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## An Ecological analysis of relic diatoms in sediments of Las Vegas Bay, Lake Mead

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University of Nevada,

Las Vegas

An Ecological Analysis of Relic Diatoms  
in Sediments of Las Vegas Bay, Lake Mead

A thesis submitted in partial fulfillment of the  
requirements for the degree of Master of Science  
in Biology

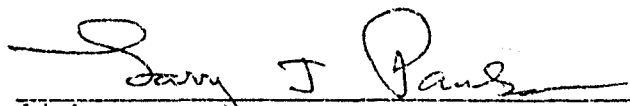
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David Ross Hetzel

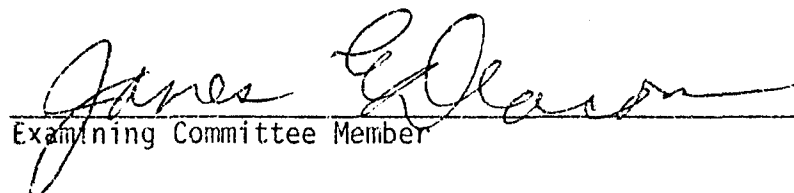
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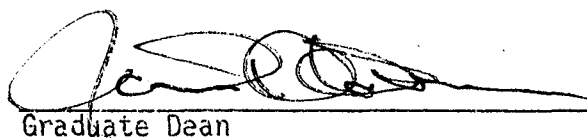
  
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June, 1982

To realize

a dream

exercise

patience and

perseverance

## TABLE OF CONTENTS

Abstract . . . . .	i
Acknowledgements . . . . .	ii
List of Illustrations . . . . .	iv
List of Tables . . . . .	v
1. Introduction . . . . .	1
1.1 Review of Diatom Core Studies . . . . .	1
1.2 Trophic Indicators . . . . .	2
1.3 Study Area . . . . .	8
2. Material and Methods . . . . .	11
2.1 Core Sampling . . . . .	11
2.2 Slide Preparation . . . . .	11
2.3 Enumeration . . . . .	12
3. Results . . . . .	17
3.1 Sedimentation Rates . . . . .	17
3.2 Taxonomic Description of the Sediment	
Diatom Community . . . . .	25
3.3 Trophic State . . . . .	31
4. Discussion . . . . .	31
Bibliography . . . . .	39

## ABSTRACT

Relic diatoms in sediments of the inner Las Vegas Bay, near the Las Vegas Wash sewage inflow, were examined in order to assess historic trophic conditions in this area of Lake Mead. Diatom sedimentation rates and ratios of Araphidineae/Centrales (A/C) diatom groups were determined from sediment cores collected in the old wash channel 1.5 km from the sewage inflow (station 2), in a small cove 1.5 km further downstream (station 3) and in an adjacent embayment off Gypsum Wash (station 4). Diatom sedimentation rates generally increased from the bottom to the top of each core, but pronounced minima existed at various sediment intervals. Siltation from floods that occurred during 1975 appeared to cause these minima and may also have masked true rates of diatom sedimentation and A/C ratios at stations 2 and 4 which were located in areas most affected by flooding. A/C ratios in sediments at station 3 revealed that the inner bay has been primarily mesotrophic-eutrophic since 1971, but a sharp decrease in annual diatom sedimentation rates after 1975 indicates there has been a decline in diatom production. This could, in part, account for the recent decrease in chlorophyll-a concentrations observed in past monitoring of the inner bay.

## ACKNOWLEDGEMENTS

"My son, sayeth the old Indian chief, look upon everything and everyone in this world as teachers. Now go forth, listen and learn" (Ancient Indian Proverb)

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## LIST OF ILLUSTRATIONS

1. Map of Las Vegas Bay showing the location of the sampling stations and the Las Vegas Wash - Lake Mead interface in 1969, 1971, and 1972 . . . . . 10
2. Species area curves for six 1 cm sections from three core samples in Las Vegas Bay, Lake Mead. Sections representing maximum density are illustrated in cores (1a, 2a, 3a) and minimum density in (1b, 2b, 3b) . . . . . 15
3. Diatom sedimentation for three coring stations in Las Vegas Bay, Lake Mead . . . . . 19
4. Las Vegas Wash average monthly discharge with extremes and minima for period of record (USGS data) . . . . . 22
5. Sediment Araphidineae/Centrales trophic ratios for the three coring stations in Las Vegas Bay, Lake Mead . . . . . 37

## LIST OF TABLES

1. Index for Lake Trophic Distinctions Based on  
Araphidineae/Centrales Ratio . . . . . 6
2. Bulk Properties of Sediment Samples from  
Las Vegas Bay . . . . . 24
3. Sedimentation Rates for Diatoms in Las Vegas Bay . . . . . 27
4. Las Vegas Bay Sediment Diatom Species . . . . . 29
5. Dominant Relic Diatom Species Ranking in Las Vegas Bay  
with Diatom Percentages . . . . . 33

## 1. INTRODUCTION

### 1.1 Review of Diatom-Core Studies

Long-term trophic succession patterns in lakes have often been determined from studies of relic diatom remains in sediments. Many of these studies have shown that changes in sediment nutrient concentrations are accompanied by changes in the relic diatom community. Haworth (1969) analyzed changes in Blelham Tarn's relic diatom community from the late glacial period to the present. She concluded that a depletion of nutrients caused changes in certain diatom species commonly associated with eutrophic water. Manny et al. (1978) found historical evidence for succession to eutrophy in a hypereutrophic hardwater lake. Evidence was derived from a paleolimnological study of organic carbon, nitrogen, phosphorus, fossil pigments, pollen and diatoms. Five periods, each with increasing eutrophy, were identified from 14,075 B.P. to present. In Lake Taupo, New Zealand, sediment phosphorus and diatom data indicated that the lake had been oligotrophic for over 14 centuries (Rawlence et al., 1976). The recent appearance of Asterionella formosa Hassall in the sediments indicated a change to more enriched conditions. Haworth (1977) found that changes in diatom assemblages in the sediments of Lake George, Uganda, which spanned the last 3600 years, were due to increases in organic matter and nitrogen compounds in the water.

In other studies, relic diatoms have been used to assess more recent changes in lake trophic conditions that resulted from cultural eutrophication. A classic example of this is work done on Lake

Washington by Stockner and Benson (1967). A striking correlation was found between diatom remains in the sediments and the pattern of sewage enrichment over the past 80 years. The diatom stratigraphy in the sediments of Lake Sallie, Minnesota indicated that benthic and planktonic diatom communities changed in species composition and probably in productivity as a result of cultural eutrophication (Bradbury and Winter, 1976). A study of the biological and chemical characteristics in sediment cores from three mountain lakes was done to assess the effects of recent human activities in the watersheds (Meyerhoff et al., 1978). Increased values of percent organic matter, sedimentary chlorophyll degradation products (SCDP), the Araphidineae/Centrales diatom ratio, and the relative abundance of Fragilaria crotonensis Kitton in the sediments were interpreted to reflect higher productivity.

Thomas and Soltera (1977) found that numbers of diatom frustules in superficial sediment appeared to correspond with levels of planktonic diatom production in the overlaying waters. Haworth (1980) compared 38 years of continuous phytoplankton records with the diatom stratigraphy in the recent sediments of Blelham Tarn. She found that increases or decreases in the number of diatoms in the sediments reflected similar increases or decreases in the planktonic populations, despite modifications caused by wind turbulence, littoral resuspension, redeposition, and losses due to floods or mixing by benthic fauna.

## 1.2 Trophic Indicators

Historically, algal species composition has been used as an indicator of trophic conditions in lakes. It was felt that the autecologies

of certain species were understood well enough to estimate general nutrient conditions in the waters in which they were found (Rawson, 1956). However, caution should be exercised in this analysis since factors other than nutrients also influence the species composition and abundance of phytoplankton. The U.S. Environmental Protection Agency studied 250 lakes in the continental United States and failed to detect any phytoplankton genera that could be classified as trophic level indicators (Taylor et al., 1980).

An early study by Williams (1964) analyzed the relationships between planktonic diatom abundance and water quality in 103 scattered stations on major rivers and the Laurentian Great Lakes of the U.S. and Canada. He concluded that analyzing the diatom community probably was the best way for evaluating water quality. Stockner and Benson (1967) proposed a community scheme based on the Araphidineae/Centrales ratio of planktonic diatom groups in the sediment. The average yearly contribution of species to the sediment was suggested as a sensitive potential indicator of lake trophic state. This principle is based on the observation that lakes which exhibit accelerated eutrophication generally undergo a major shift in planktonic diatoms from initial centrate dominance to an increasing abundance of Araphidineae diatoms. This has been observed in Zurichsee (Thomas, 1964, as cited from Stockner, 1971), Lake Washington (Stockner and Benson, 1967) and Lake Windermere (Pennington, 1943). Data interpretation is not subject to distortion by the presence or absence of a given single species when species are grouped into tribes (Stockner and Benson, 1967). When species have similar ecological requirements, replacement of one by another could occur without large changes in environmental conditions. The nutrient uptake efficiencies between centrates

and tribe Araphidineae are likely to differ based on different cell wall shapes and sizes (Tilman, 1977). The shape of the cell wall of centrates are radially symmetrical while cells in the tribe Araphidineae are bilaterally symmetrical. Cells of spherical shape, which have a larger surface/volume ratio than nonspherical shaped cells are more efficient in nutrient uptake than any other shape because a larger surface area is exposed per unit volume. Also, differences in growth rates, settling time, or predation could alter annual diatom sedimentation rates. These facts weaken the single species scheme of trophic classification and support usage of species grouping.

Stockner (1971) proposed an index for lake trophic distinctions based on the Araphidineae/Centrales ratio (Table 1). This scheme was tested on 16 lakes in the Canadian Experimental Lake Area. The A/C ratio calculated from the superficial sediment counts agreed closely with the trophic state of the lakes as determined by studies of phytoplankton abundance and primary production, zoobenthos, periphyton, and water chemistry (Stockner, 1971). A close agreement was also found between the A/C sediment ratio and the A/C phytoplankton ratio in comparisons of two ELA lakes. Meyerhoff et al. (1978) in their study of three mountain lakes, found the A/C ratio to be a reliable index of the trophic conditions in the lakes.

There are problems, however, with this technique of trophic classification. Stockner (1971) found that in instances where isothermal conditions prevail, such as in shallow lakes, bogs, or rivers, benthic diatom populations will predominate, making the calculation of the planktonic ratio meaningless because benthic populations of diatoms are dominated by Araphidineae and Raphidineae species with few centrates.

Table 1. Index for Lake Trophic Distinctions Based  
on Araphidineae/Centrales Ratio (From  
Stockner 1971).

TABLE 1. INDEX FOR LAKE TROPHIC DISTINCTIONS BASED ON ARAPHIDINEAE/  
CENTRALES RATIO.

Type	A/C
Oligotrophic	0 - 1.0
Mesotrophic	1.0 - 2.0
Eutrophic	>2.0

Koivo and Ritchie (1978) studied 20 boreal-arctic lakes and found the A/C ratio had little relevance. However, they did acknowledge the effectiveness of the index for other geographical regions besides the boreal-arctic region.

The A/C ratio has not been widely used in reservoirs, but it seemed to be an appropriate technique for evaluating trophic state changes in Las Vegas Bay, Lake Mead. This bay receives secondary-treated sewage effluents from metropolitan Las Vegas via Las Vegas Wash. The effluents are high in nutrient loads, which has historically elevated productivity in the inner portion of the bay (Deacon and Tew, 1973; Deacon, 1975, 1976, 1977). Chlorophyll-a concentrations in the bay, however, decreased from a maximum of  $80 \mu\text{g l}^{-1}$  in 1968 to  $25 \mu\text{g l}^{-1}$  in 1978 (Paulson, 1981), despite continued high phosphorus loading from Las Vegas Wash. The decline in chlorophyll-a has been attributed to a reduction in nitrate loading from the Colorado River that occurred after 1970 (Paulson, 1981).

Phosphorus loading into Lake Mead from the Colorado River was reduced from historic levels of about  $6000 \text{ t yr}^{-1}$  (Prentki et al., 1981) to current levels of  $200 \text{ t yr}^{-1}$  (Baker and Paulson, 1981), primarily due to reductions in suspended sediment loads when Glen Canyon Dam was constructed in 1963. From the changes in nutrient loading, Paulson and Baker (1981) concluded that the productivity of Lake Mead must have decreased. Chemical analysis of the sediments (Prentki et al. 1981) have since shown that reservoir-wide productivity has decreased by as much as 77% from pre-Lake Powell levels.

The productivity in Las Vegas Bay was apparently also affected, but Prentki et al. (1981) were only able to date these sediments prior

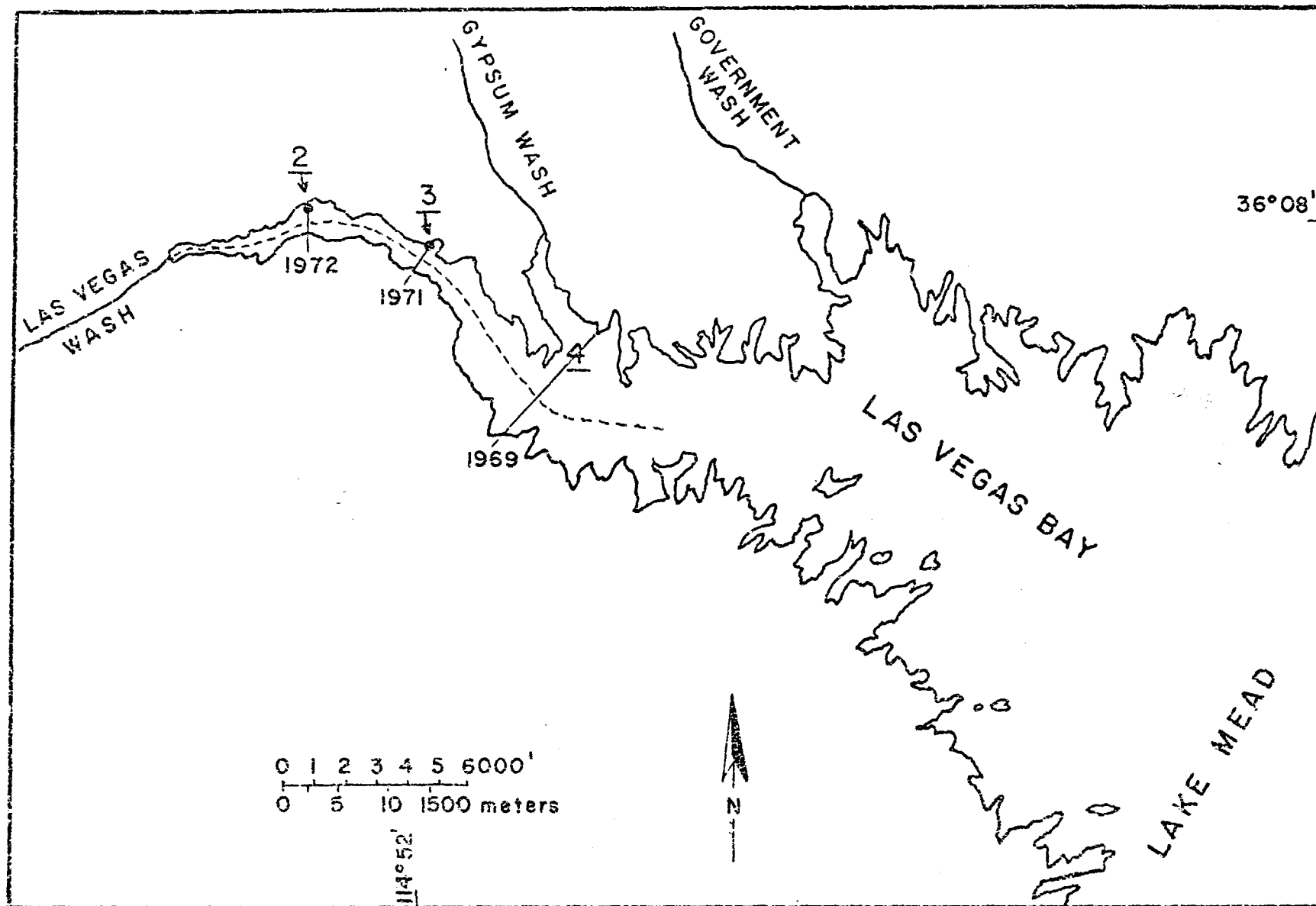
to and after 1969, using  $\text{Cs}^{137}$  analysis. These time periods did not provide adequate resolution for analysis of the events that may have contributed to the decline in chlorophyll-a concentrations after 1968. The purpose of this study is to determine if changes in the diatom populations, as reflected by A/C ratios and diatom sedimentation rates, could have contributed to the decline in chlorophyll-a concentrations in Las Vegas Bay.

### 1.3 Study Area

Las Vegas Bay is a large embayment located in the southwestern portion of Lake Mead (Figure 1). The bay has a surface area of  $26 \times 10^6 \text{ m}^2$  and a volume of  $812 \times 10^6 \text{ m}^3$  at a surface elevation of 360 m (Goldman, 1976). The morphometry is canyon-like in the area where the Las Vegas Wash inflow enters the bay. The Las Vegas Wash-bay interface location varies with lake levels which have risen steadily since 1963. This has progressively shifted the interface location further into Las Vegas Wash (Figure 1).

Las Vegas Wash contributes less than 1% of the annual inflow to Lake Mead, but it carries a large salt load ( $2.4 \times 10^8 \text{ kg yr}^{-1}$ ) (Baker and Paulson, 1981). The Las Vegas Wash inflow forms a density current in Las Vegas Bay as a result of higher salinity in the wash, and temperature differences between the wash and bay (Baker and Paulson, 1981). The Colorado River provides 85% of the inorganic nitrogen to Lake Mead, but Las Vegas Wash contributes the major source (60%) of phosphorus loading ( $263 \times 10^3 \text{ kg yr}^{-1}$ ) (Baker and Paulson, 1981). The high phosphorus loading elevates chlorophyll-a

Figure 1. Map of Las Vegas Bay showing the location of the sampling stations and the Las Vegas Wash - Lake Mead interface in 1969, 1971, and 1972.



concentrations in the inner bay, but concentrations decrease in the middle and outer bay due to dilution of the effluents. Phytoplankton cell abundance in the inner Las Vegas Bay has been limited by nitrogen since 1972 (Deacon and Tew, 1973).

## 2. MATERIAL AND METHODS

### 2.1 Core Sampling

Polyvinylchloride pipe, 122 cm long by 2.54 cm diameter with 0.63 cm thick walls was used to collect sediments. One end of each core was filed into a sharp edge to facilitate penetration into the sediments. Core sampling was done by SCUBA divers. The plastic cores were driven into the sediment and when the top core end was 5 cm from the surface of the sediment, a cap was placed on the top. The core was removed from the sediment, the bottom end capped and then the core was taken to the surface, and stored upright. The cores were then frozen and cut into one centimeter sections using a vibrating saw. Careful notation was made regarding the sediment color and texture. The samples were placed into plastic petri dishes and frozen until further analysis.

### 2.2 Slide Preparation

Approximately 0.5 grams of wet sediment was taken from the central portion of each one centimeter sediment section. Each subsample was placed in a plastic jar and treated with 5.0 ml concentrated

$\text{HNO}_3$  to homogenize the sample and degrade organic matter and residual carbonates. After one minute, 45 ml of distilled water were added and the mixture was shaken thoroughly to insure a random distribution of particles. Depending on the density of diatoms in the mixture, 0.5, 1.0, or 2.0 ml were immediately injected into a 125 ml Erlenmeyer flask using a MLA (Medical Laboratory Automation, Inc.) microliter pipette. Five ml of  $\text{HNO}_3$  and 10 ml of water were then added and the mixture was heated and allowed to boil for one minute. Ten ml of water were added to aid in cooling and to dilute the acid and prevent damage to the filter. The cleaned sample was filtered through a 0.45  $\mu\text{m}$  HA Millipore filter (Millipore Corp, 1974) under low pressure (approximately 5 inches Hg of vacuum). The flask was rinsed with distilled water five times, and the rinse water filtered to insure that all of the diatoms had been recovered from the sides of the flask. The filtering tower was rinsed in the same manner. The filter was placed on a clean glass microscope slide with a drop of immersion oil in the center and the filter was allowed to clear by air drying. A permanent slide was made by placing a drop of Permount on the cleaned filter. The filter was covered with a glass cover slip and the periphery sealed with fingernail polish.

### 2.3 Enumeration

Diatoms were counted using an American Optical phase - contrast microscope. Species were identified using oil immersion, 1000X magnification. Strip transects were counted under 400X magnification until approximately 400 diatom frustules had been enumerated or  $8.8 \text{ mm}^2$

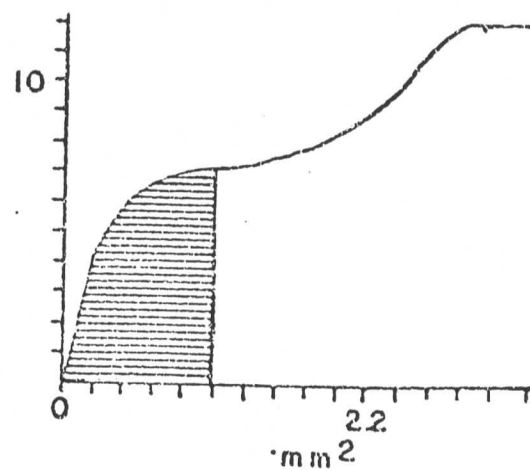
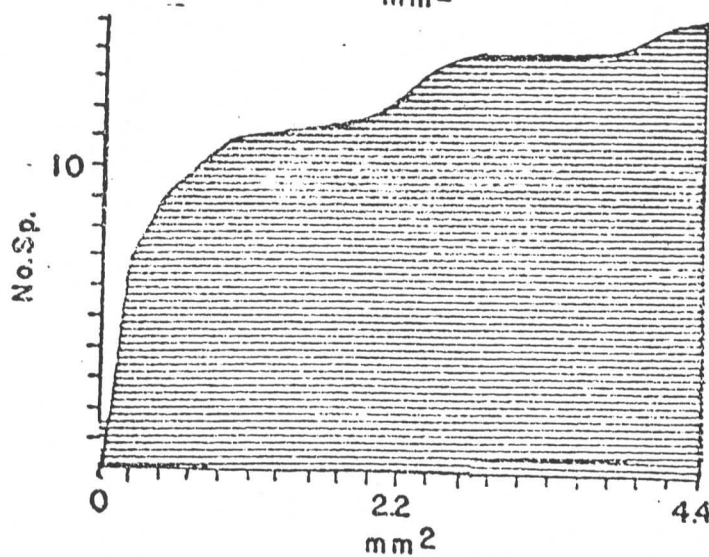
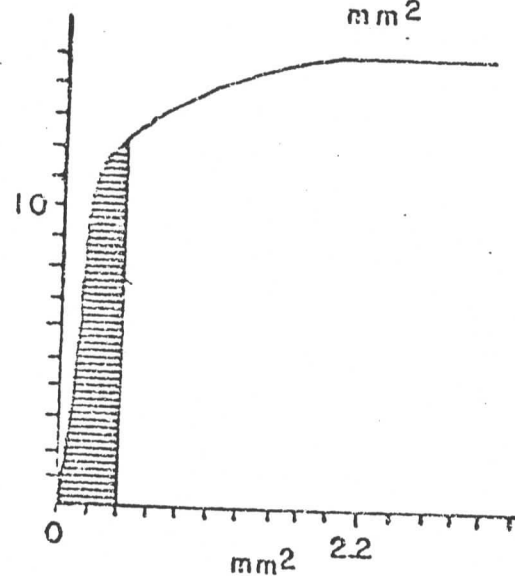
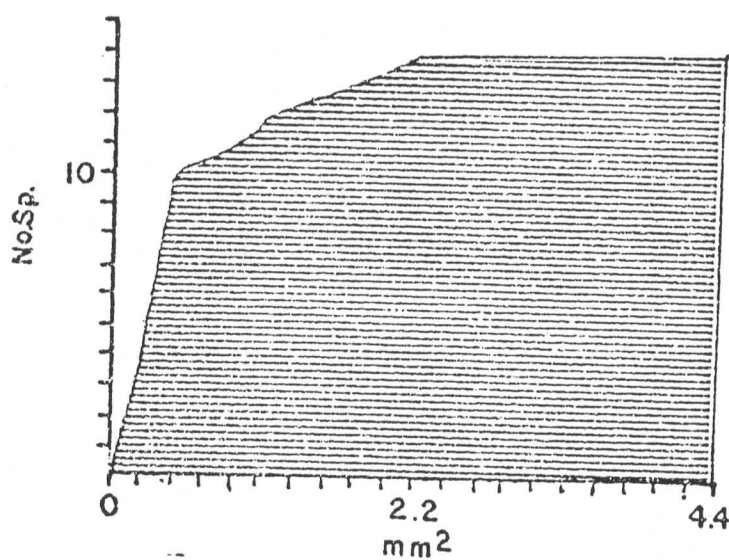
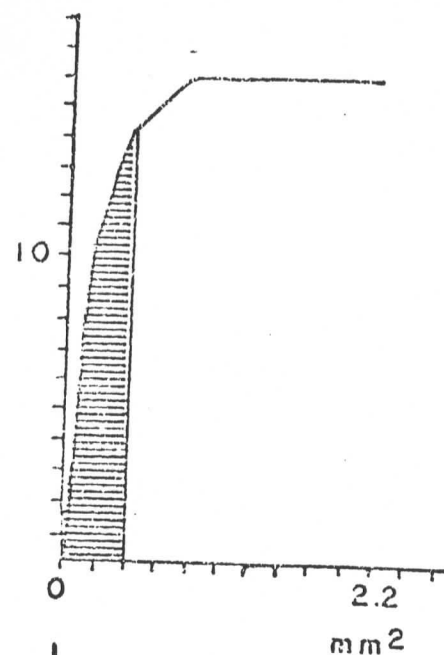
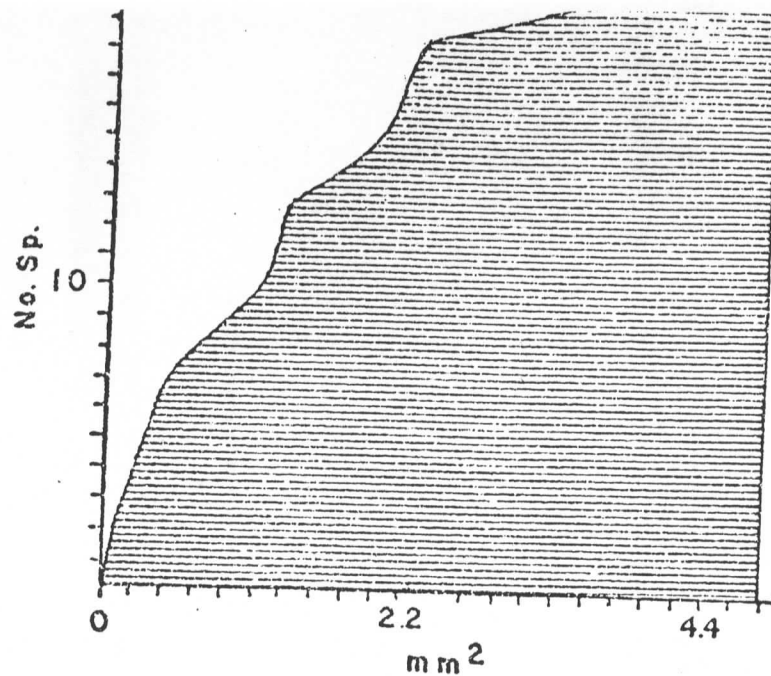
had been examined on the filter, depending on diatom density. Diatom taxonomy and nomenclature followed Patrick and Reimer (1966), Hustedt (1930), Czarnecki and Blinn (1977, 1978).

To insure that the common species were being accounted for, six species-area curves, two for each core, were made (Figure 2). Diatom species which comprised greater than 10% of the total population were considered to be common. A maximum and a minimum species richness slide for each core was analyzed. This was done to ensure that a sufficient area of the slide was being analyzed to account for all common species. Column A represents sections from each core which had the minimum species richness. An area of  $4.4 \text{ mm}^2$  was analyzed for common species. With the exception of core 3B, few new common species were found after  $2.2 \text{ mm}^2$ . Column B represents sections from each core which had a maximum species richness. A total of 400 diatom frustules were counted on slides with high diatom densities. Two and three new common species appeared after  $0.44 \text{ mm}^2$  in cores 1B and 2B respectively while six common species appeared after  $0.44 \text{ mm}^2$  in core 3B.

A Chi-Square test for showing that the data did not depend on the transects was performed on the species distribution data. This showed no significant difference ( $p > .05\%$ ) among transects on the slide or among subsampling from the cleaned sample mixture used to make the slide. This indicates that a uniform distribution was obtained.

All diatoms or diatom fragments with central areas or other distinctive morphological structures intact were enumerated. Battarbee (1979) found that Fragilaria crotonensis may have been underestimated due to breakage into fragments too small to be identified clearly.

Figure 2. Species area curves for six 1 cm sections from three core samples in Las Vegas Bay, Lake Mead. Sections representing minimum species richness are illustrated in cores (1a, 2a, 3a) and maximum species richness in (1b, 2b, 3b). Striped area represents the area examined in calculating for diatom densities.



AREA EXAMINED IN ACTUAL ANALYSIS

This area represents at least 4.4  $\text{mm}^2$  (A) or 400 diatom frustules (B).

I did not observe this in the Las Vegas Bay sediments. Although the long, slender apices occasionally were broken, the central areas remained intact. This may be a function of the length of time that the diatom remains in the sediment. Three replicates were run on four random samples, and one selected depth of each core. A random number generator was used to select which sample to test. The coefficient of variability for the log-normal transformations was 9% for core 2, 10% for core 3, and 12% for core 4, reflecting a high level of precision.

Cell abundance was expressed in cells per milligram dry weight. This was computed by equation 1:

$$D_c = (V_t A_f W C) / (1000 V_a L_f W_f S D) \quad (1)$$

where:

$D_c$  = Diatom cell density per mg dry weight

$V_t$  = Total volume of mixture (50 ml)

$V_a$  = Total volume of mixture analyzed (0.5, 1.0, 2.0 ml)

$A_f$  = Area of filter ( $\text{mm}^2$ )

$L_f$  = Length of strip analyzed (mm)

$W_f$  = Width of strip analyzed (mm)

$S_w$  = Wet weight of sediment subsampled from core (g)

$W$  = Wet weight of sediment (g)

$D$  = Dry weight of sediment (g)

$C$  = Cells counted

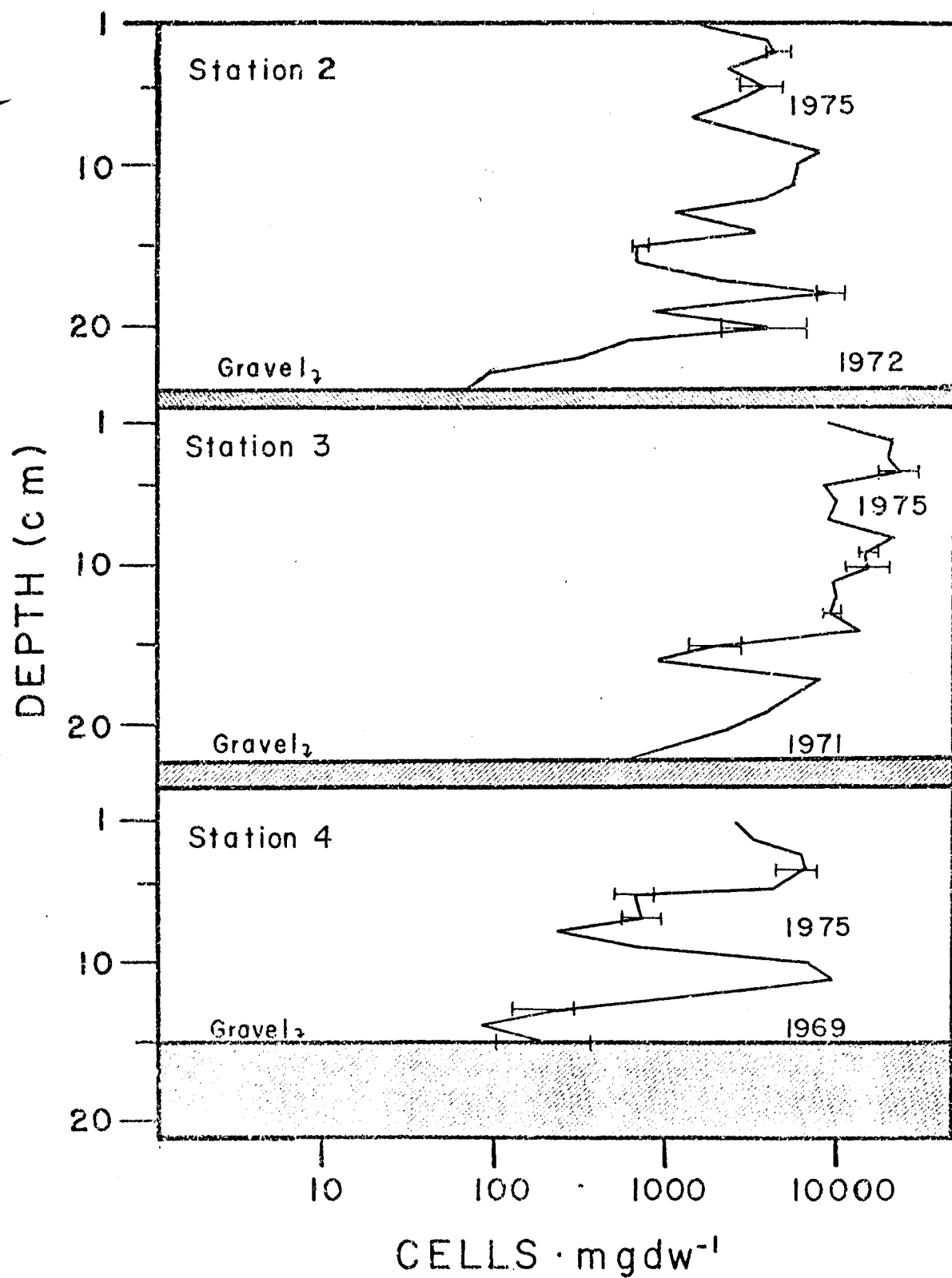
Average annual areal diatom sedimentation rates ( $\text{cells cm}^{-2} \text{ yr}^{-1}$ ) were calculated by multiplying diatom densities ( $\text{cell milligram dry weight}^{-1} \text{ yr}^{-1}$ ) in layers of each core by bulk density ( $\text{mgdw cm}^{-3}$ ) measurements made by Prentki et al. (1981) at station 3.

### 3. RESULTS

#### 3.1 Sedimentation Rates

Diatom sedimentation ( $\text{cells . mgdw}^{-1}$ ) computed for the three sediment coring stations are presented in Figure 3. There was considerable variation in the diatom sedimentation rates at each station. This was most pronounced at station 4 where rates ranged from 10,000  $\text{cells . mgdw}^{-1}$  to fewer than 100  $\text{cells . mgdw}^{-1}$ . Similar variations existed at the other stations, but the magnitude was not as great as at station 4. The general pattern was for an increase in sedimentation from the bottom to the top of the core. However, pronounced minima existed at various intervals in all cores. This indicated that perhaps the minima were caused by a common process.

Figure 3. Diatom sedimentation for three coring stations in Las Vegas Bay, Lake Mead. Error bars represent three replicates which were run on four random samples and one selected depth from each core.



Flooding has commonly occurred in the Las Vegas Wash and Gypsum Wash inflows to Las Vegas Bay (Figure 4). The largest flood on record occurred in 1975 when flows in Las Vegas Wash increased to 2400 CFS ( $68 \text{ m sec}^{-1}$ ) (Figure 4). This was followed by another large flood of nearly 1000 CFS ( $28 \text{ m sec}^{-1}$ ) in February of 1976. These floods resulted in enormous erosion in Las Vegas Wash which deposited large amounts of suspended sediments into the mouth of Las Vegas Bay. Floods of lower magnitude have been observed to disperse sediment throughout the inner bay and out into the middle portion of Las Vegas Bay (Paulson, personal communication). The minima that occurred in the diatom sedimentation rates appear to reflect dilution caused by siltation. The flood induced siltation increases the sedimentation resulting in a dilution of diatom concentration in the sediments.

Further evidence that the minima are caused by the 1975 and 1976 floods was derived from a recent study of the sediment particle composition of cores collected in the vicinity of my sampling stations (Murray et al., 1981). This study is limited in that no replicates were taken to insure precision of the results. However, given that it is the only data base of particle size composition in Las Vegas Bay, I utilized this resource. At station 2, there was an increase in the percentage of sand within the core between 6 and 8 cm (Table 2). They also found an increase in silt fraction of sediments between 6 and 8 cm at stations 3 and 4. This pattern of settling is expected from flooding conditions in which heavier sand would settle out faster than would silt. The minimum that occurred in diatom deposition at 7 cm within the three cores and the percentage of sand and silt provided a useful marker whereby sedimentation rates per

Figure 4. Las Vegas Wash average monthly discharge with extremes and minima for period of record (USGS data).

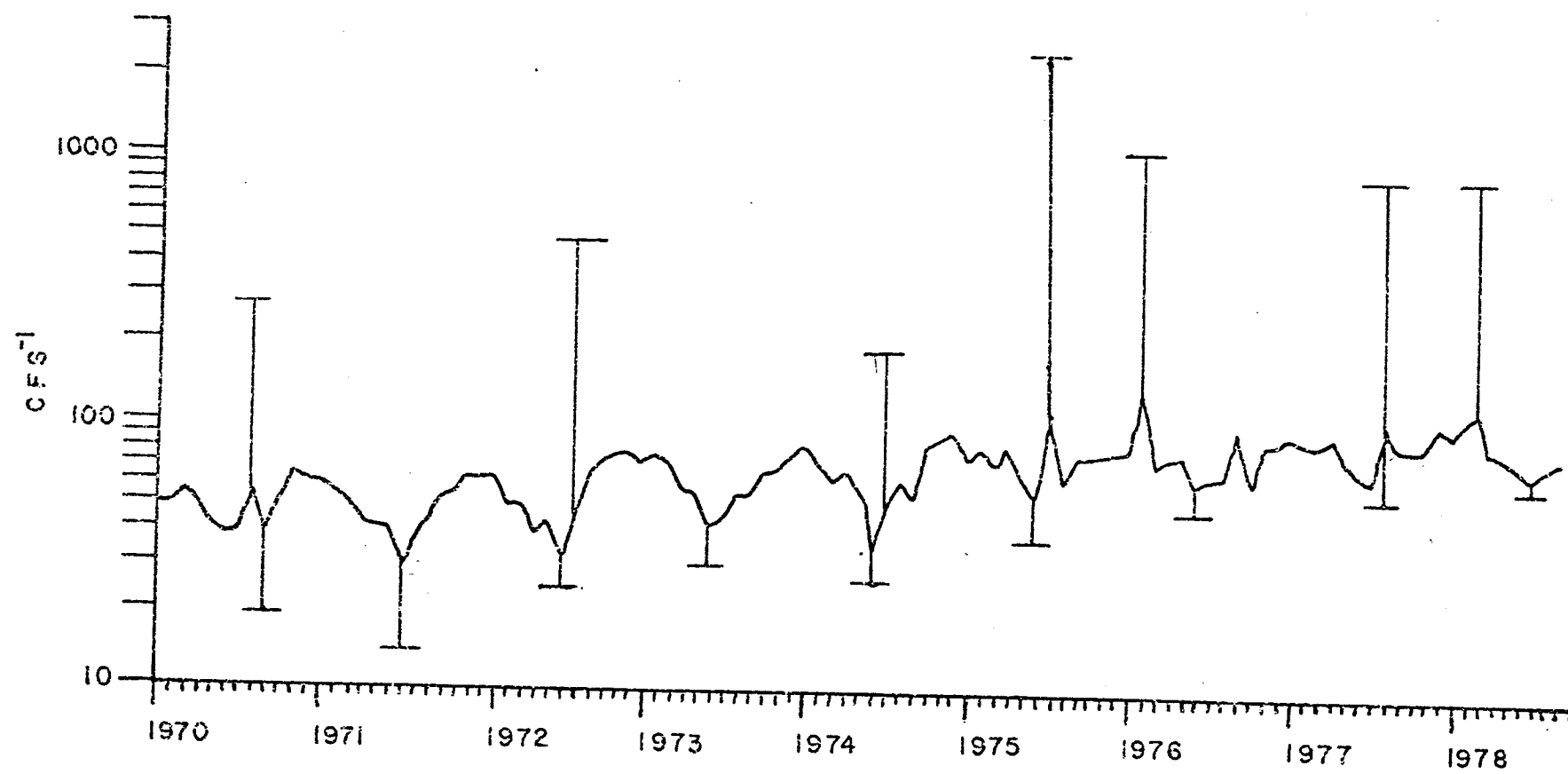


Table 2. Bulk Properties of Sediment Samples From  
Las Vegas Bay.

TABLE 2. BULK PROPERTIES OF SEDIMENT SAMPLES FROM LAS VEGAS BAY  
(From Murray et al., 1981).

	cm	% Sand	% Silt
Core 2	0-2	27.0	52.3
	2-4	58.0	31.9
	4-6	-	-
	6-8	89.0	8.6
	8-10	-	-
	10-13	74.4	18.9
	13-17	66.3	29.6
Core 3	2-4	0.20	71.2
	6-8	0.63	79.3
	13-16	0.50	74.7
	22-25	0.49	82.8
	25-31	0.38	73.1
Core 4	0-2	0.21	70.6
	2-4	0.31	71.3
	4-6	-	-
	6-8	1.5	79.4
	10-13	38.4	52.5
	13-16	36.1	50.6

unit time could be computed for each station (Table 3). It was also possible to establish another marker for the old reservoir floor. The upper most gravel layer was assigned the date of the last period of dessication at each site.

The sedimentation rates computed for each station using these dates are given in Table 3. There was a decrease in sedimentation rates at station 2 and 3 after 1975 but little change at station 4. Sedimentation rates at station 3 were higher than those at station 2 for comparable periods.

### 3.2 Taxonomic Description of the Sediment Diatom Community

A total of 41 different diatom genera, species or variations were identified in samples from the sediment cores (Table 4). There were five species whose abundance comprised more than 10% of the total diatom population. These included Fragilaria crotonensis Kitton, Cyclotella glomerata Bachmann, Asterionella formosa Hassall, Fragilaria construens var. venter (Ehr.) Grunow and Amphora perpusilla (Grun) var. perpusilla. A. perpusilla var. perpusilla is a common periphytic species while the others are common in the phytoplankton. These dominant algae were in the order Centrales or the tribe Araphidineae.

The same species generally occurred in all three sediment cores, but there were differences in dominance between the three stations. The species with the largest cell abundance was considered dominant. F. crotonensis was dominant throughout the sediment core at station 4 except for a brief appearance of C. glomerata in the 6 cm interval

Table 3. Sedimentation Rates for Diatoms in Las Vegas Bay.

TABLE 3. SEDIMENTATION RATES FOR DIATOMS IN LAS VEGAS BAY.

Station	Time Interval	Cell/cm <sup>2</sup> /yr x 10 <sup>3</sup>
2	1972 - 1974	17545
	1975 - 1976	2795
3	1971 - 1974	35094
	1975 - 1976	13532
4	1969 - 1974	3027
	1975 - 1976	3449

Table 4. Las Vegas Bay Sediment Diatom Species.

TABLE 4. LAS VEGAS BAY SEDIMENT DIATOM SPECIES.

## ARAPHIDINEAE

Asterionella formosa HassallFragilaria capucina var. mesolepta (Rabh.) GrunowF. construens var. subsalina Hustedt (?)F. construens var. venter (Ehr.) GrunowF. crotonensis KittonF. pinnata Ehr.Synedra rumpens var. meneghiniana Grun.S. ulna (Nitz.) Ehr. var. ulna

## RAPHDINEAE

Amphora coffeiformis (Ag.) Kutz.A. perpusilla (Grun.) var. perpusillaCaloneis lewisii Patr. var. lewisiiC. ventricosa var. truncatula (Grun.) Meist.Cocconeis placentula Ehr.Cymatopleura solea (Breb.) W. SmithCymbella affinis Kutz.Denticula elegans Kutz.Diploneis puella (Schumann) Cleve.Epithemia sorex Kutz. var. sorexGomphonema affine Kutz. var. insigneG. angustatum (Kutz.) Rabh. var. angustatumG. parvulum Kutz.Mastogloia dieselbe var. lacustrisNavicula sp.Navicula capitata var. hungarica (Grun.) RossN. cryptocephala var. veneta (Kutz.) Rabh.N. cuspidata Kutz. (?)N. pupula var. rectangularis (Greg.) Grun.Navicula sp.Nitzschia amphibia Grun.N. linearis W. SmithN. sinuata var. tabellaria (Grun.) Bourrelly

(Continued)

TABLE 4. LAS VEGAS BAY SEDIMENT DIATOM SPECIES (Continued)

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Rhoicosphenia curvata (Kutz.) Grun.

Rhopalodia gibba (Ehr.) O. Mull.

Stauroneis (probably)

Surirella ovalis (Breb.)

CENTRALES

Cyclotella glomerata Bachmann

C. meneghiniana Kutz.

M. sp.

Melosira granulata (Ehr.) Ralfs

M. varians C. A. Ag.

Stephanodiscus astrea (Ehr.) Grun.

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(Table 5). At station 3, dominance shifted between C. glomerata and F. crotonensis but C. glomerata was dominant more frequently. A. formosa and F. construens also appeared as the dominant species for brief periods.

### 3.3 Trophic State

The dominant phytoplanktonic diatom species observed in sediment cores in Las Vegas Bay were included in the tribe Araphidineae or centrates. It was therefore possible to compute an Araphidineae/Centrales ratio for each sediment core based on a trophic state scheme of 1 to 3 proposed by Stockner (1971). The index for lake trophic distinctions based on the A/C ratio is given in Table 1. The ratios computed from sediment cores in Las Vegas Bay are presented in Figure 5 and indicate that there have been considerable fluctuations in the trophic state of inner Las Vegas Bay. Station 2 showed an early oligotrophic state changing at 11 cm interval to a meso-eutrophic state. The trophic state at station 3 fluctuated from oligotrophic to eutrophic, but the trend has been toward eutrophy in recent years. Station 4 was eutrophic with a few peaks into mesotrophy and oligotrophy.

## 4. DISCUSSION

There were marked spatial and temporal variations in diatom sedimentation rates in the inner Las Vegas Bay. Prior to 1975, annual sedimentation rates averaged  $1.7545 \times 10^7$  cells  $\text{cm}^{-2} \text{yr}^{-1}$  at

Table 5. Dominant Relic Diatom Species Ranking in Las Vegas Bay with Diatom Percentages.

TABLE 5. DOMINANT RELIC DIATOM SPECIES RANKING IN LAS VEGAS BAY WITH DIATOM PERCENTAGES.

	Station 2	%	Station 3	%	Station 4	%
1	F.const.	30	F.c.	59	F.c.	46
2	C.g.	31		58		51
3	F.c.	44		58		59
4		24		59		69
5		35		61		60
6	C.g.	38	C.g.	47	C.g.	53
7	C.g./F.c.	30	F.c.	61	F.c.	40
8	F.c.	44		72	F.c./F.const.	17
9	A.f.	25		72		41
10		18		72		79
11	C.g.	30		72		79
12		38		54		79
13		46		36	1969	42
14		73		50		
15	F.c.	55	C.g.	67		
16	C.g.	50		50		
17		36	F.c.	33		
18		35		38		
19		34		48		
20	C.g./A.f.	22	C.g.	51		
21		45		27		
22		37	— 1971	21		
23		44				
24	— 1972	47				

F.const. = Fragilaria construensF.c. = F. crotonensisC.g. = Cyclotella glomerataA.f. = Asterionella formosa

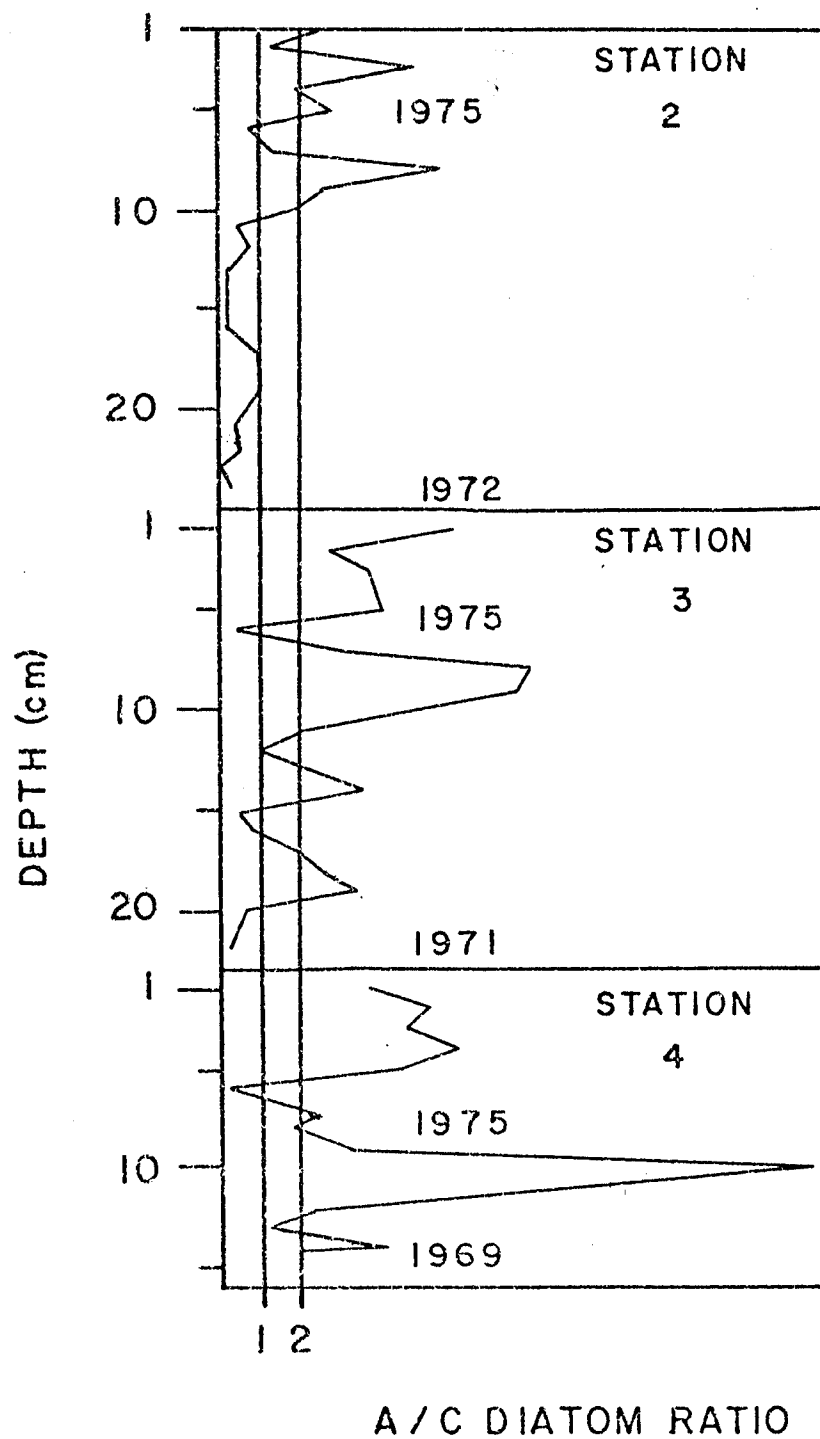
station 2,  $3.5,094 \times 10^7$  cells  $\text{cm}^{-2} \text{yr}^{-1}$  at station 3 and  $3027 \times 10^3$  cells  $\text{cm}^{-2} \text{yr}^{-1}$  at station 4 (Table 3). Average annual sedimentation rates decreased to  $2.795 \times 10^6$  cells  $\text{cm}^{-2} \text{yr}^{-1}$  at station 2,  $1.3532 \times 10^7$  cells  $\text{cm}^{-2} \text{yr}^{-1}$  at station 3 but remained almost unchanged at station 4 during the 1975-1979 period. These patterns are consistent with historic monitoring data in that chlorophyll-a concentrations in the inner bay have decreased from an annual maximum of approximately  $80 \mu\text{g l}^{-1}$  to approximately  $25 \mu\text{g l}^{-1}$  since the first measurements were made in 1968 (Paulson, 1981). However, the higher sedimentation rates at station 3 were unexpected based on a consistent trend observed in the historic monitoring data. Chlorophyll-a and phytoplankton productivity decrease progressively from the inner Las Vegas Bay to the outer bay (Deacon and Tew, 1973; Deacon, 1975, 1976, 1977 and Paulson et al., 1980) due to progressive dilution of the Las Vegas Wash inflow. Diatom sedimentation and the A/C ratio should, therefore, be higher at station 2.

The apparent discrepancy between spatial patterns in diatom sedimentation the A/C ratio and historic monitoring data appears to be due to siltation. Siltation from the floods that occurred in Las Vegas Wash (Figure 4) during the summer of 1975 and winter of 1976 resulted in minimums in the 6-8 cm intervals of the cores. High siltation acts to dilute diatom densities in these layers and results in lower estimates of diatom sedimentation. I tried to compensate for this by computing average annual areal diatom sedimentation (cells  $\text{cm}^{-2} \text{yr}^{-1}$ ) for each time period. In order to make these calculations, I multiplied diatom densities (cells  $\text{mgdw}^{-1} \text{yr}^{-1}$ ) in layers of each core by bulk density ( $\text{mgdw cm}^{-3}$ ) measurements made by Prentki et al. (1981)

at station 3. The floods that occurred in 1975 and 1976 initiated bedcutting in Las Vegas Wash that resulted in high erosion under normal flows in the wash during 1975-1979. The erosion caused an extensive delta to form upstream from station 2. It also resulted in higher siltation at station 2. The percentage of sand in these sediments (Table 2) was considerably higher than at the other stations. Sand ranged from 60-75% in the 10-17 cm interval to 89% in the 6-8 cm intervals (Murray et al., 1981). However, this decreased to 58% in the 2-4 cm layers and 27% in the 0-2 cm layers. Silt fractions comprised the major percentage of sediment at station 3, and in the layer above 6-8 cm at station 4. Below 10 cm at station 4, the percentage sand increased to 35-40% (Murray et al., 1981). Sand has a different bulk density than silt, and the use of Prentki et al. (1981) data for station 3 apparently resulted in underestimates of diatom sedimentation rates in sand layers of station 2 and 4. However, rates estimated for station 3 should be accurate because this station is the same location used by Prentki to determine bulk sediment rates. At this station diatom sedimentation decreased after 1975. This is consistent with historic monitoring data and indicates that reductions in the diatom population after 1975 likely did contribute to the decline observed in chlorophyll-a concentrations.

The application of Stockner's A/C ratio to sediments in Las Vegas Bay indicates that trophic state has ranged from oligotrophic to eutrophic at each station (Figure 5). The A/C ratios showed that oligotrophic conditions persisted during early inundation at Station 2 and periodically at stations 3 and 4. Historic monitoring data show that oligotrophic conditions have never existed in the inner Las Vegas Bay (Deacon and

Figure 5. Sediment Araphidineae/Centrales trophic ratios for the three coring stations in Las Vegas Bay, Lake Mead.



Tew, 1973; Deacon 1975, 1976, 1977; Paulson, 1981). Although chlorophyll-a maximas decreased from  $80 \mu\text{g l}^{-1}$  in 1968 to  $25 \mu\text{g l}^{-1}$  in 1978, the inner bay has still been mesotrophic-eutrophic since monitoring began.

The low A/C ratios in the sediments at the bottom of station 2 and in the 1975 sediment layers at each station suggest that the A/C ratios were also altered by siltation. The mechanisms for this are not known but could involve some sort of differential sedimentation of the various diatom groups. Increased turbidity which would decrease the light penetration may have also altered the diatom composition. Araphidineae and centrate diatoms are also present in marsh areas of Las Vegas Wash (Deacon and Tew, 1973), and erosion could result in advective inputs of certain species into the bay.

It is thus difficult to use Stockner's A/C ratios for assessing changes in past trophic conditions in Las Vegas Bay. Differential settling of diatom groups and contamination from Las Vegas Wash diatoms may have affected true A/C values. Nonetheless, changes in rates of diatom sedimentation at station 3 do indicate that decreased diatom abundance could have contributed to the decline in chlorophyll-a values since 1968.

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