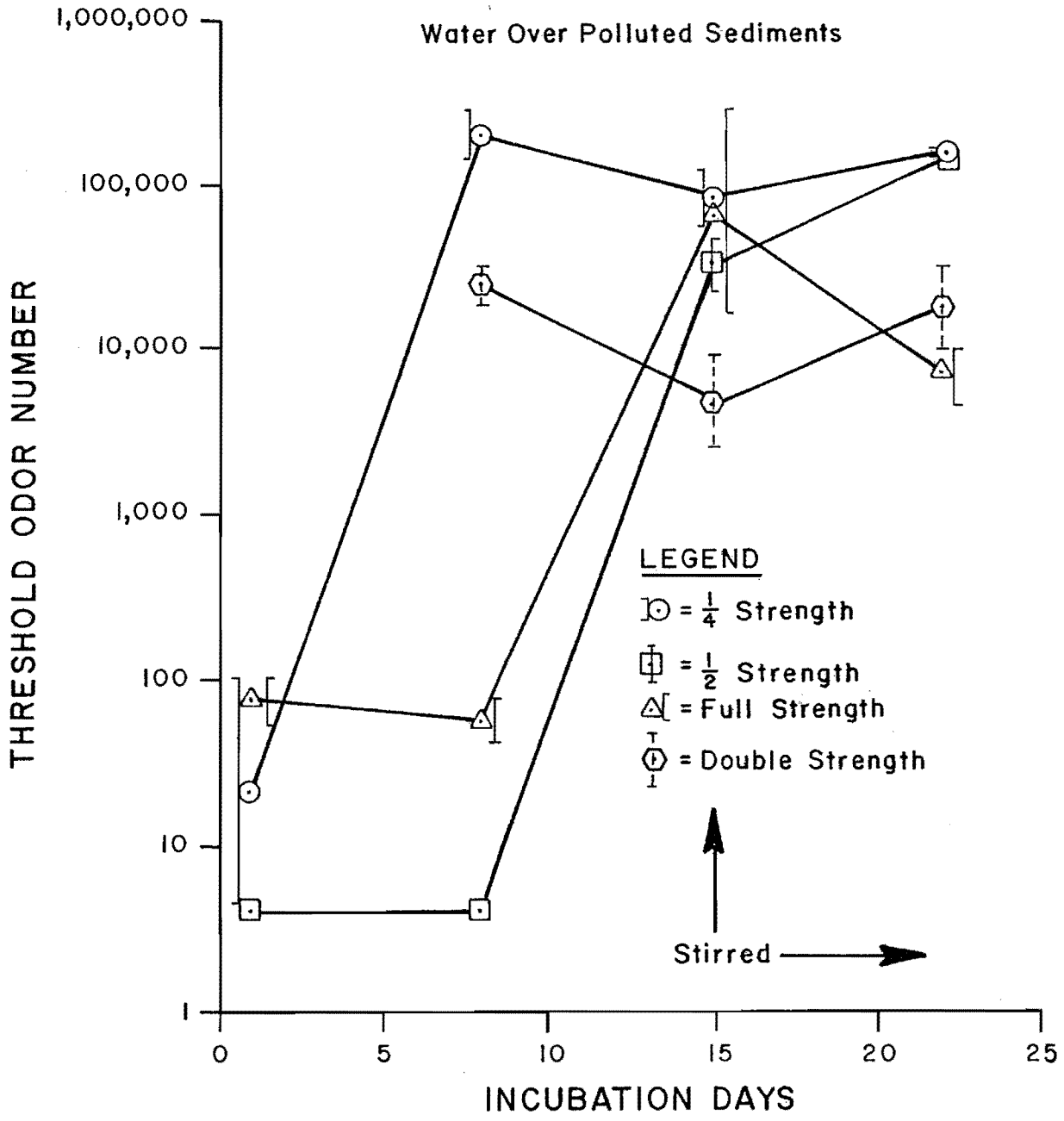

Figure 3. Odor intensity of water over "polluted" sediments.

that a halocline had developed in some of the microcosms and that the difference in density was inhibiting the diffusion of water near the sediment to the surface. To overcome this problem the microcosms were gently stirred before sampling, beginning with the thirteenth incubation day. In nature, wind action probably mixes the water in shallow areas sufficiently to move water that is in close proximity to the sediments to the surface where odoriferous volatile compounds are readily transferred to the air. The magnitude of the threshold odor number for water over anaerobic "polluted" sediment indicates that the potential for this sediment to contribute to odor problems is high. At the first sampling, there was no statistically significant difference ($p \leq 0.1$) in odor intensity between the salinity treatments. On the eighth incubation day significant differences between all treatments were observed, probably reflecting the salinity stratification that had developed within certain microcosms. After stirring on the fifteenth incubation day, only the double strength (10 percent salinity) treatment was significantly lower in odor intensity. On the twenty-second day, again after stirring, the odor intensity in the quarter and half strength salinity treatments was not significantly different and was virtually ten-fold higher than in the full and double strength treatments. Although the difference was relatively small, the odor intensity in the double strength treatment was significantly higher than the full strength treatment. Odor judges used words such as "sulfur," "sulfide," and "oil" to describe odors from these sediments suggesting a strong influence of H_2S and petroleum wastes on the quality of odor produced by these "polluted" sediments.

Initially, odor production from the marsh sediments tended to be more intense than in the polluted sediment, but was highly variable and

no significant difference between salinity treatments was found (Figure 4). All treatments were significantly different in odor intensity on the sixth incubation day. Again, this was probably due to salinity stratification. After stirring on the thirteenth, twentieth, and twenty-seventh incubation days, no statistically significant difference in odor intensity between any treatments was found. Odor intensity showed a decreasing tendency from the thirteenth through the twenty-seventh day, and tended to be higher in the half and quarter strength treatments on the twenty-seventh day. Judges described the odor produced in the marsh sediment microcosms as "marshy," "earthy," and "potatoes," as well as "sulfury." Again the intensity of the odor is striking. The TON for the double strength salinity when the microcosms were first stirred averaged 407,500.

These results indicate that both "polluted" sediments and newly inundated marsh sediments produce intense odors under summer temperature conditions at all of the salinity concentrations of the overlying water that were tested. These odors may be most intense when the water column is mixed after a period of stagnation. Odor production in the microcosms was highest in the lower salinity treatments at the end of the experiment for both sediments. This difference was statistically significant only in the "polluted" sediments.

Algae Production in the Three-Phase Microcosms

Algae production in the three-phase microcosms revealed major differences between the two sediments tested. Table 5 shows that planktonic algae production, as reflected by chlorophyllous pigment production, in water of full, half, and quarter strength salinity over "polluted" sediment was severely limited relative to the marsh sediment. Highest

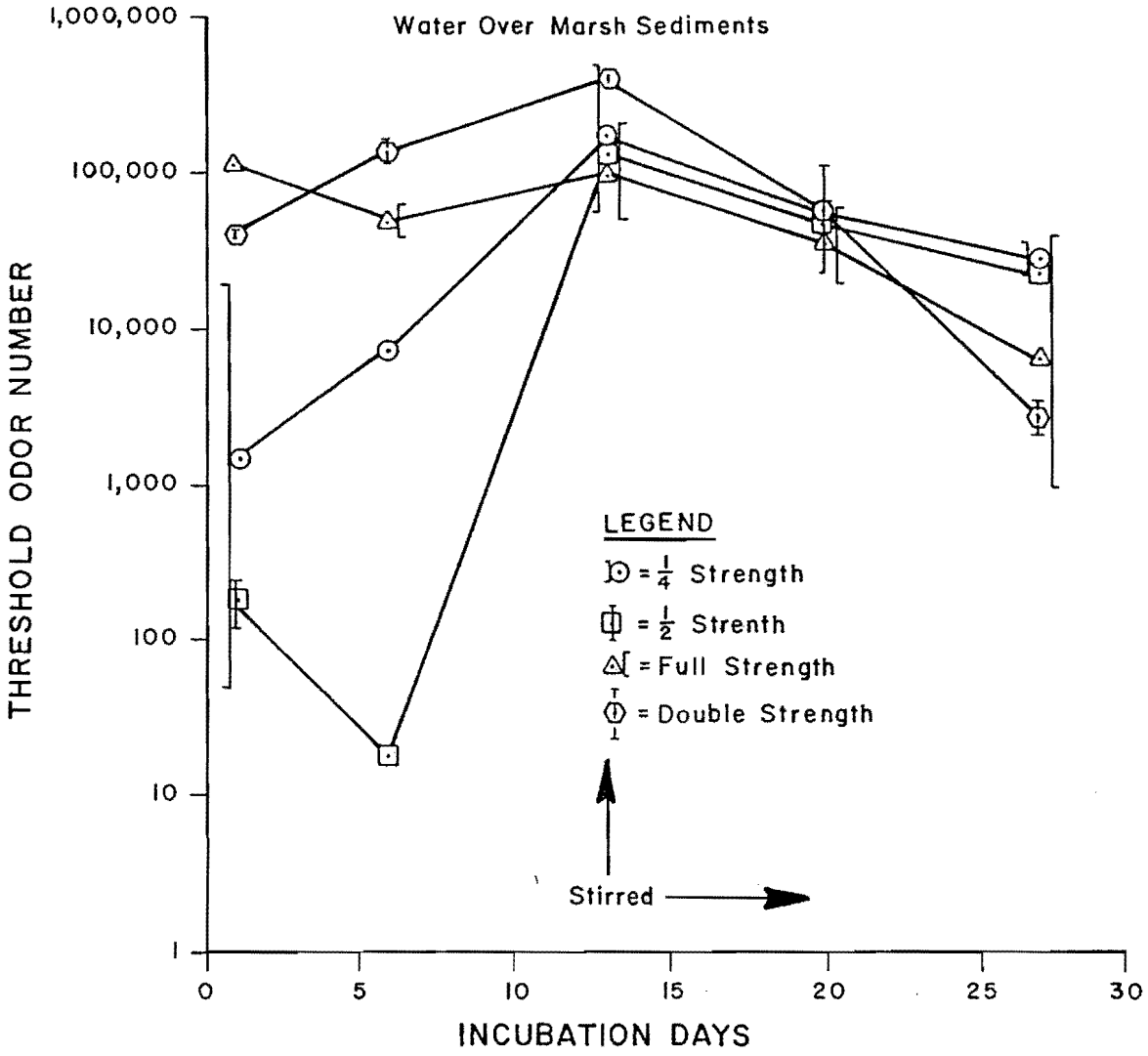

Figure 4. Odor intensity of water over West Layton marsh sediments.

Table 5. Chlorophyllous pigments in the three-phase microcosms. All values are µg/ml. The average ± the standard deviation of replicate microcosms are shown.

Sediment	Day	Full			Half			Quarter		
		Chl. a	Chl. b	Phaeo a	Chl. a	Chl. b	Phaeo a	Chl. a	Chl. b	Phaeo a
Polluted	7	0.13±0.11	<0.13	<0.13	>0.27	<0.55	>0.27	0.10±0.02	<0.09	<0.09
	9	0.27±0.19	<0.17	<0.27	0.15±0.03	0.10±0.06	<0.13	0.13±0.01	0.13±0.1	<0.13
	17	0.45±0.17	0.46±0.10	<0.20	<0.17	<0.19	<0.17	<0.13	<0.04	<0.20
	23	0.41±0.17	0.16±0.04	0.26±0.17	0.07±0.06	0.06±0.04	<0.08	<0.01	<0.02	<0.02
Marsh	7	0.94±1.29	0.59±0.81	1.03±1.42	1.77±1.05	1.08±0.62	1.97±1.32	1.85±2.39	1.40±1.55	1.79±2.10
	9	3.84±1.51	2.62±0.83	3.89±1.99	>4.08	<2.70	>3.42	3.60±0.36	4.08±0.20	<2.22
	17	>3.50	2.53±0.59	4.21±0.97	>4.20	2.14±1.47	3.57±1.67	>4.90	1.71±0.84	3.79±2.24
	23	3.69±0.43	3.84±0.93	2.27±1.28	5.09±1.13	5.12±0.13	4.22±4.03	<2.73	2.10±1.04	<2.73

chlorophyll *a* concentrations were observed in the full strength salinity treatment, and the concentrations increased in this treatment through the seventeenth day. In both of the more dilute treatments, amounts of pigment present were frequently below the working range of the assay. These results suggest that some inhibitor of algal growth may exist in these sediments. The time frame of the present study did not allow follow-up analyses to be made of the sediment to determine what this inhibitor might be. These sediments had a distinct odor of petroleum at the time of collection and it seems plausible that toxic hydrocarbons or heavy metals may be released from the sediments and interfere with algal growth. Evidence of inhibition of algae growth was noted near the sewage canal outfall also by McDonald and Garifin (1965) and Bott and Shipman (1971).

Dense blooms of algae developed in the microcosms with marsh sediments within 7 days of start-up. Green color was noted first in the quarter strength salinity microcosms followed in succession by the half and full strength microcosms. Microscopic examination of the water from the quarter strength microcosms revealed a predominance of the cyanobacterium (bluegreen alga) *Nodularia* sp. This organism reached concentrations of approximately 10^8 trichomes per ml. Many eucaryotic algae were also present, but in much lower numbers than the *Nodularia*. However, the relatively high amount of chlorophyll *b* in the pigment analysis suggests that green algae contributed significantly to the algal biomass. The large amount of phaeophytin *a* indicates that at all of the sampling times a large fraction of the algae may have been dead or dying.

Nutrient Dynamics in the Three-Phase Microcosms

Nutrient dynamics in the microcosms are illustrated in Figures 5 through 16. In general, the "polluted" sediment microcosms tended to transform or immobilize both nitrogen and phosphorus during the 23 days of microcosm operation (Figures 5 through 10). The notable exception to this rule was total phosphorus (Figure 5). Total phosphorus remained consistently above the 1.5 mg P/l added in the microcosm medium. Both organic and inorganic forms of phosphorus are included in total phosphorus measurements. The more biologically available orthophosphate phosphorus (Figure 6) hovered around the feed level of 1.5 mg P/l in the full and quarter strength microcosms, but fell to the 0.2-0.3 mg P/l range in the half strength polluted sediment microcosms. This loss of phosphorus may be due to biological uptake or chemical precipitation. As noted above, however, a planktonic algae bloom was not observed and only sparse attached algae growth was observed in any of the "polluted" sediment microcosms.

Total nitrogen in the "polluted" sediment microcosms decreased to about the 2.1 mg N/l level added in the microcosm medium (Table 3) by the 16th day of operation, and remained at about that level. Ammonium nitrogen decreased in all polluted sediment treatments, but the quarter strength salinity microcosms tended to maintain higher levels than the other treatments (Figure 8). The very high levels of nitrite that occurred in the quarter strength microcosm on days 16 and 23 (Figure 9) indicate that the process of nitrification may be inhibited somewhat at the nitrite oxidation step at this salinity level. Perhaps the bacteria (probably Nitrobacter) that carry out this process are not adapted to

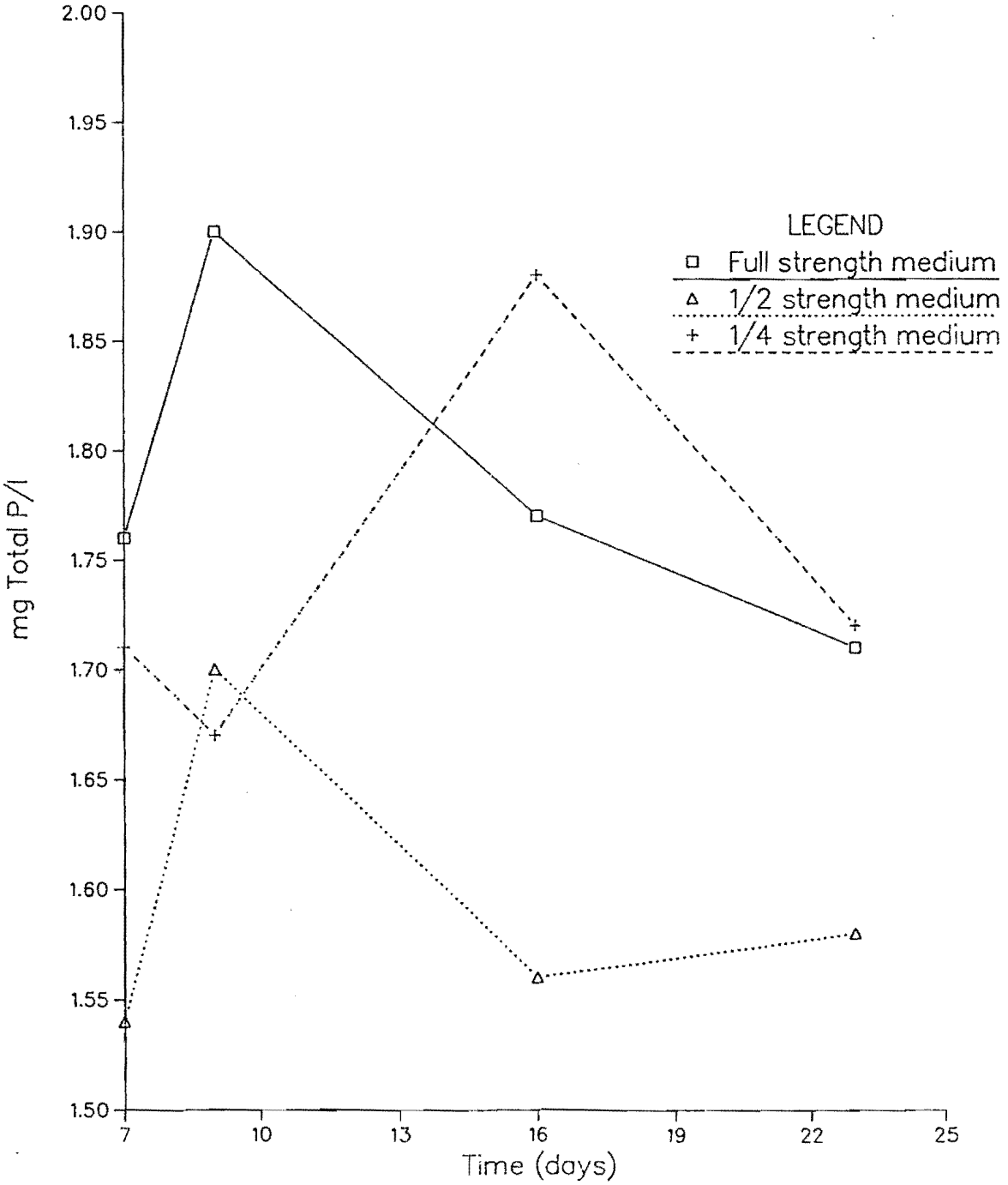

Figure 5. Total phosphorus dynamics in "polluted" sediment microcosms. Data points are averages from duplicate microcosms.

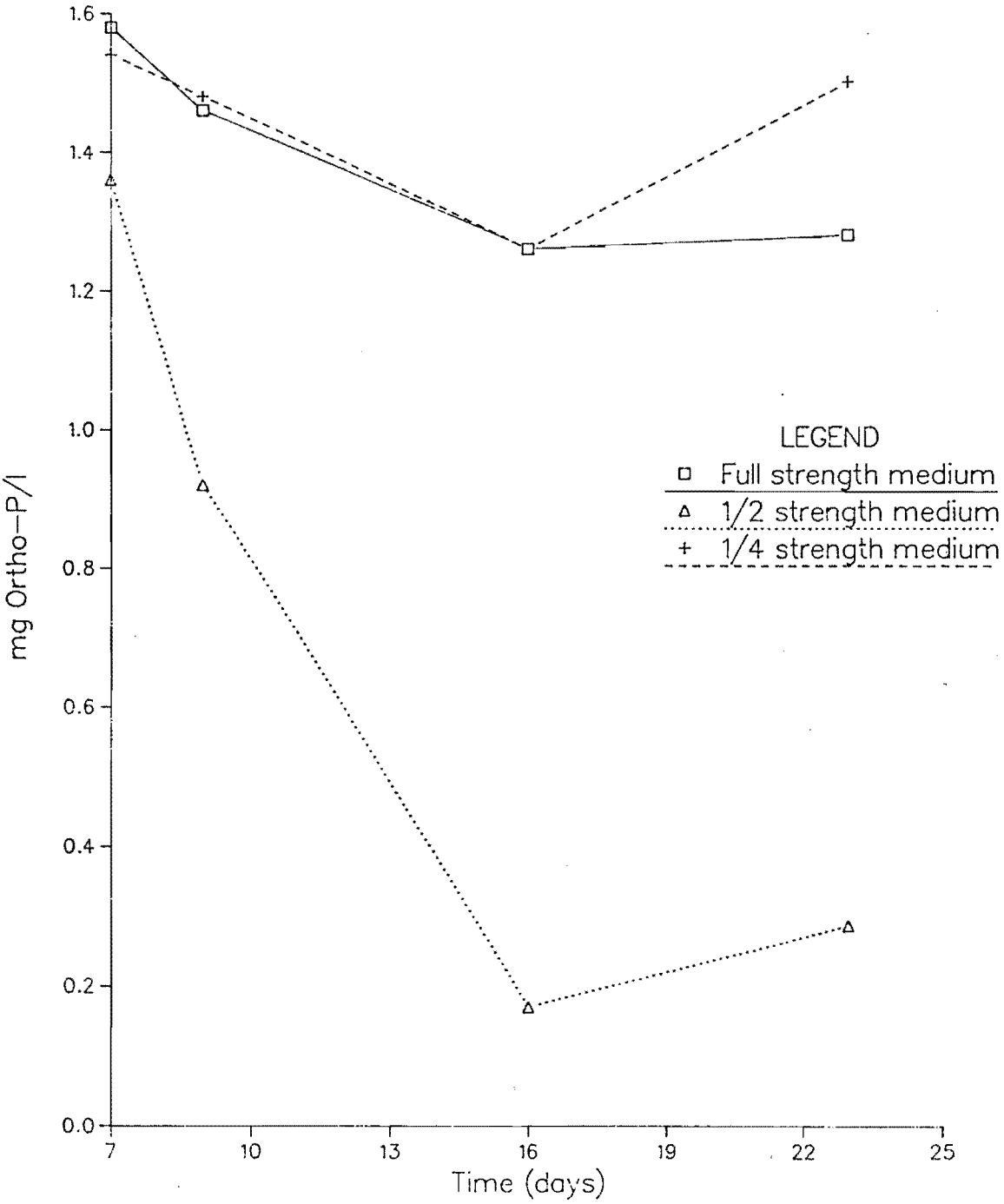

Figure 6. Orthophosphate dynamics in "polluted" sediment microcosms. Data shown are averages from duplicate microcosms.

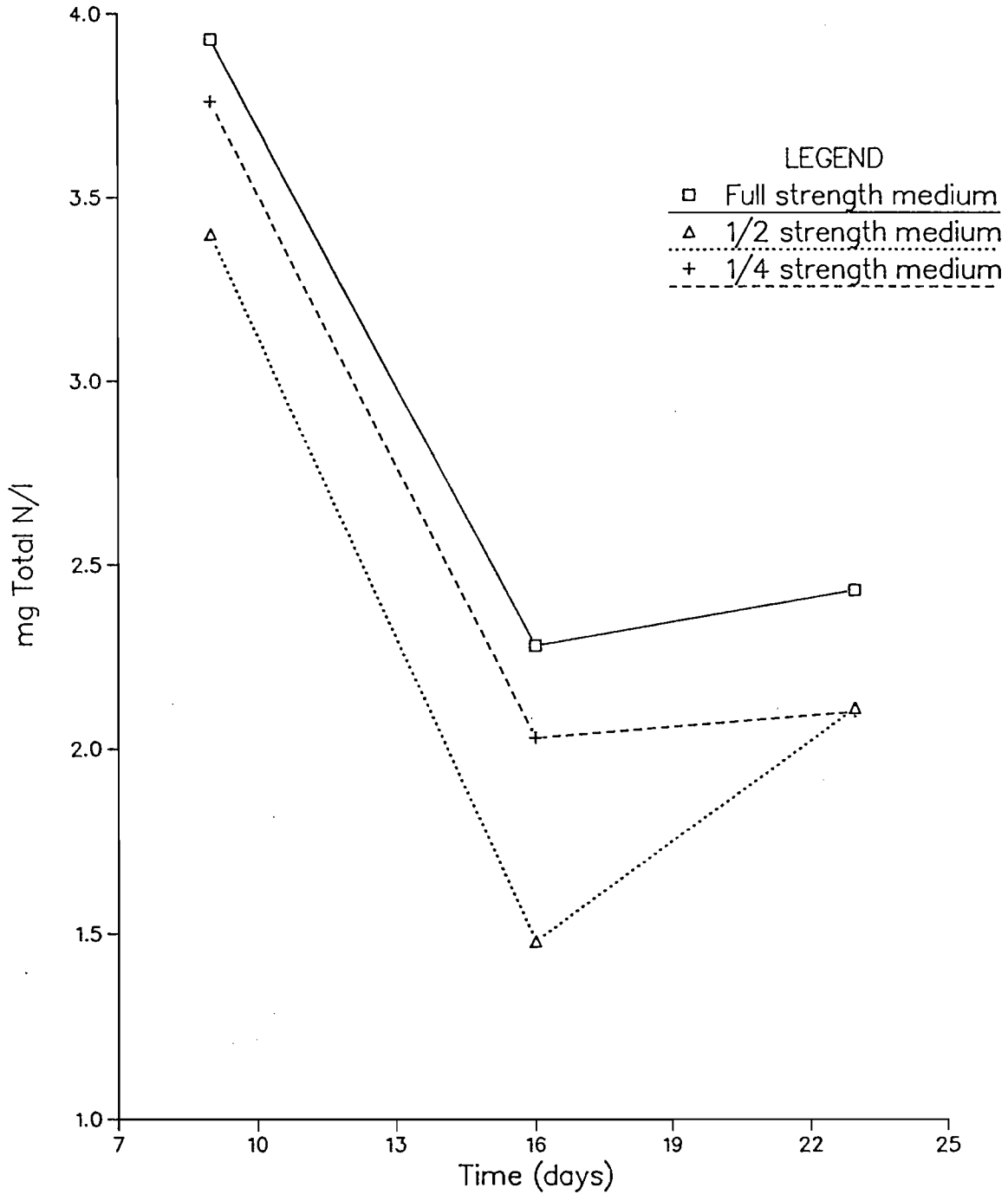

Figure 7. Total nitrogen dynamics in "polluted" sediment microcosms. Average values from duplicate microcosms are shown.

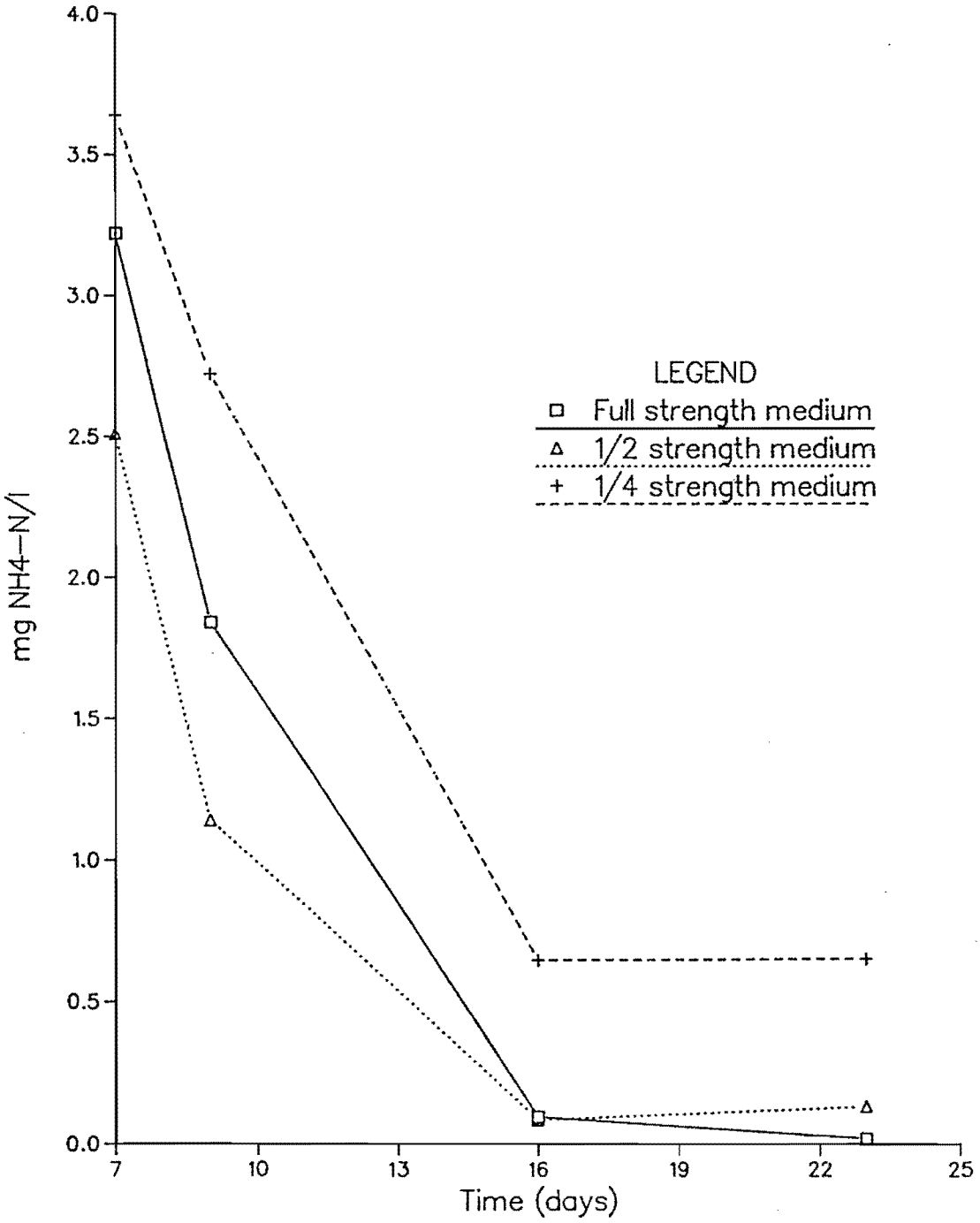

Figure 8. Ammonium-nitrogen dynamics in "polluted" sediment microcosms. Average values from duplicate microcosms are shown.

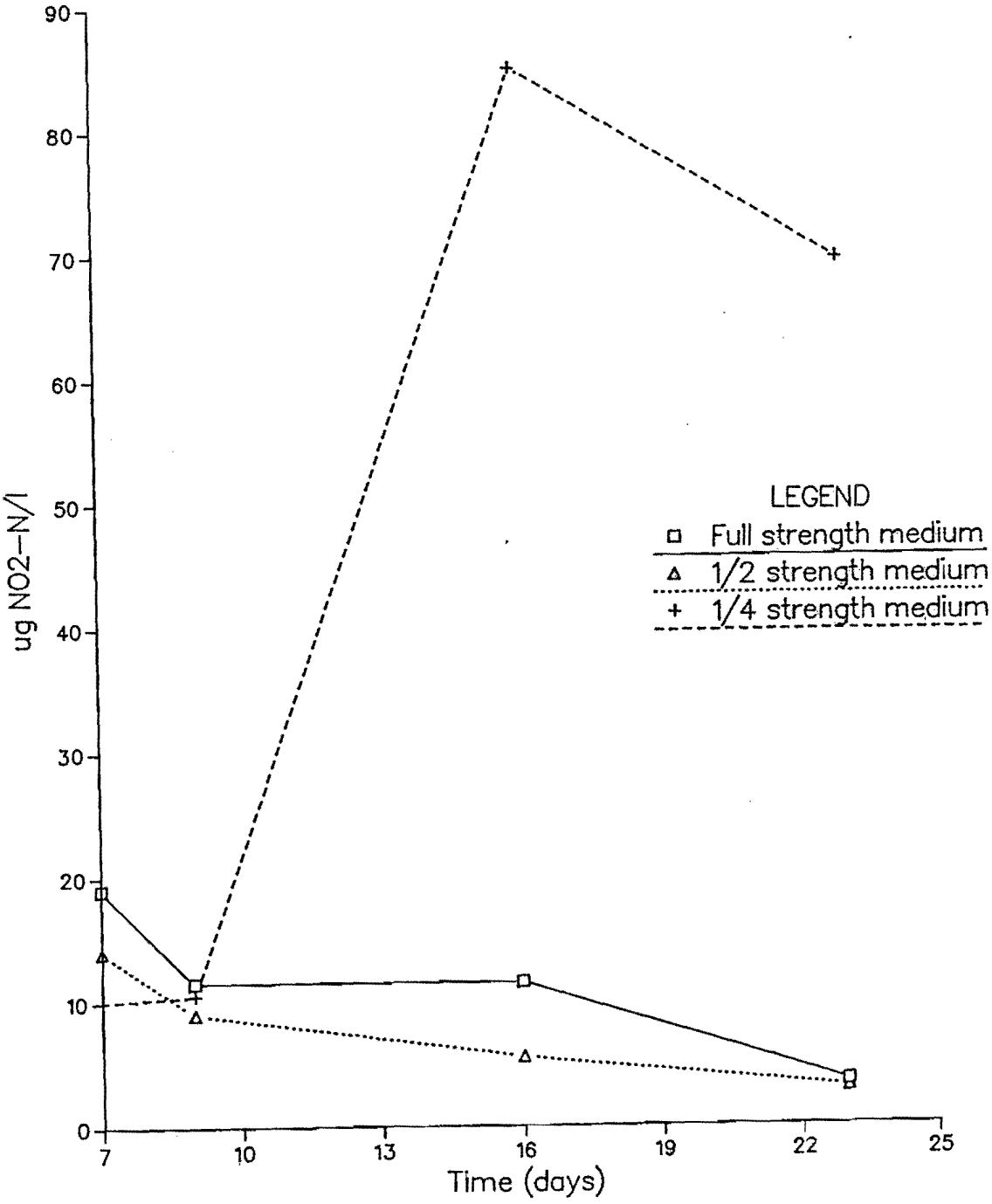

Figure 9. Nitrite-nitrogen dynamics in "polluted" sediment microcosms. Average values from duplicate microcosms are shown.

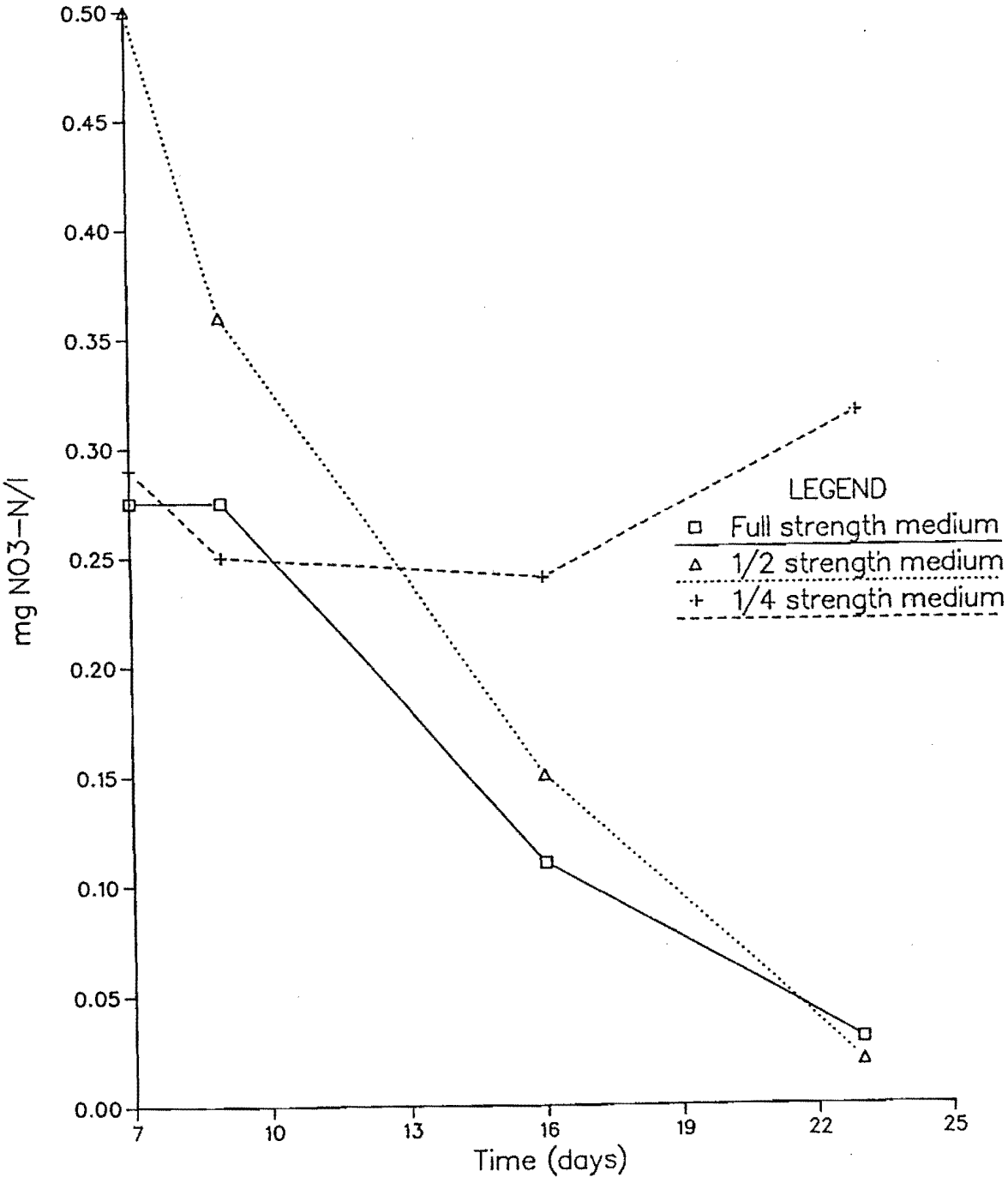

Figure 10. Nitrate-nitrogen dynamics in "polluted" sediment microcosms. Average values for duplicate microcosms are shown.

this lower salinity. Nitrate immobilization or transformation within the microcosms was remarkable (Figure 10). Virtually all of the nitrate (1.7 mg/l) added to the full and half strength microcosms was consumed by the 23rd day of operation. Nitrate remained at about 0.3 mg/l in the quarter strength salinity microcosms.

These results, when considered together with the low algal productivity in the "polluted" sediment microcosms, indicate that the "polluted" sediments are not major sources of algal growth nutrients, but may act as a sink for these nutrients. However, phosphorus levels were sufficient to support nitrogen fixing cyanobacteria (e.g., Nodularia sp.), and the lack of a bloom of these algae again suggests that some toxicity may be associated with these sediments.

The marsh sediments generally released nutrients (Figures 11 through 16). Total phosphorus concentrations climbed to more than 2.5 times the concentration of phosphorus added in the media (Figure 11). Apparently, total phosphorus was being rapidly lost from the quarter strength microcosms after the 9th day of operation. The orthophosphate phosphorus concentration stayed somewhat above the concentration in the microcosm feed media (i.e., 1.5 mg P/l) in the full strength medium while the half strength medium stayed somewhat below this concentration. The quarter strength medium decreased sharply below the microcosm medium orthophosphorus concentration. The early immobilization of phosphorus in the dense production of algae in the marsh sediment quarter and half strength microcosms may account for the decrease in orthophosphorus seen here. It is noteworthy that despite the immobilization of phosphorus in the production of algae, the concentrations of orthophosphorus remained

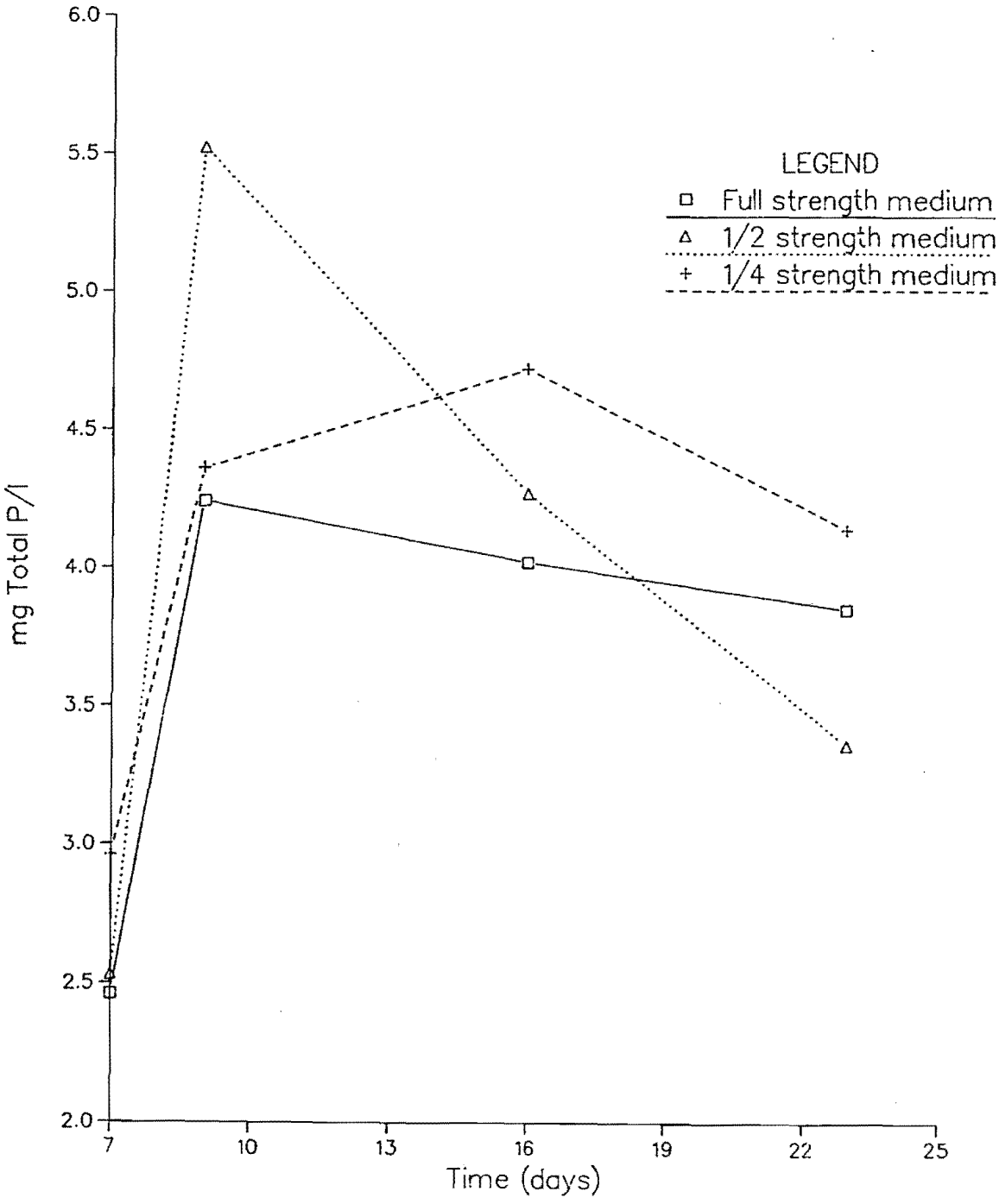

Figure 11. Total phosphorus dynamics in marsh sediment microcosms. Average values from duplicate microcosms are shown.

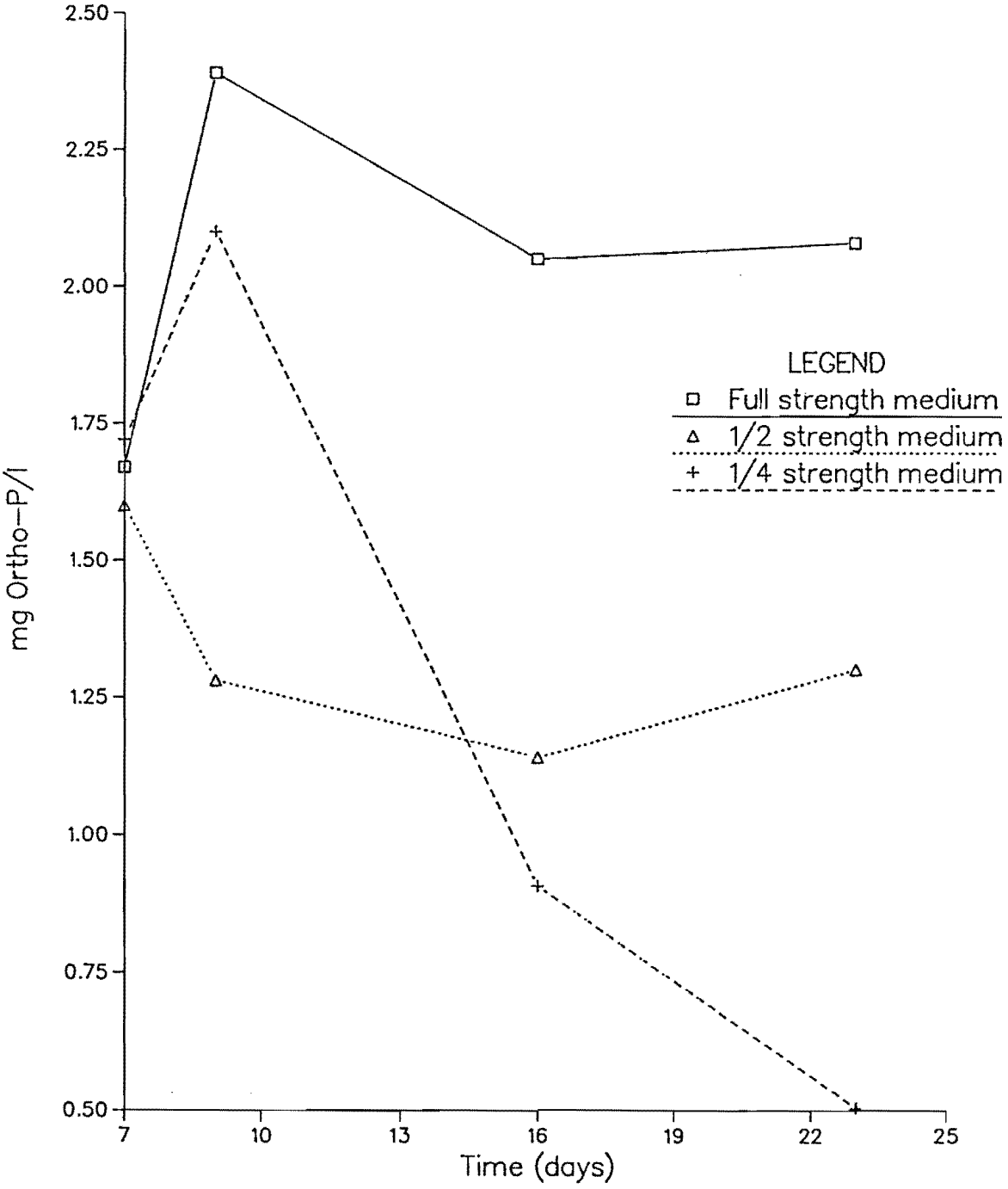

Figure 12. Orthophosphate dynamics in marsh sediment microcosms. Average values from duplicate microcosms are shown.

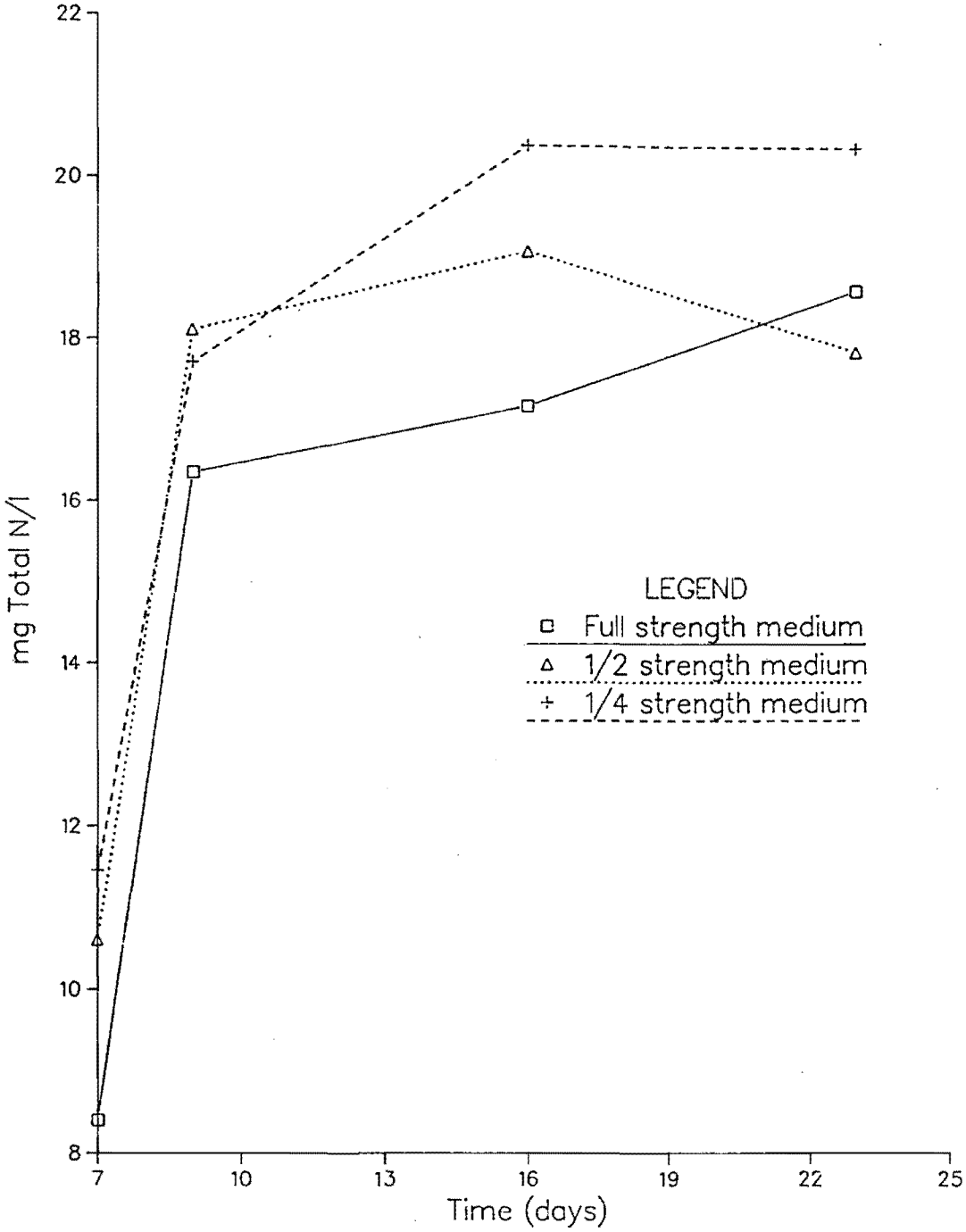

Figure 13. Total nitrogen dynamics in marsh sediment microcosms. Average values from duplicate microcosms are shown.

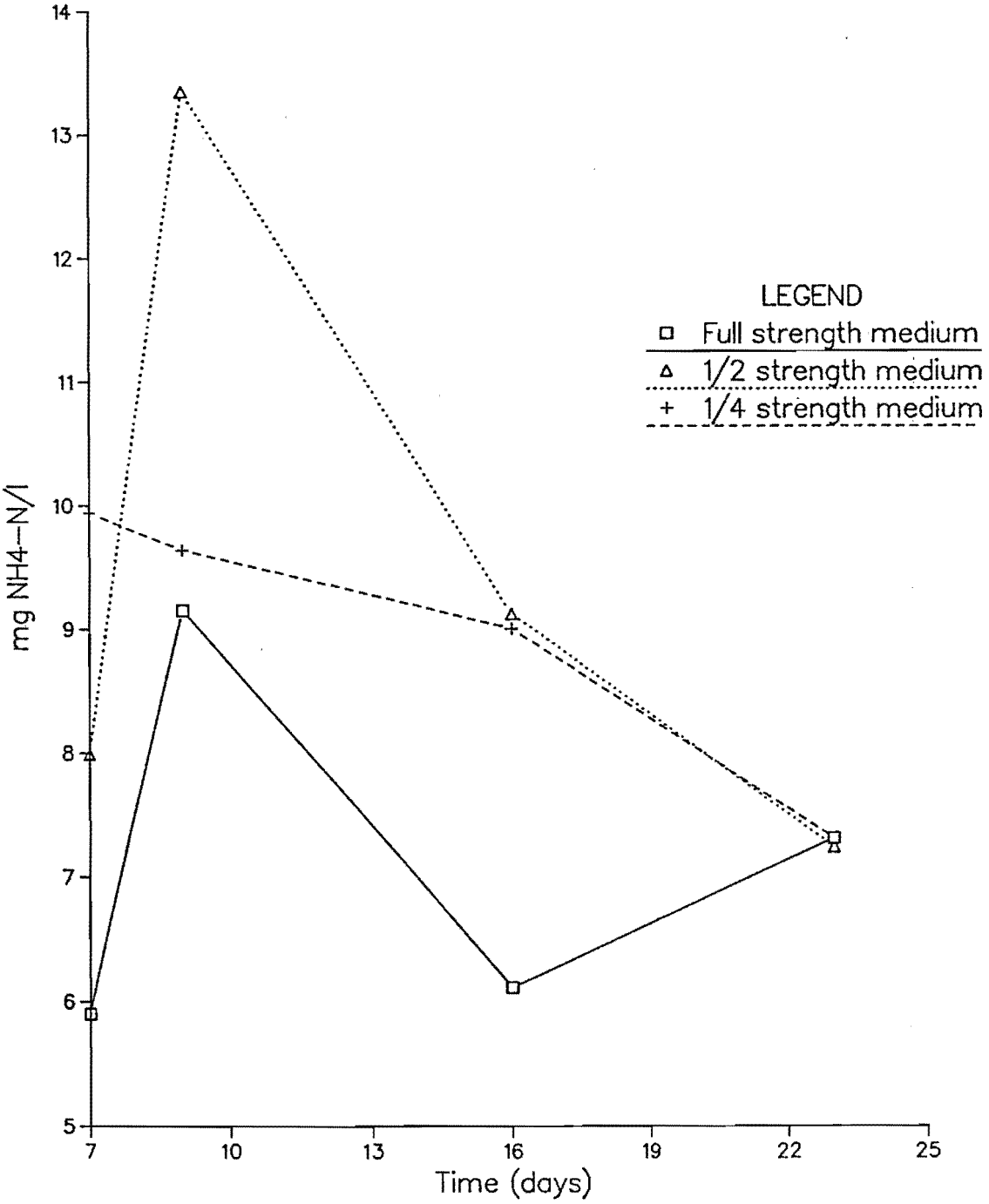

Figure 14. Ammonium-nitrogen dynamics in marsh sediment microcosms. Average values from duplicate microcosms are shown.

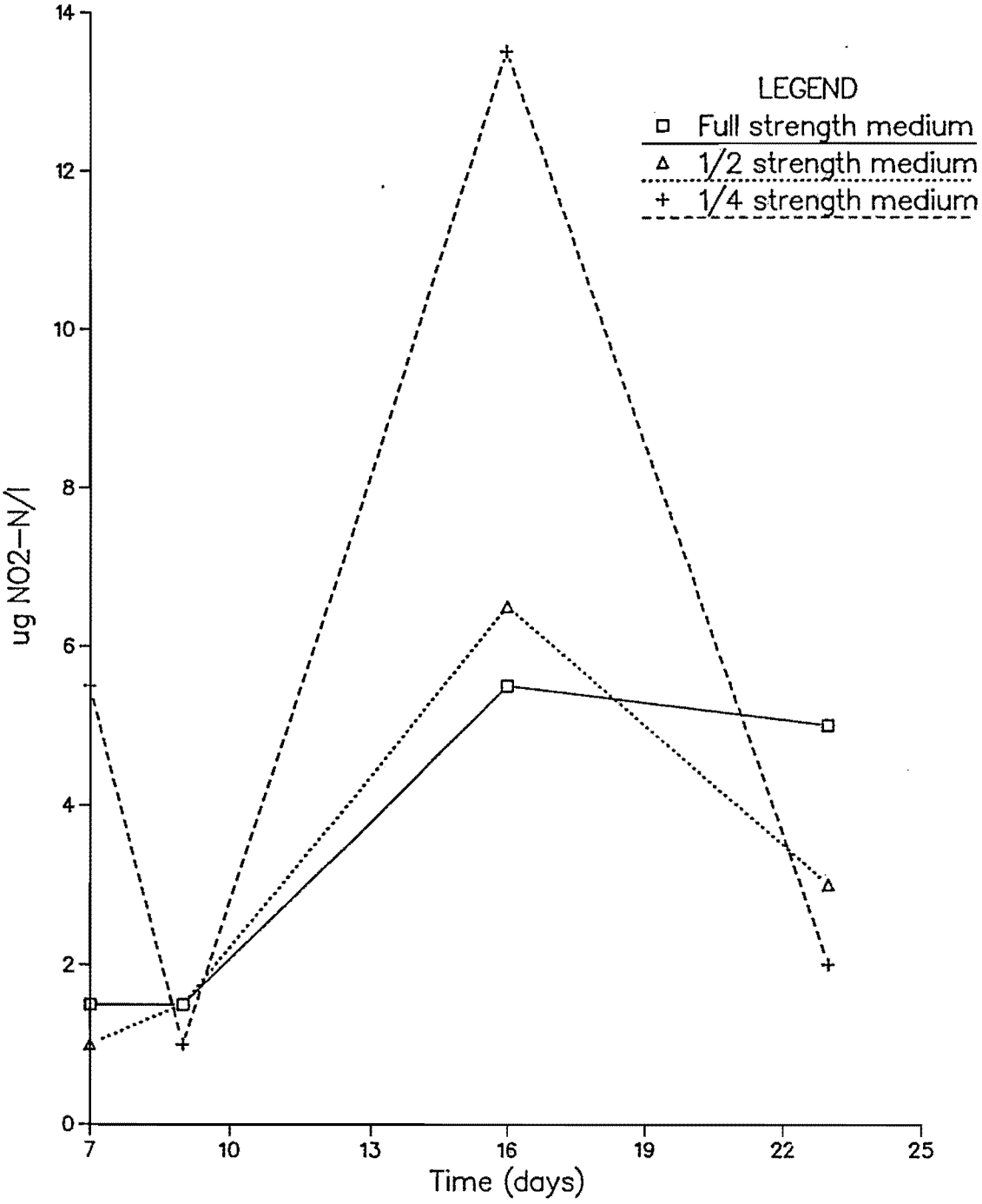

Figure 15. Nitrite-nitrogen dynamics in marsh sediment microcosms. Average values from duplicate microcosms are shown.

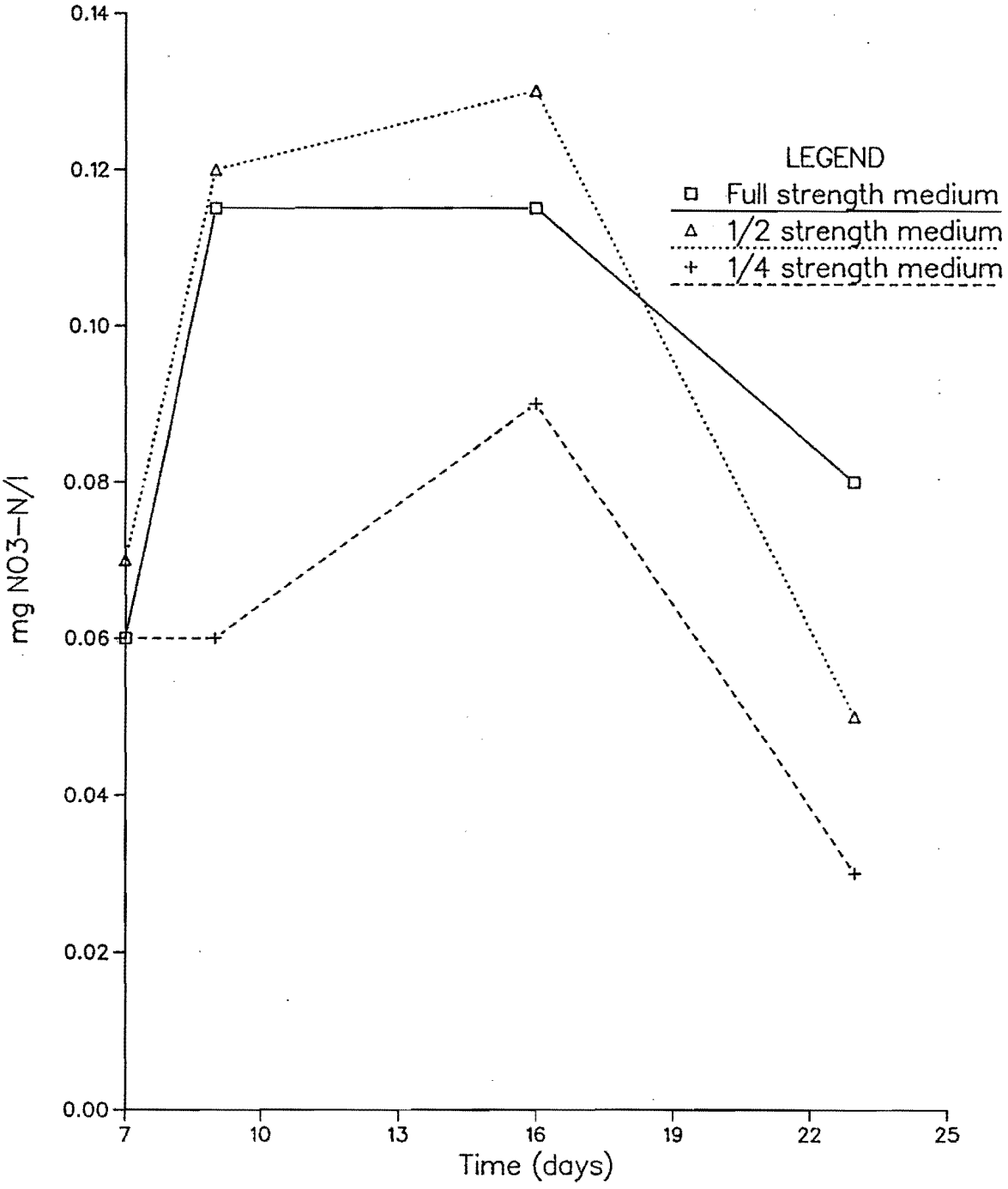

Figure 16. Nitrate-nitrogen dynamics in marsh sediment microcosms. Average values from duplicate microcosms are shown.

higher in the marsh sediment microcosms than in the "polluted" sediment microcosms.

The release of nitrogen from the marsh sediments is obvious in the total nitrogen pool (Figure 13). After the 9th day of operation, the concentration of total nitrogen was more than 8 times the total amount of mineral nitrogen added to the microcosm medium. Within experimental variation, the concentration of total nitrogen was essentially the same for all the salinity treatments. Ammonium nitrogen release from the marsh sediments was also apparent since concentrations were at least 12 times the concentration added to the media. The process of nitrification appeared to be functioning since nitrite nitrogen first increased then decreased (Figure 15), while ammonium decreased and nitrate (Figure 16) increased. Nitrate immobilization may account for the low levels of nitrate observed in these microcosms. Nitrate nitrogen levels were always less than 8 percent of the nitrate added in the microcosm media.

These results suggest that marsh sediments recently inundated by the waters of Farmington Bay may supply significant quantities of nutrients to algal production which may directly and indirectly add to the odor problems.

Gas Production in the Three-Phase Microcosms

Cumulative total gas production in the three-phase microcosms is shown in Figures 17 and 18. "Polluted" sediment microcosms consumed gas or showed negligible net gas production during the first six days of operation. This implies that respiratory biological processes dominated during this time and oxygen was consumed. As algae (primarily attached forms) began to grow, oxygen was produced through photosynthesis and a

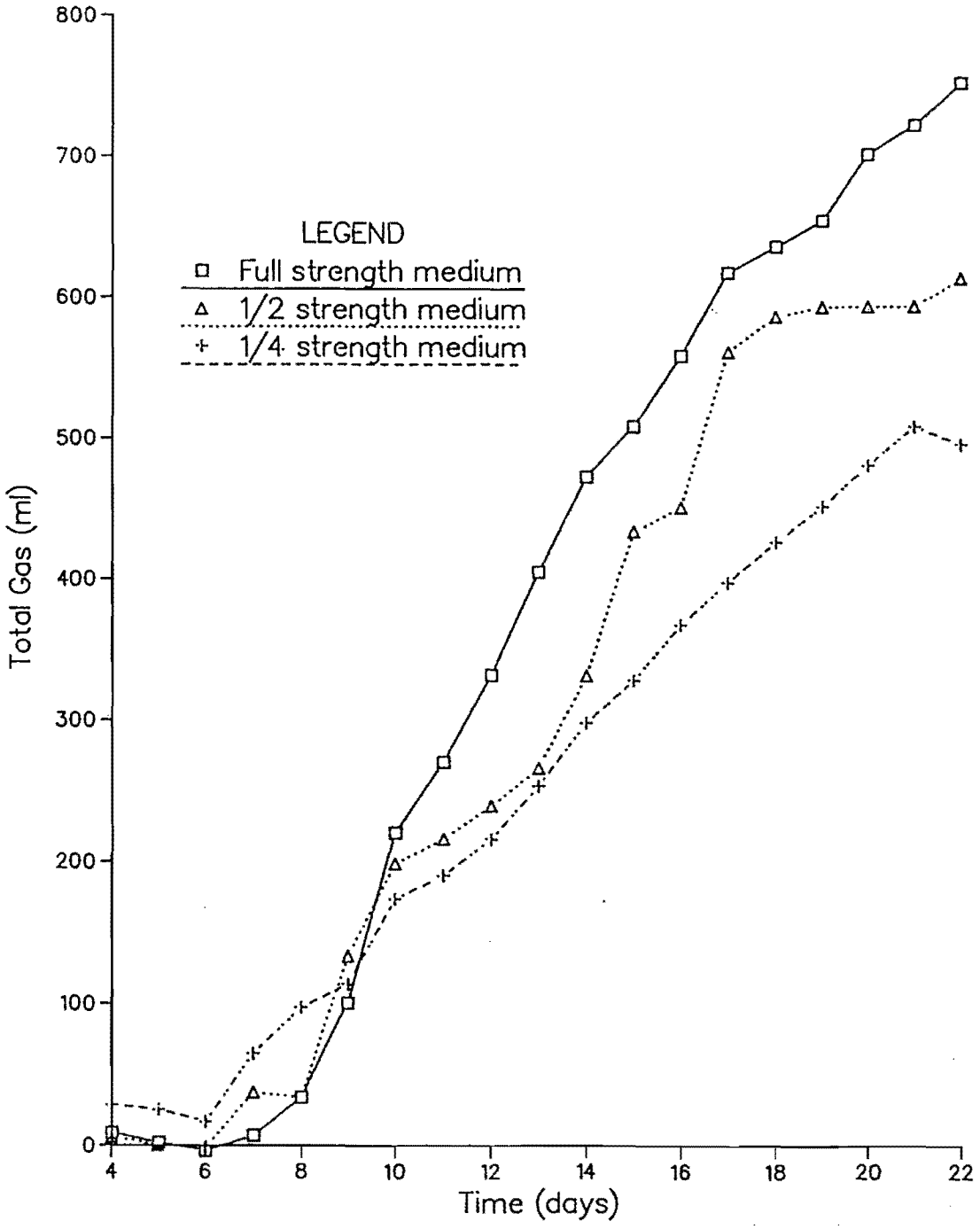

Figure 17. Cumulative total gas production within the polluted sediment three-phase microcosms.

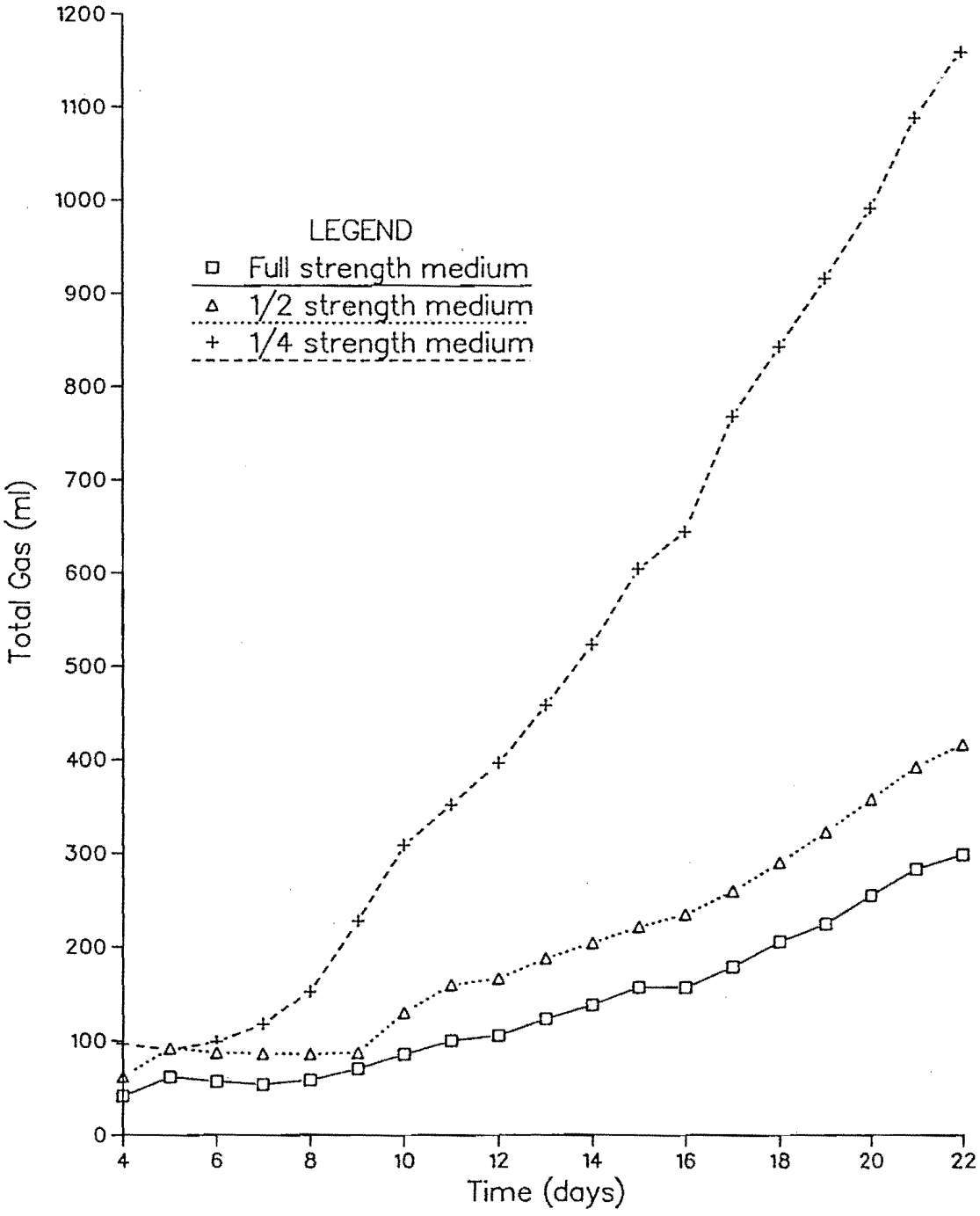

Figure 18. Cumulative total gas production within the marsh sediment three-phase microcosms.

net increase in gas production began between days 6 and 8. The largest amount of total gas was produced in the full strength salinity microcosms, but no statistically significant difference ($p \leq 0.1$) existed between salinity treatments in the "polluted" sediment microcosms at the end of the experiment (Figure 17).

Gas production in the marsh sediment microcosms was most dramatic in the quarter strength salinity treatment. After a six day lag period where net gas production was essentially nil, gas production accelerated rapidly through the ninth day and then continued at about the same rate throughout the remainder of the experiment. When the experiment was terminated, total gas production in the quarter strength salinity microcosms was significantly higher ($p \leq 0.1$) than in the higher salinities. This reflects the high rate of photosynthesis and oxygen production by the dense growth of algae in the quarter strength microcosms. Ultimate total gas production in the half and full strength salinity microcosms was not significantly different.

At the termination of the experiment, analysis of the gas produced in the microcosms showed enrichment with oxygen to nearly 50 percent by volume. Carbon dioxide and methane were less than 1 percent of the gas volume. Again, this demonstrates the major role of photosynthesis in microcosm gas production.

Odor Assessment of the Three-Phase Microcosms

The intensity of odor associated with the microcosm water on the 23rd day of operation was assessed by the odor panel. Water in the marsh sediment microcosms was significantly more odiferous than in the "polluted" sediment microcosms (Figure 19). This difference is probably

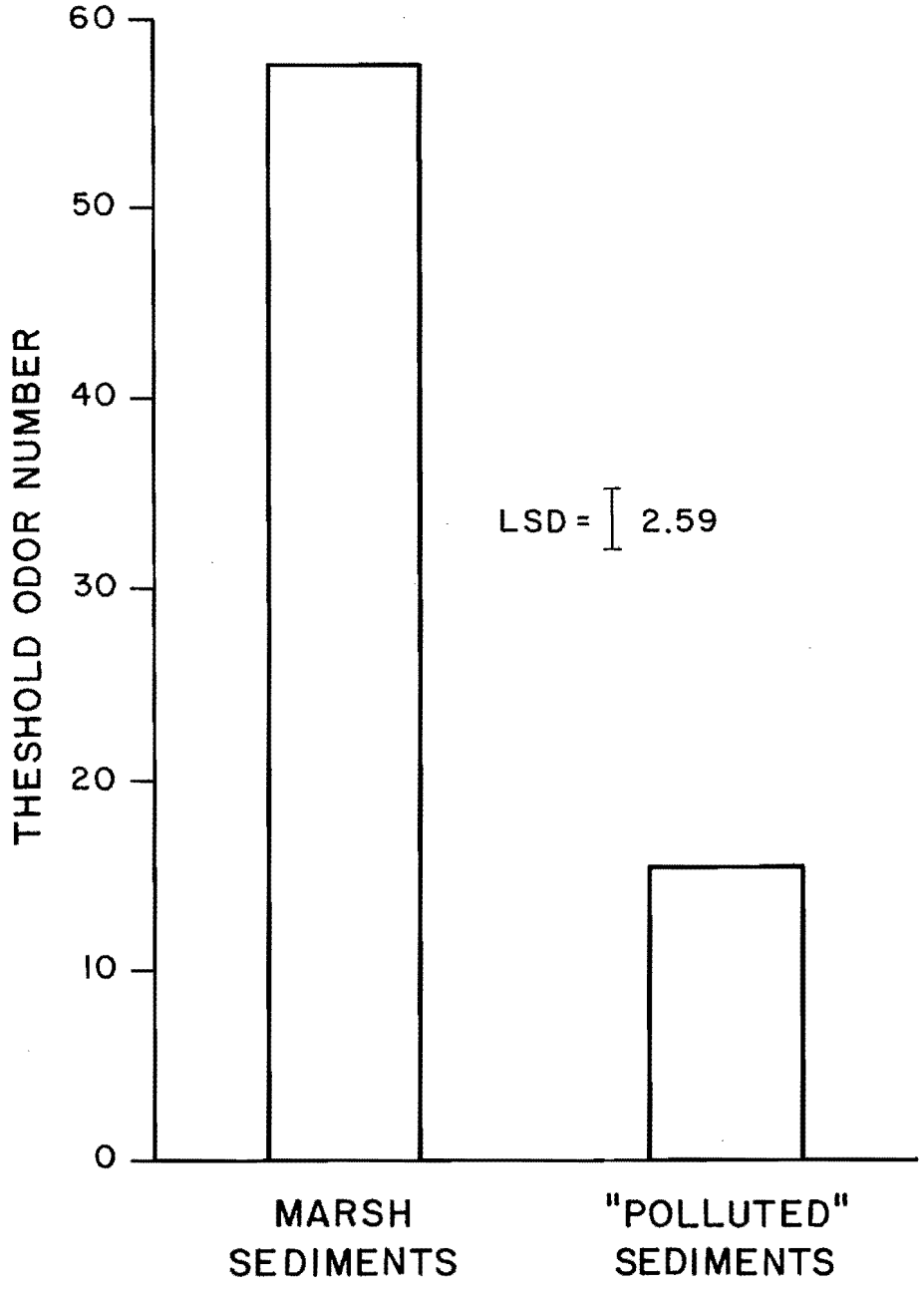

Figure 19. Odor associated with the waters of the three-phase microcosms.

due to the dense algae production in the marsh sediment microcosms. This odor was described as "grassy" or "dirty diapers." No significant difference in odor could be ascribed to salinity treatments or the interaction between salinity and sediment type. The average TON for the marsh sediment three-phase microcosm was less than 0.02 percent of the highest TON determined for the anaerobic microcosms. Apparently, there are significant odors associated with the algae that may bloom in Farmington Bay, but these odors are much less intense than those produced under anaerobic conditions by decaying material (including the algae) in the sediments. The relative importance of these sources of odor in the natural setting remains to be determined.

The Effect of Salinity on Algae Production

The results of a mixed culture bioassay to examine the effect of salinity on algal growth in Farmington Bay water are shown in Figure 20 and Table 6. Despite the use of an inoculum prepared from a quarter strength marsh sediment three-phase microcosm dominated by Nodularia sp., the algae that dominated all but the most dilute bioassay treatment was a chysophyte (diatom) apparently of the genus Rhizosolenia. This organism also appeared to dominate the algal flora of the sample collected from the lake that was used in the bioassay. The green alga Chlorella dominated the 13.7 g/l salinity treatment (Table 6) and became badly clumped and seemed to be dying at the end of the assay. This may account for the low volatile suspended solids observed in this treatment. Chlorella was also an important component of the algal community growing in the other treatments, but became less important as salinity increased. In Table 6, a comparison of treatments 5 and 6 points out that algal productivity is

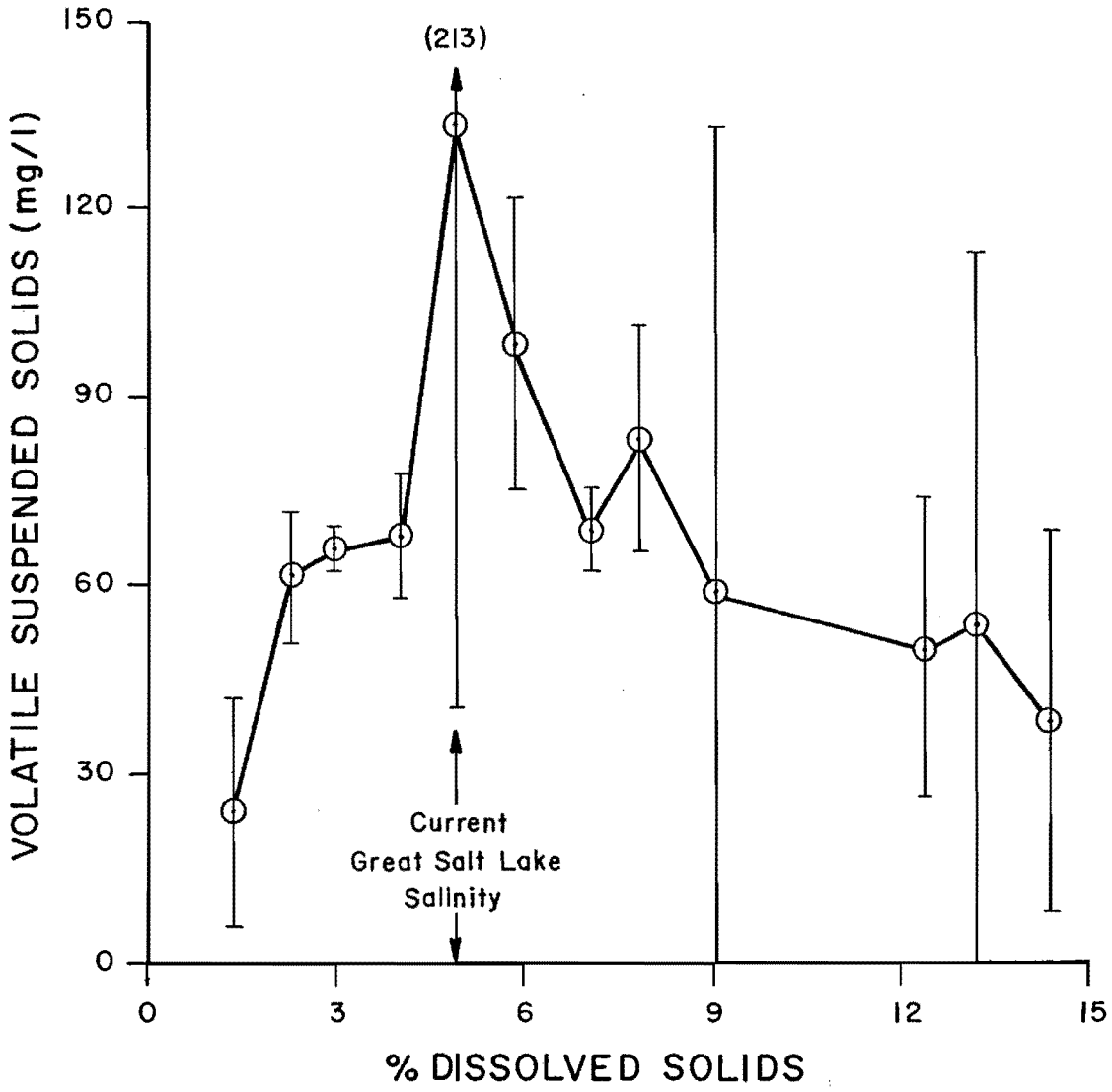

Figure 20. Algal biomass (volatile suspended solids) produced at various Great Salt Lake salinities in closed culture bioassays. Error bars represent plus/minus one standard deviation of the mean of three replicate assays.

Table 6. Salinities and biomass (volatile solids) production for algal growth experiment.

Treatment Number	Total Dissolved Solids (g/l)	Electrical Conductivity mmhos/cm	Terminal Volatile Suspended Solids (mg/l)
1	13.7	20	23.9 ± 10.9
2	22.7	33	61.3 ± 6.4
3	30.2	46	65.6 ± 1.9
4	40.6	57	67.3 ± 5.8
5	49.3	55	126.6 ± 51.3
6*	50.1	61	43.9 ± 22.7
7	59.0	68	98.0 ± 13.8
8	71.0	72	68.9 ± 4.2
9	78.9	74	83.0 ± 10.8
10	90.4	74	57.9 ± 44.6
11	124.0	99	49.6 ± 14.3
12	132.0	104	53.5 ± 34.8
13	144.0	116	37.9 ± 17.8

*Great Salt Lake water with no nutrients added; otherwise identical with treatment No. 5.

nutrient limited, but since both nitrogen and phosphorus were added to each treatment in the bioassay it is not possible to determine which element is limiting.

It is noteworthy that Rhizosolenia, growing in Farmington Bay in December, can dominate other algae under summer temperatures and relative high nutrient concentrations in the laboratory over a broad range of salinities, and that the optimum salinity for this diatom under these artificial conditions appears to be the current salinity of the Bay at the Syracuse causeway. It is doubtful that similar results would be obtained using a pure culture of Nodularia which usually dominates the summer Farmington Bay algae blooms. However, the results of the mixed culture assay point out that the ability of Farmington Bay algae to adapt

to salinity changes must be investigated before a clear understanding can be reached of how salinity concentration changes affect algal blooms in Farmington Bay.

CONCLUSIONS AND RECOMMENDATIONS

A review of the literature and a short-term laboratory study of odor-causing mechanisms in the Great Salt Lake have lead to the following conclusions and recommendations:

1. Brine flies (E. cinerea and E. hians) have inhabited Great Salt Lake in large numbers since earliest recorded history. Decomposing biological matter, produced at all stages of their life cycle, contributes to the objectionable odors emanating from the Great Salt Lake. There may be an increase in brine fly population as lake water freshens because of an increase in the production of algae upon which brine fly larvae feed.

2. Grazing by brine fly larvae helps control the algal biomass, and the flies themselves are an important part of the foodweb of the Great Salt Lake ecosystem. Therefore, artificial control of the flies would have far reaching ecological impacts, and might also intensify the odor problem. Chemical control of the flies would be complicated by their short life span and generation time.

3. Brine fly larvae are apparently able to adapt to salinities ranging from about 1 to 20 percent, but survive better in the lower concentrations.

4. Odor production under anaerobic conditions in sediments polluted by municipal and industrial wastes was comparable in intensity to that in marsh sediments recently inundated by Farmington Bay water.

5. Varying the salinity of the water over these sediments from approximately double the current salinity (10 percent) to one-fourth the current salinity (1.4 percent) did not initially result in obvious differences in odor production, but after 20 days incubation, the lower salinities produced the most intense odors. Similar type studies extended over about a 6-month period, and coupled with field monitoring of odor production in areas of different sediment types, would be needed to adequately interpret these laboratory results.

6. Algae production in three-phase lighted microcosms with "polluted" sediments was very limited; an inhibitory factor is suspected but was not isolated. Studies to identify possible inhibitors should be made.

7. "Polluted" sediments did not release nutrients in the three-phase microcosms, but seemed to act as a sink for both nitrogen and orthophosphate. This phenomenon may contribute to the lack of ability of these sediments to promote algal growth.

8. Marsh sediments released both nitrogen and phosphorus in the three-phase microcosms and supported dense algal blooms dominated by Nodularia sp., the blue-green alga that dominates blooms in Farmington Bay.

9. Algal production was noticeably faster in quarter-strength salinity (1.4 percent) water over the marsh sediments than in other salinity concentrations, but dense growths of algae were also produced in half and full-strength water over marsh sediment within approximately 10 days of microcosm start-up.

10. The strongest odors in water from the aerobic three-phase microcosms were associated with the high algae populations produced

over marsh sediments, but these odor intensities were low compared to those associated with the apparently anaerobic odor microcosms.

11. Field studies are needed to assess the relative importance of brine fly odors, algae odors, and anaerobic sediment odors under natural conditions.

12. Resolving the limits to algae production imposed by increasing or decreasing salinity is a complex problem requiring additional information over longer periods of time on the ability of dominant species of algae to adapt to salinity change. It is estimated that from 6 to 12 months would be required for these adaptations to take place, and data should be collected and analyzed throughout. The diatom Rhizosolenia, that was predominant in samples collected from Farmington Bay on December 10, 1984, dominated laboratory cultures to which nitrogen and phosphorus were added at an average temperature of 25°C over a salinity concentration range of approximately 2 to 14 percent.

13. It is one thing to identify the dominant sources of foul odors in the Great Salt Lake and quite another to devise means of mitigating or controlling them. Preliminary evidence suggests that increasing salinity concentration of the lake water might have a mitigating or deterring effect on odor production. Controlling salinity, within limits, may be possible in some near-shore areas such as Farmington Bay with combinations of diking and pumping. This control scheme may be worthy of a reconnaissance-type study.

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