Research Technical Completion Report

BLUE-GREEN ALGAE TOXICITY IN BLACK LAKE, KOOTENAI COUNTY, IDAHO

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and

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ABSTRACT

Increasing occurrences of explosive growths or blooms of blue-green algae in lakes throughout the western United States have been linked to recreational use, sewage inputs, and non-point runoff associated with agriculture and grazing. In certain instances these blooms produce a toxin which can be lethal to fish, aquatic invertebrates, mammals and humans.

Black Lake in northern Idaho has experienced massive late summer and fall growths of a toxic algae, *Nostoc commune*. At times, demonstrated fatal toxicity to cattle and small mammals has resulted in three of the last four years. Since little is known of the exact environmental conditions required to cause toxicity, environmental and phytoplankton parameters were monitored throughout the lake during summer and fall, 1984.

Although conditions seemed favorable, and other blooms were intermittent through the summer-fall 1984, *Nostoc* did not develop to bloom proportions and toxicity did not occur. Algal assay results showed that algal growth potential ranged in the very productive range of 9.60 to 12.16 mg dry weight l^{-1}/14 days for the late summer-early fall period. The limiting nutrient switched from phosphorus to nitrogen during the fall months, also indicating the potential for a *Nostoc* bloom. All indicators showed that Black Lake was highly productive in 1984 despite the absence of a toxic *Nostoc* bloom. Water transparency ranged from 0.8 to 3.4 m, averaging 1.2 m from June to October. pH values went as high as 8.2, with the total absence of CO_2 in some of the littoral areas. Dissolved oxygen values were at

super saturated levels throughout most of the sampling regime. Diatoms (Fragilaria sp., Melosira sp., and Asterionella sp.) dominated the phytoplankton composition with Nostoc only showing up in early August. Chlorophyll "a" values correlated with phytoplankton trends, with highs of 15 to 31 mgl^{-1}, and lows of 0 to 5 mgl^{-1}.

The fact that Black Lake is clearly eutrophic, and that the potential for a blue-green bloom was present but did not materialize, may possibly be explained by two factors...climatological trends and stratification pattern. The absence of a well developed hypolimion along with excessive cloudiness and lack of a protacted calm, bright, and warm fall may have accounted for the lack of a toxic bloom in Black Lake during 1984.

INTRODUCTION

Increasing occurrences of explosive growths or blooms of blue-green algae in lakes throughout the western United States have been associated with recreational use and sewage inputs to these lakes. As these largely point sources are brought under treatment, the contributing role of non-point pollution sources associated with agricultural and grazing use is becoming apparent as a significant, and in some cases, the major cause of these blooms. Stream degradation is also known to occur, but the lake basins or watershed low points show cumulative effects of excessive nutrient loading.

Black Lake in North Idaho is now at this point, with massive late summer and fall growths of a toxic alga (actually a cyanobacteria), Nostoc commune. At times, demonstrated fatal toxicity to cattle and small mammals has resulted in the last four years. Algal toxicity arises when dense concentrations of blue-green algae produce a neurotoxin which can be lethal to fish, aquatic invertebrates, and all mammals, including man. At lower concentrations, algal toxicity manifests itself as the cause of gastro-enteritis, simlar to bacterially-caused water-born outbreaks of intestinal upsets. Water managers are, therefore, faced with a situation of severe water use limitations to a multitude of water users...lakeshore cabin owners, fishermen, recreational boaters, and ranchers.

Objectives:

This study has the following objectives:

1. To document the biological elements and timing of toxic blue-green blooms in Black Lake of northern Idaho;

2. To relate the above to the physical-chemical environment before and during the bloom occurrence;

3. To determine bloom toxicity throughout the above sequence; and

4. To calculate annual loading of nitrogen, phosphorus, and organic matter by major sources to Black Lake.

Justification:

It has long been known that certain types of algae produce toxins detrimental to both man and other animals. Since the first documented case reported by Francis (1878), when mass killings of sheep and cattle were observed on the shores of Lake Alexandrina, South Australia, there have been numerous reports of similar occurrences around the world. More recently, summer fish kills are being attributed to algal toxicity where formerly such events were routinely ascribed to deoxygenation or pesticide toxicity (Gorham and Carmichael 1980). These losses have usually occurred during terminal stages of a massive algal bloom (Olson 1960). As supported by the recent lake classification survey in Idaho (Milligan et al. 1983), these explosive algal growths in much of the western United States, and especially the Northwest, are often associated with mismanagement of cattle grazing on forests and their related rangelands, leading to excessive silt and nutrient runoff.

The freshwater algae strains most frequently accounting for such heavy blooms include Anabaena flos-aquae, Microcystis aeruginosa, Aphanizomenon flos-aquae, and Nostoc commune (= Anabaena flos-aquae). All of these are known to produce endotoxins (Carmichael 1981), but in a pattern of unpredictability. These strains are only toxic under bloom conditions, however, implying that toxicity is affected by different environmental conditions prior to or at the time of bloom development (Carmichael and Gorham 1977). Ecological conditions in lakes favoring these blooms are high nutrients (especially nitrogen and phosphorus), high temperatures, and high carbon dioxide reserves as dissolved bicarbonates (Prescott 1948, Vollenweider 1968). These algal species can reproduce under such conditions, and their habit of floating high in the water can cause them to become concentrated on the downwind side of the lake, resulting in the occurrence of thick green surface scums. At such times, usually in the late summer or fall of the year, these concentrations result in large-scale livestock poisonings or massive fish dieoffs. Anatoxin A is the most commonly produced toxin of the freshwater blue-green algae.

Anatoxin A, acting as a powerful neuromuscular blocking agent, can become concentrated enough to cause illness or death in almost any mammal, bird, or fish which ingests enough of the toxin cells or extracellular toxin (Carmichael 1981). Although there is no definitive evidence that Anatoxin A produces oral toxicity in humans, there is increasing evidence for certain gastrointestinal disorders and skin irritations caused by contact with the poison (Sykora and Keleti 1981). The toxin will only be produced by a concentrated bloom of algae...perhaps of adaptive significance as a population self-limiter. Despite that known fact, we know little of the exact requirements for toxicity production. The timing, intensity, or even the occurrence of toxicity production in a bloom of _N. commune_ cannot be predicted at this time (Gorham and Carmichael and Bent 1981).

The Regional Problem:

Black Lake in northern Idaho is such a lake whose watershed is principally agricultural and grazed forest land. Stream deterioration is severe with subsequent high runoff of silt and nutrients, especially phosphorus, to the lake. The degraded watershed conditions have been documented by Hagihara (1983). These studies, along with Milligan et al. 1983, then further related those cause-effect scenarios to resulting algal blooms in the lakes. Black Lake has an additional problem of feedlot drainage to the lake.

In the fall of 1981, such a bloom with associated toxicity occurred in Black Lake. Five cattle and two dogs died shortly after drinking water from a lake shore where algae had become concentrated (R. Krieger, Personal communication 1983). *Nostoc commune* was identified a few weeks later as the dominant blue-green alga present at that time (Kann 1983). Based upon the speed of death and symptoms occurring just prior to death (i.e., convulsions, respiratory distress, and neural toxicity), Anatoxin A was judged to be the agent of toxicity (R. Krieger, personal communication 1983). This was further substantiated by mouse bioassays on the lake water. Outbreaks of toxicity also related to a bloom of *N. commune* again occurred in Black Lake in the fall of both 1982 and 1983. Livestock mortality was observed in each instance.

Physical Characteristics:

Black Lake is a shallow, eutrophic lake located in the floodplain of the Spokane-Coeur d'Alene River system (River mile 135) in northern Idaho at an elevation of 655 meters. Located on the Coeur d'Alene

River approximately four miles above Lake Coeur d'Alene, it has a surface area of 162 hectares, with mean and maximum depths of 4.6 and 7.9 m, respectively. Its approximate volume is 7.32 x 10^6 m^3 (6,000 acre feet). There is one outflow channel connecting Black Lake to the Coeur d'Alene River, with backflow into the lake occurring at high flows in March and April.

The surrounding watershed is largely agricultural, consisting mainly of cattle ranching and wheat farming. The lake itself sustains extensive recreational use by fishermen and water skiers during the summer months. Year-round and summer residences (< 30) are also scattered around the lake shore.

In the spring of each year, Black Lake receives effluent from two adjacent winter cattle feeding areas. This effluent consists of spring flood water which has collected on the floodplain pastures during runoff. It is then pumped into the lake via three pumps located at two locations (Figure 1). In addition to this effluent and to the river backflow, there are also four surface tributaries contributing to Black Lake inflows (Figure 1). The average flushing time for the lake is 10.5 months. The surface level of Black Lake fluctuates 1.5 to 2.0 m annually, and is controlled by the Post Falls dam located downstream on the Spokane River (RM 100.7). Low levels occur from October until high flows in spring.

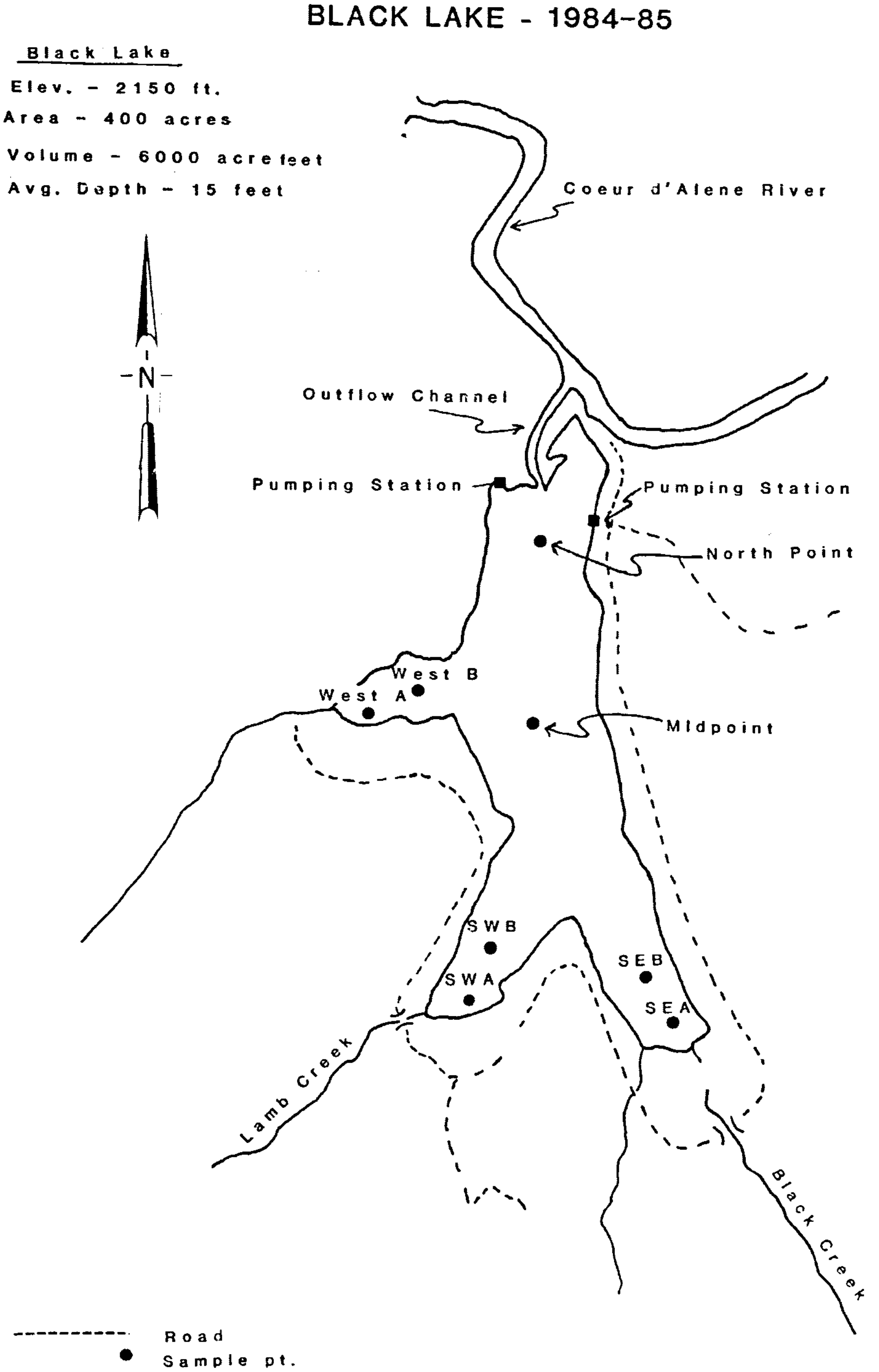

Figure 1. Black Lake, Coeur d'Alene River system with 1984 sample points.

METHODS

The Black Lake blooms raise several questions: (1) What combinaton of environmental conditions are critical to bloom formation and subsequent formations of Anatoxin A? (2) What is the longevity of Anatoxin A as a free toxic agent in the aquatic ecosystem? In other work, Kann (1983) has demonstrated via mouse bioassays the persistence of lethal algae toxin in lake water for six months. (3) Will other elements of the aquatic system, such as the filter-feeding clams or detrital-feeding oligochaetes, accumulate Anatoxin A over a time period of chronic exposure as documented in marine invertebrates? (4) Is longevity of the toxin in the lake related to silt inputs to the lake? These questions are being explored in this research project.

Methodology:

Objective 1: To document the biological elements and timing of toxic blue-green blooms in selected lakes of northern Idaho.

Objective 2: To relate the above to the physical-chemical environment before and during the bloom occurrence.

Objective 3: To determine bloom toxicity throughout the above sequence.

We have established a lake monitoring plan to document specific aspects of Black Lake phytoplankton development through the summer-fall period (Figure 1). Concurrently, we have been measuring salient physical and chemical points of the water column. These controllers have been selected for their known controlling influence on algae growth (Table 1). Standard methods are being followed in analyses (APHA 1980).

TABLE 1. ENVIRONMENTAL AND PHYTOPLANKTON INDICES-BLACK LAKE, 1984

Parameter	Unit	Methodology
Environmental Indices		
Water temperature	^0C	YSI Model 33 S-C-T Meter
Dissolved oxygen	mgl^{-1}	Membrane electrode method (APHA 1980), YSI Model 57 Dissolved Oxygen Meter
Electrical Conductivity	$\mu mho\ cm^{-1}$	Platinum electrode method (APHA 1980), YSI Model 33 S-C-T Meter
pH	---	Corning Model 7 pH meter
Turbidity	NTU	Nephelometric method. (APHA 1980) Hach Model 2100A Turbidimeter
Nitrogen availability (NO_3, NH_3, total N)	mgl^{-1}	Ultraviolet spectorphotometric screening method, macro-Kjeldahl method (APHA 1980)
Total phosphorus	mgl^{-1}	Stannous chloride method (APHA 1980)
Inorganic carbon (CO_2 and HCO_3)	mgl^{-1}	Titrametric methods (APHA 1980)
Zinc and Cadmium	mgl^{-1}	AA spectrophotometry (EPA 1979)
Total suspended solids	mgl^{-1}	Total suspended solids dried at 105 C
Phytoplankton Indices		
Algae biomass	gm^{-3}	Gravimetric method for determining algal biomass (APHA 1980)
Algae Cholorphyll content	μgl^{-1}	Spectrophotometric determination of chlorophyll "a" - trichromatic method (APHA 1980)
Algae composition	$\#'sl^{-1}$	Inverted microscope method (Lund et al 1985)
Density of toxin producers	$\#'sl^{-1}$	Inverted microscope method (Lund et al 1985)
Water transparency	m	Secchi disk (Tyler 1968)
Algae bioassays	$mgl^{-1}14\ days^{-1}$	Selenestrum capricornutum Algal Assay Bottle Test (Miller et al 1978)

Sampling has been conducted monthly in the summer and fall (1984-85) until phytoplankton concentrations reach bloom levels at which time we have reverted to a bi-weekly sampling schedule. Because of the near absence of blue-green blooms in 1984, we conducted toxicity testing by standardized mouse bioassay (Astrachan and Archer 1981; Carmichael and Bent 1981) only once. The literature and our own experience with Black Lake blooms suggest that toxicity develops about two to three weeks into bloom conditions during late summer and fall.

The Idaho Department of Health and Welfare, Division of Environment, Coeur d'Alene Office (Mike Beckwith) has assisted our data-gathering effort on Black Lake by conducting chemical water analyses. We have worked closely with Health and Welfare to ensure coordination of their descriptive field data with our own experimental data.

Through the summer-fall bloom period, controlled algal bioassays were conducted by the US EPA (Corvallis). Each 21-day test was initiated shortly after a field sampling, using water collected at that time. Water was collected from 1 and 3 meters at three central points on the lake and then composited as a single sample. Algal assays were then performed according to the methods outlined in The Selanastrum capricornutum Algal Assay Bottle Test (Miller et al 1978). Nutrient spikes of nitrogen and phosphorus were added to assess algal growth potential, and EDTA was added to assess the inhibitory effect of heavy metals on algal growth.*

* In Black Lake, as in all lateral lakes of the Coeur d'Alene River system, there exists heavy loading of zinc and cadmium from the Coeur d'Alene mining district some 50 miles upstream. Resulting toxicity limits all segments of the downstream aquatic ecosystem to a varying and largely unknown extent.

Metals analysis were performed for calcium, magnesium, zinc, copper, chromium, nickel, cadmium, mercury and sulfur (Table 2). Only zinc, calcium, magnesium and sulfur are shown in Table 2. All other elements measured were below the levels of detection. The zinc concentrations were at background levels and did not inhibit algal growth in these tests.

Nutrient analysis was performed for nitrite, nitrate, ammonia, total phosphorus and ortho-phosphorus. The sum of the nitrogen species were used to predict the algal yield under nitrogen-limited conditions. The ortho-phosphorus concentrations were used to predict the algal yield under phosphorus-limited conditions.

Objective 4: To develop annual loading of nitrogen, phosphorus, and organic matter by major sources to Black Lake.

Efficient management of this water pollution situation is possible only with allocation of pollution sources. We are, therefore, developing an annual nutrient budget for Black Lake detailing significant point and non-point sources of total nitrogen, total phosphorus, and organic matter. At five times selected to provide coverage of the hydrograph through the water year, we are determining concentrations of these parameters in all significant surface flows to the lake. Subsurface septic drainage will be estimated in 1985 from number of housing units. Particular attention is being paid to pumped inflows draining adjacent cattle feedlots. Stream-flow gaging and analysis of pumping records will then permit estimation of loading amounts. Another critical area is the single channel connecting Black Lake to the Coeur d'Alene River. We suspect reverse flow into the lake at high water levels, so this potential loading source is being

TABLE 2. ELEMENTAL CHEMICAL ANALYSIS - BLACK LAKE, 1984 (composite of 3 central deep points taken from 1 and 3 meters at each point) (EPA 1985).

SAMPLE DATE	MG/L ZN	CA	MG	S
5 SEP 84	<	8.892	3.083	-
9 SEP 84	0.008	9.549	3.304	-
7 OCT 84	<	8.715	3.115	4.459
14 OCT 84	0.007	9.179	3.305	4.695
27 OCT 84	<	9.274	3.261	4.675
10 NOV 84	0.008	8.901	3.338	4.845
24 NOV 84	0.008	8.977	3.182	4.771

(-) The Element was not analyzed

(<) Analysis was performed but results fell below the level of detection assessed. We are especially concerned that phosphorus may enter the lake with high flow, be rapidly stored in the sediments, and then left behind in the lake system when lake water returns to the river. This work is in progress and will continue through 1985.

RESULTS

Weather and Discharge Patterns of the Watershed

The 1984 sampling season was characterized by a cooler than usual spring and fall (NOAA 1984). Rainfall in the spring averaged 1.5 inches above the norm, with fall rainfall only slightly above normal (NOAA 1984). Summertime averages were near normal for both temperature and rainfall based on preliminary loading data and from USGS records for the Coeur d'Alene River (USGS 1984). Average discharge from March to June was approximately 20% higher in 1984 than the March to June average for the preceeding three years (USGS 1981-84). Peak monthly discharge (141,290 cfs) occurred in May of 1984, averaging two months later than the preceeding three years.

Water Temperature

Black Lake exhibited an annual temperature-heat cycle typical of many dimictic lakes. Its warming cycle began after ice-out in early April, and continued through August when cooling and subsequent mixing began. The lake exhibited weak stratification at deep points during the June to August period of the warming cycle. During this period of weak stratification no true hypolimnion was evident as temperatures remained relatively homothermous from the surface down to 3 meters, and then steadily declined with depth to the bottom (Figure 2). Maximum surface temperature during June stratification was 20.7 C, while the minimum temperature was 13.8 C at 5 meters (24.9 C and 18.5 C respectively, for August).

No stratification occurred at any bay sites (Figure 3) where depths did not exceed four meters. Temperatures in the SW and SE bays

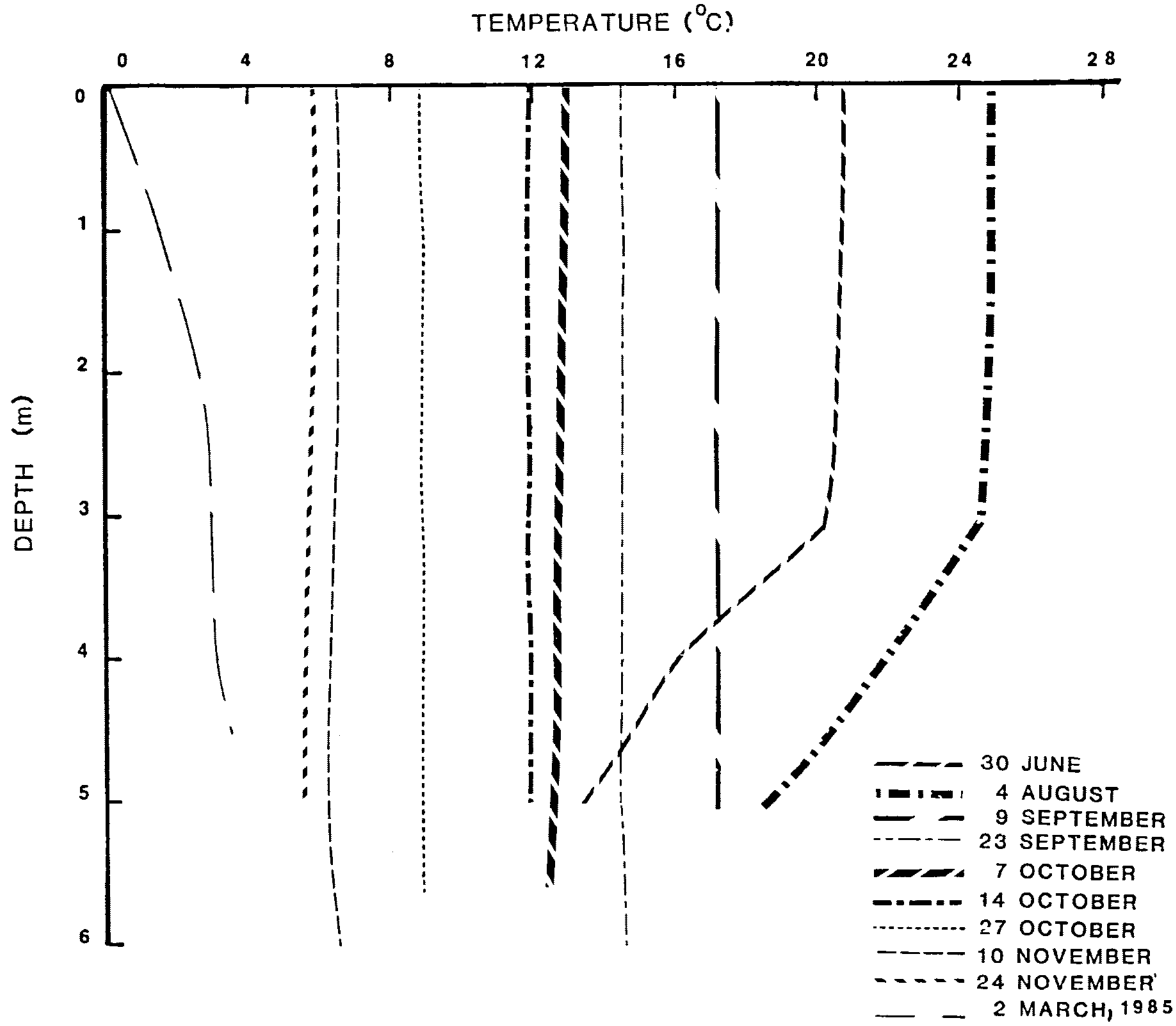

Figure 2. Temperature : depth profiles in Black Lake, Mid Point, 1984.

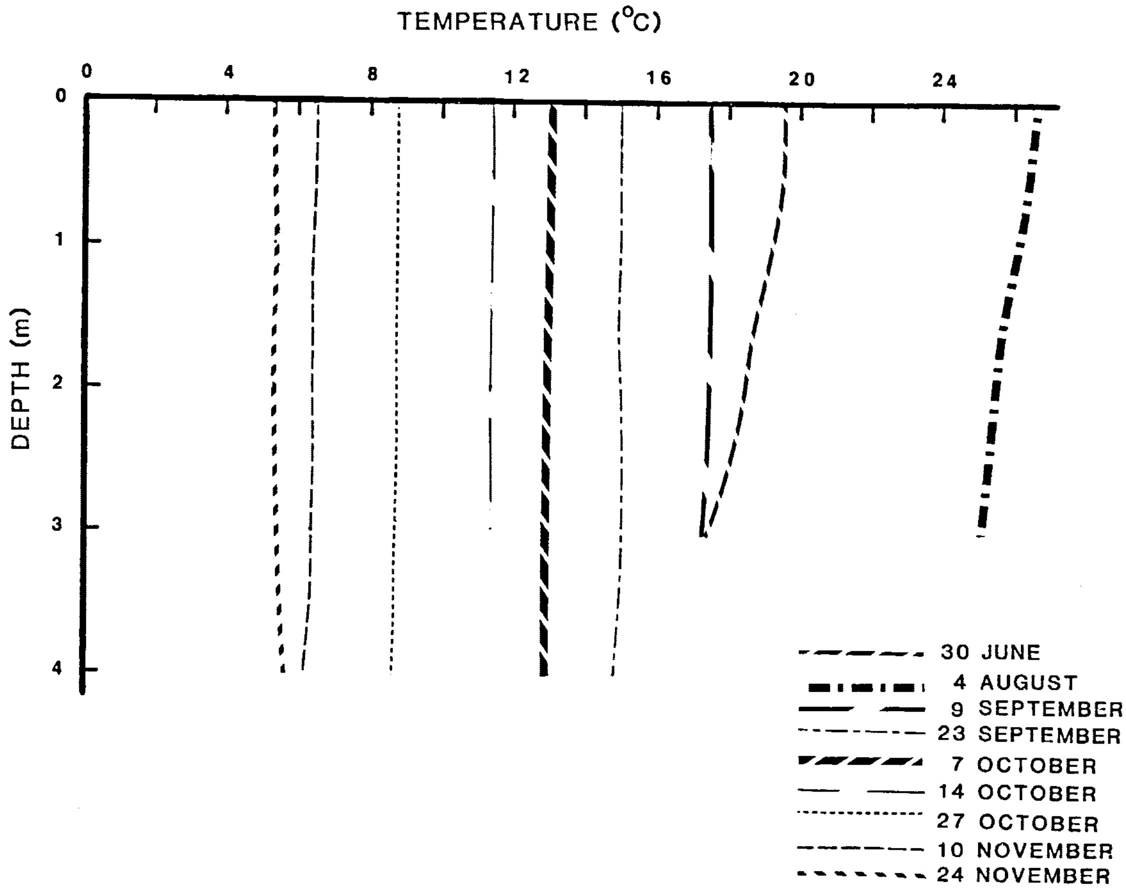

Figure 3. Temperature : depth profiles in Black Lake, Southwest Bay, 1984.

were slightly warmer than those of West, North and Mid sites (Figure 4). Bay averages did not significantly differ from Mid site averages (Figure 5). In addition, the open water North sampling site (near effluent pumps) did not show any significant temperature differences from the rest of the lake (Figure 6).

Homothermy occurred upon overturn in early September, and the water column then remained mixed throughout the cooling cycle (Figure 3). During this period, water temperatures fell from 17.2 C in September to 5.6 C in November. Ice cover occurred in late December, when slight inverse stratification occurred (Figure 3). Temperatures were 0 C at the surface, and 4 C off the bottom.

Dissolved Oxygen

Dissolved oxygen concentrations of surface water remained extremely high throughout the summer of 1984. June values for the bay and mid sites were 13.8 mg/1 and 13.6 mg/1 respectively. Surface oxygen then increased significantly to 18.3 mg/1 and 18.0 mg/1 at bay and mid sites during August. When compensated for temperature and pressure, the summer range of surface oxygen concentrations corresponded to ca. 172-200% saturation. Concentrations and percent saturation then declined to 10-11 mg/1 and 115% saturation during fall overturn in September. There was a slight rise in overall lake surface oxygen in early October (13.8-14.8 mg/1) and then a decline through the fall to seasonal lows of 10.8 mg/1 (99% saturation) in November (Figure 7).

The only significant change in oxygen concentrations with depth occurred at mid-lake sites in June (Figure 7). From the surface to 4 meters, concentrations were similar (ca. 14 mg/1 and 172% saturation), but then steadily declined from 13.8 mg/1 at 4 m to 4.8 mg/1 at 5 m

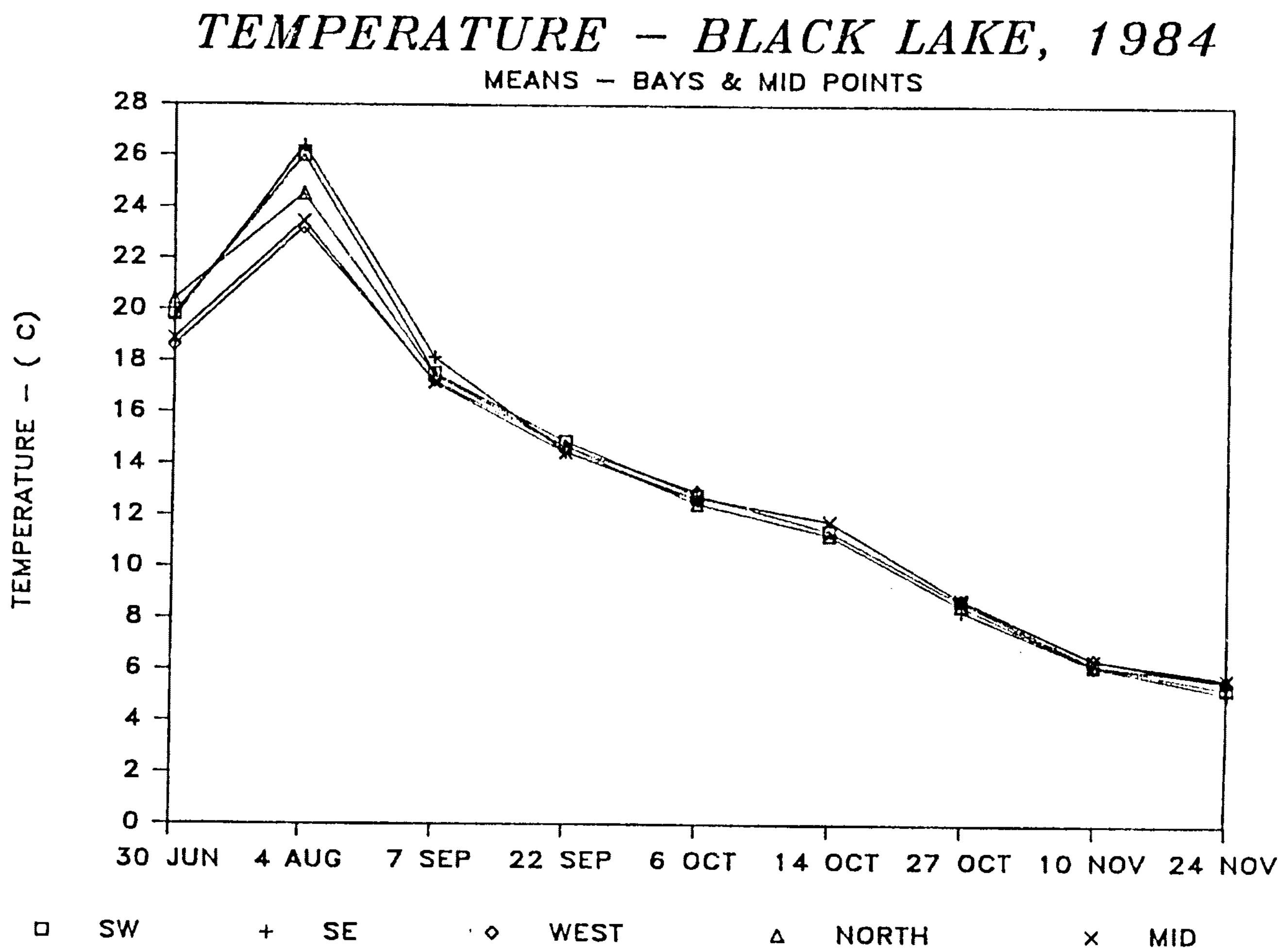

Figure 4. Mean water column temperatures compared between all sites.

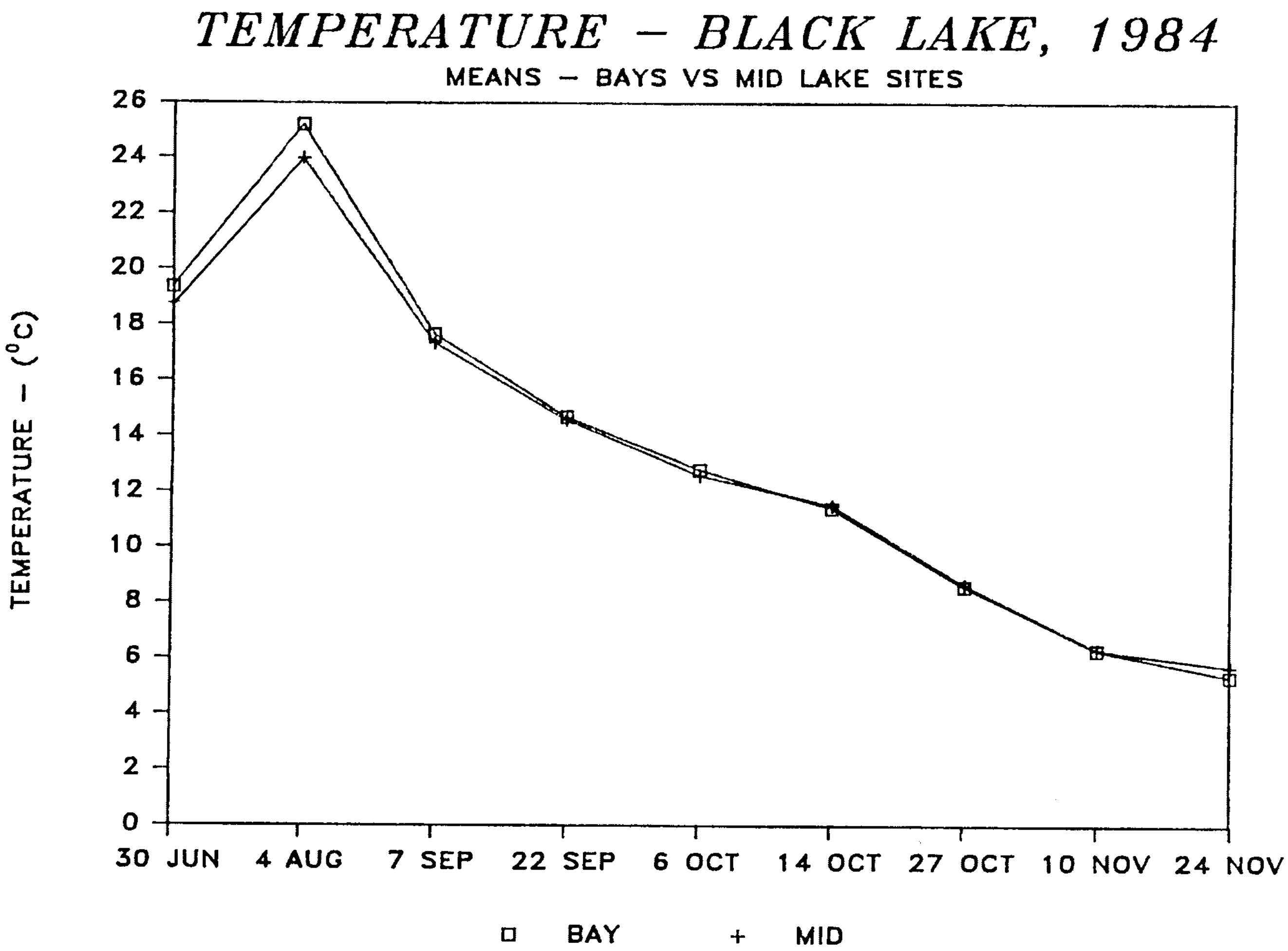

Figure 5. Mean water column temperatures compared between bays and mid lake sites.

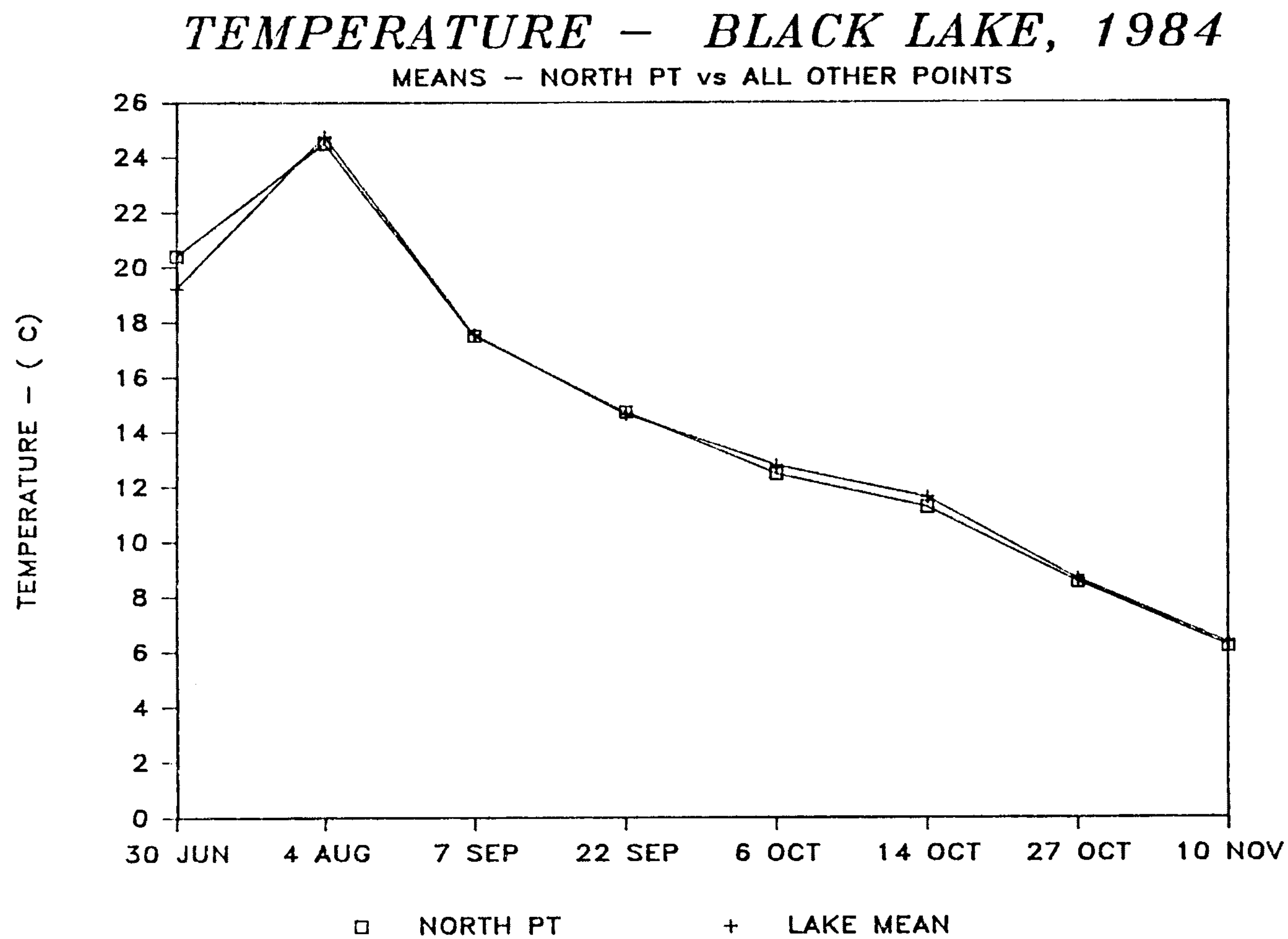

Figure 6. Mean water column temperatures compared between North point and all other points.

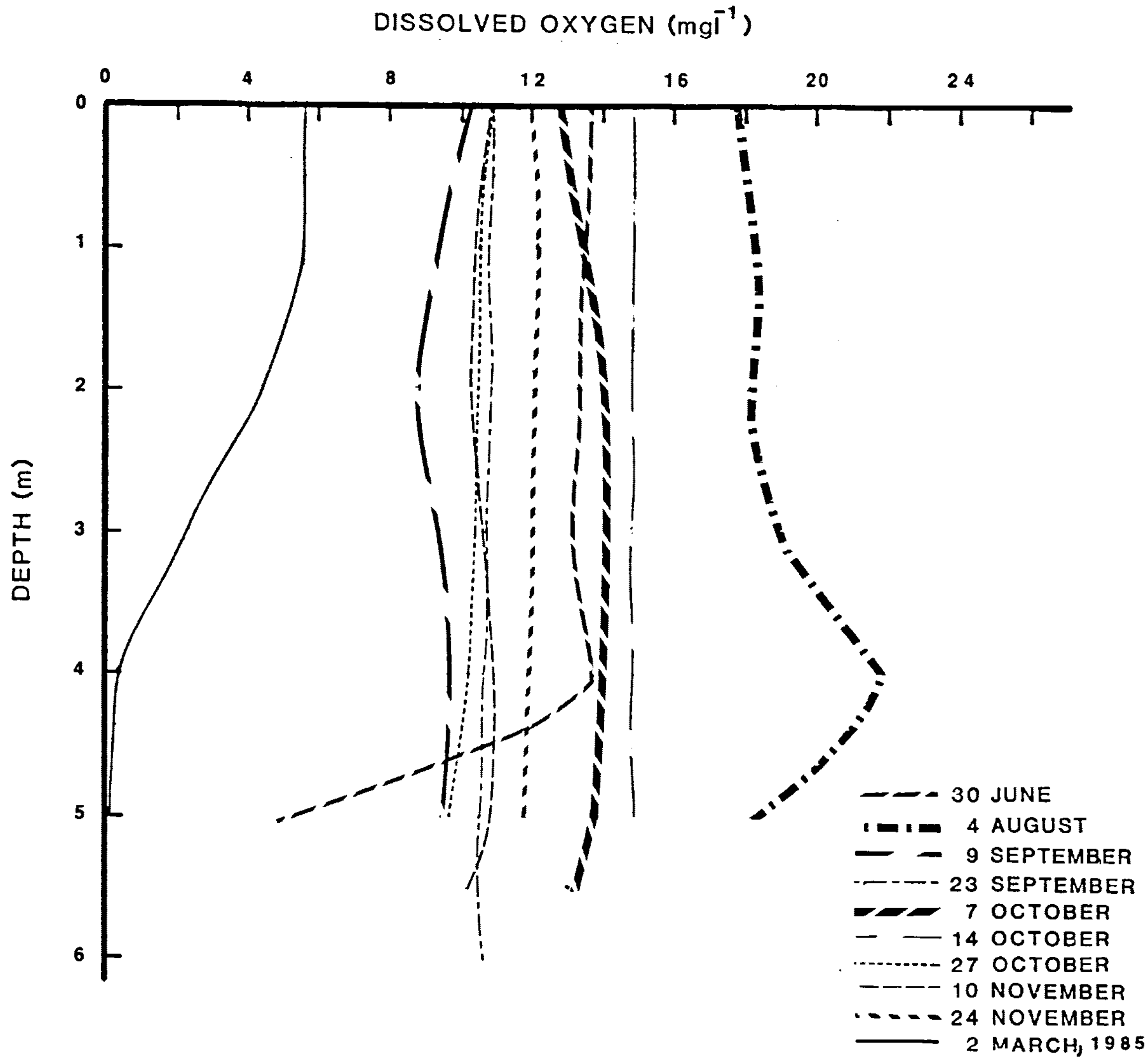

Figure 7. Dissolved oxygen:depth profiles in Black Lake, Mid Point, 1984.

(35% saturation). August through November oxygen concentrations remained relatively unchanged within the profile (Figures 7 and 8). During under-ice conditions in March, slight off-bottom deoxygenation occurred at 5 m (Figure 7).

As with temperature, there were no great differences in oxygen concentrations between bays and mid lake points (Figures 9 and 10). Also, North Point did not differ significantly from the rest of the lake (Figure 11). Shallow bay sites sustained slightly higher oxygen concentrations than mid sites throughout 1984 sampling. Oxygen trends tended to be inversely correlated with algal cycles.

pH, Alkalinity and Conductance

Depth-averaged pH in Black Lake (a measure of mean H^+ ion concentrations) ranged from 8.2 in June down to 6.95 in September. Values stayed relatively constant from October through November at 7.4. Variability in pH values between sites occurred in August and September (Fig. 12). Values then remained relatively constant between sites throughout the rest of 1984 (Figures 12, 13 and 14).

Alkalinity values remained fairly constant over time, ranging between 30 and 36 mg/1. No site specific differences occurred.

Conductance was significantly higher in August (105 umhos) than at any other time throughout 1984, with values then steadily declining to 72 umhos in November. No differences existed between bays and mid points, or between North point and all other sites (Figures 15, 16 and 17).

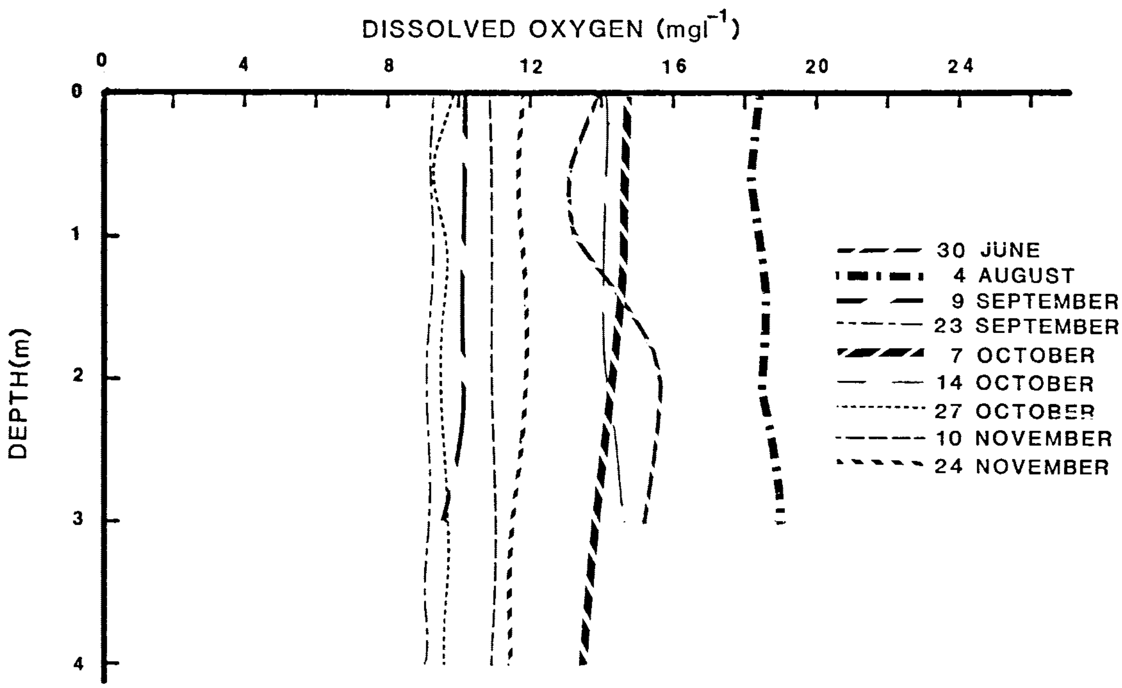

Figure 8. Dissolved oxygen:depth profiles in Black Lake, Southwest Bay, 1984.

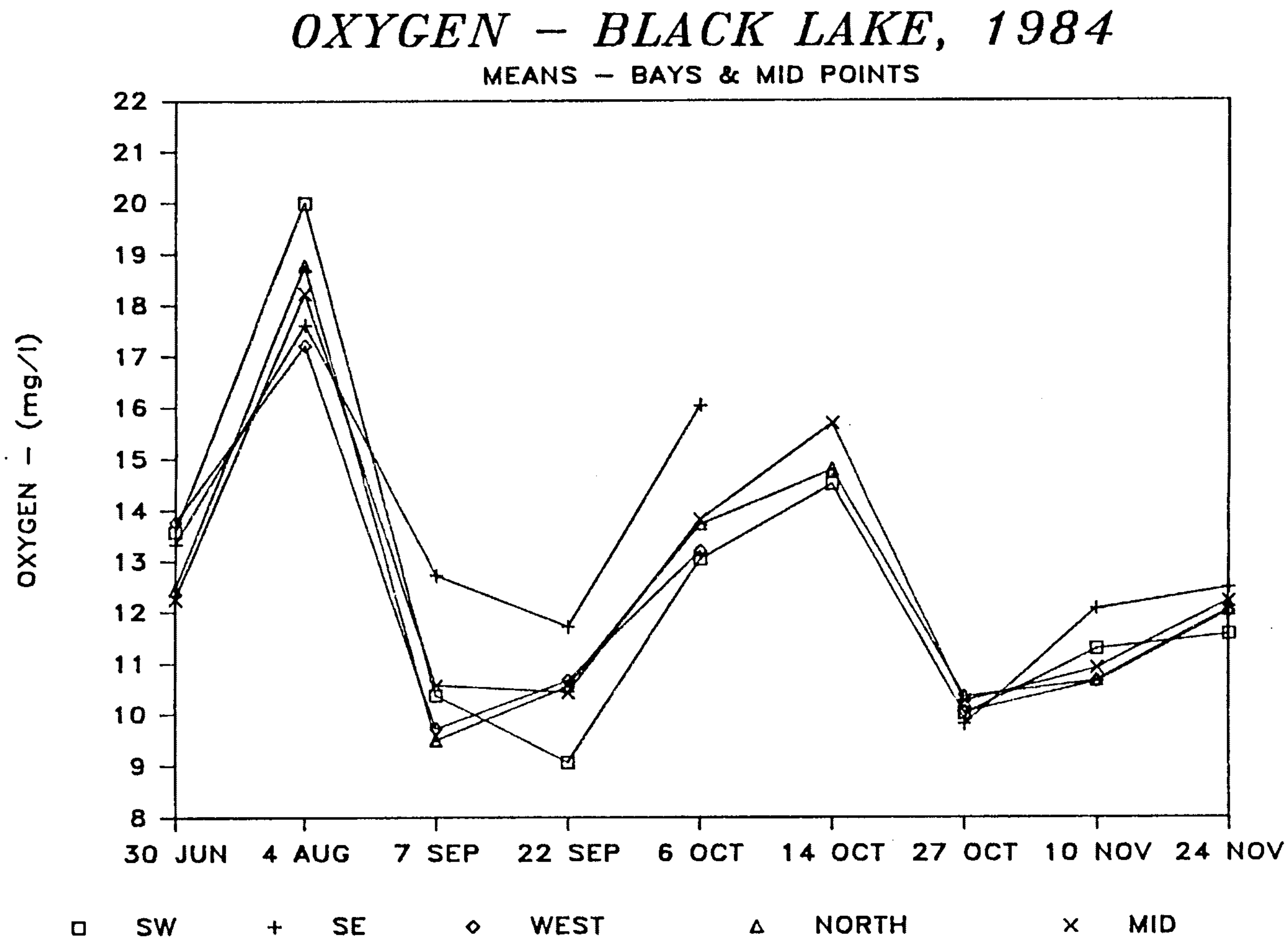

Figure 9. Mean water column dissolved oxygen compared between all sites.

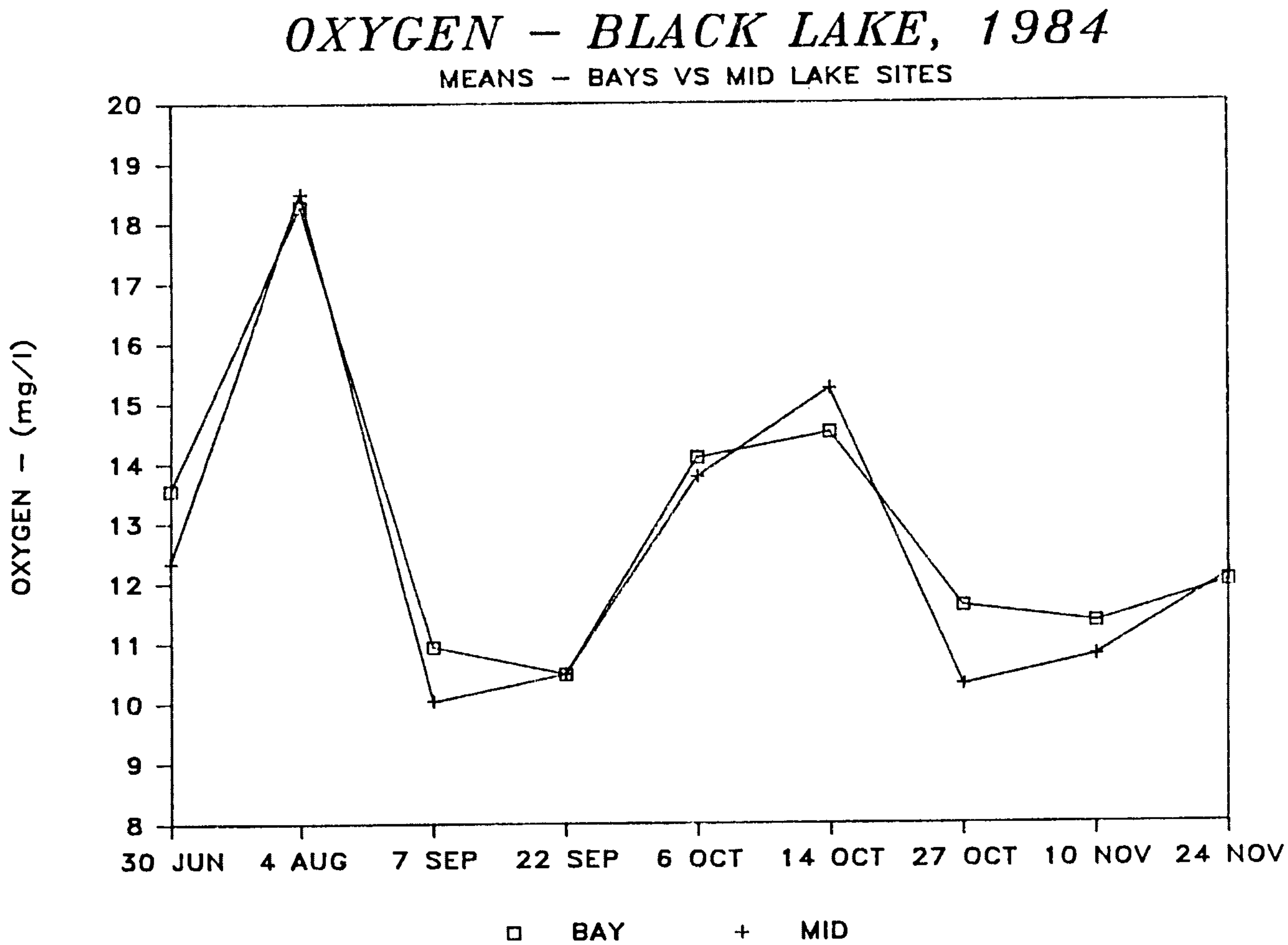

Figure 10. Mean water column dissolved oxygen compared between bays and mid lake sites.

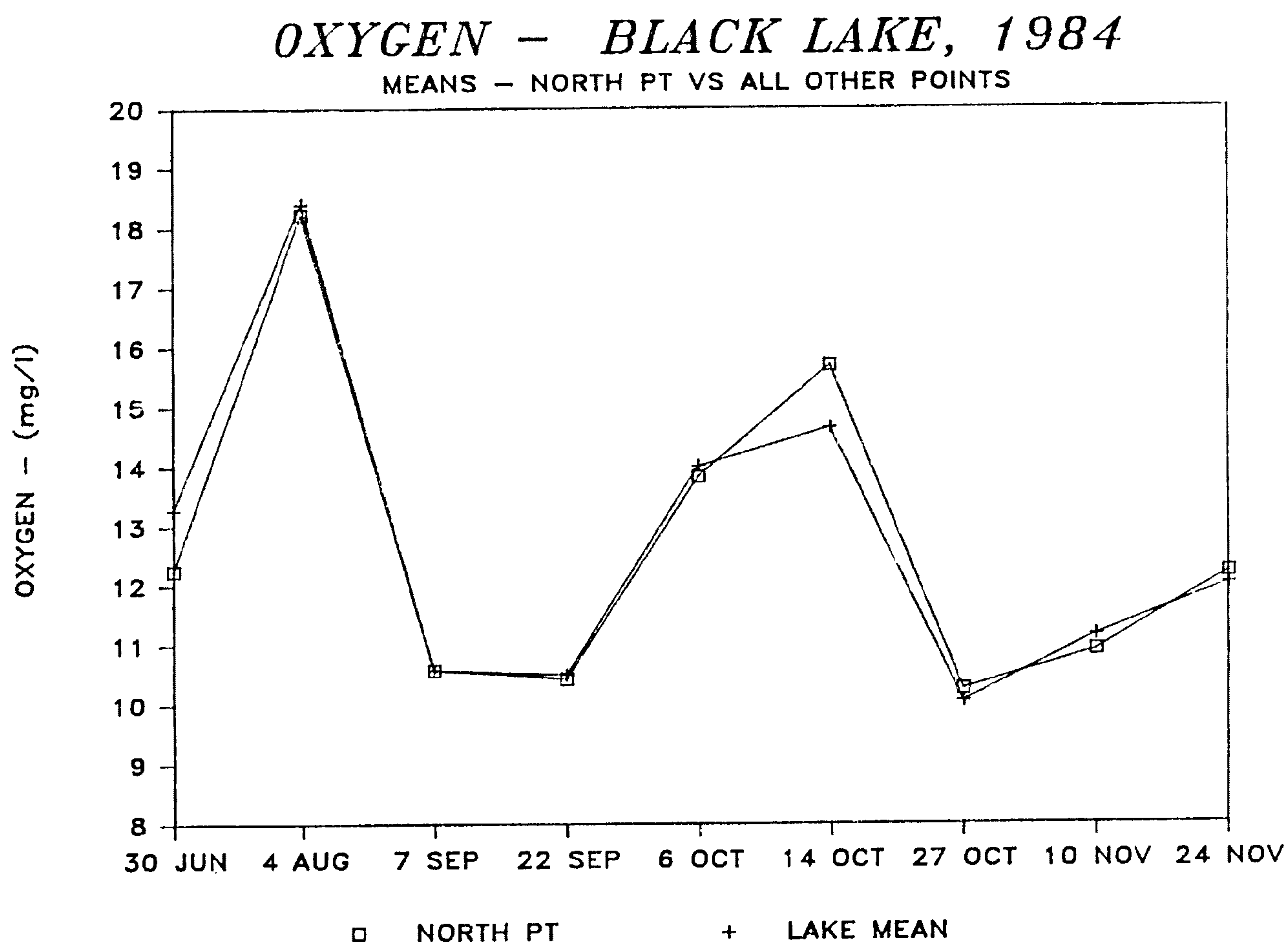

Figure 11. Mean water column dissolved oxygen compared between North point and all other points.

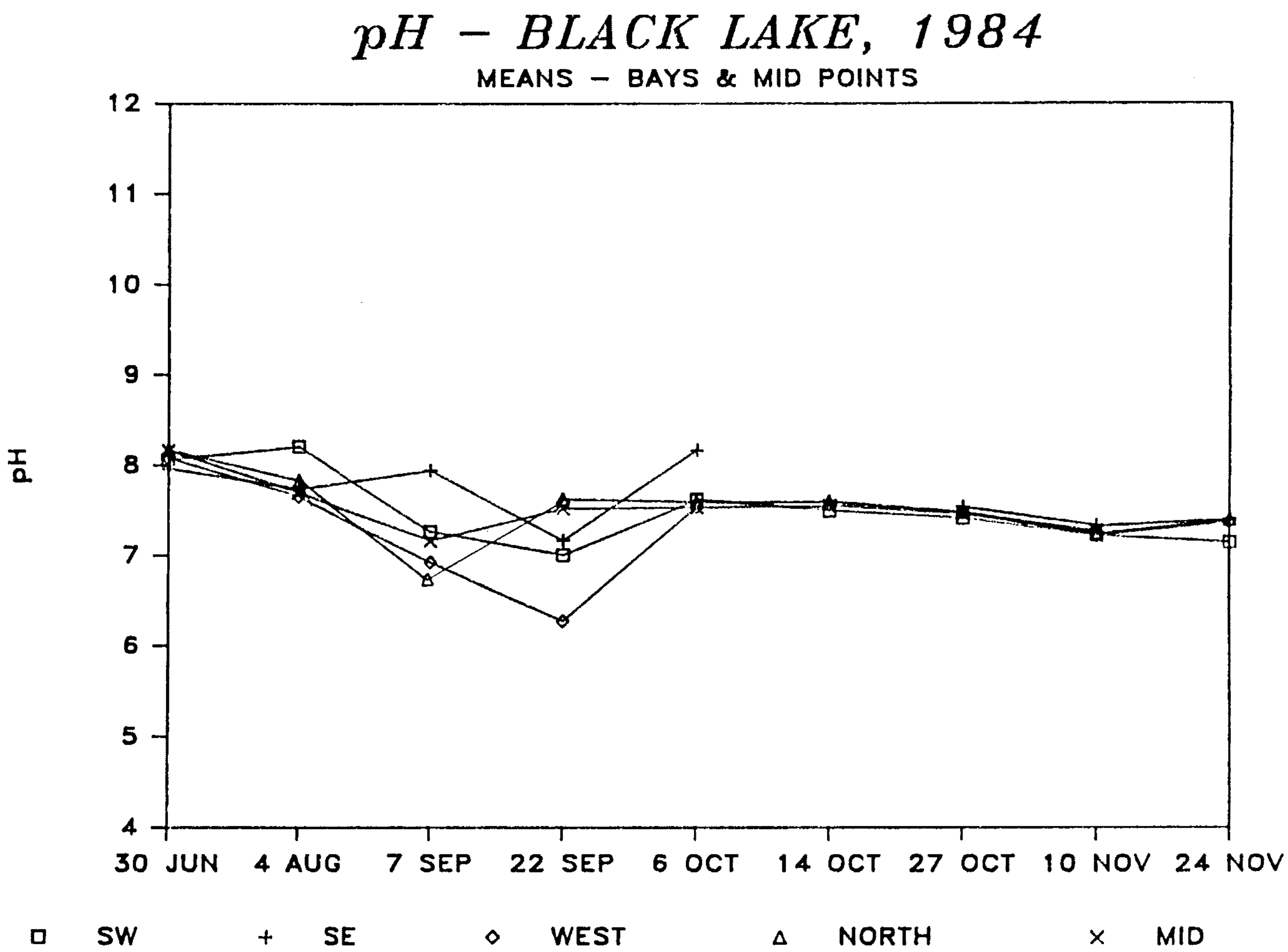

Figure 12. pH compared between all sites.

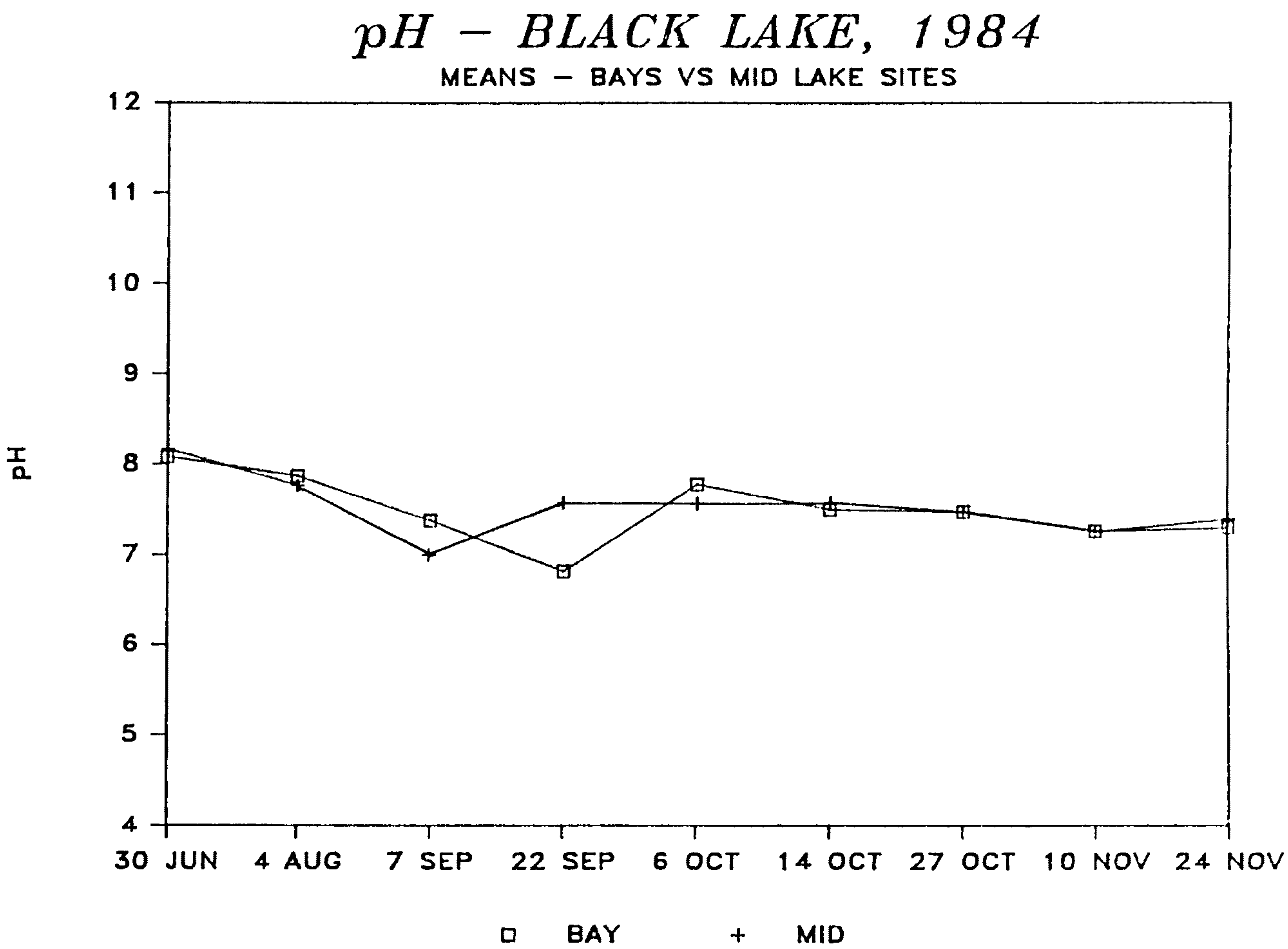

Figure 13. pH compared between bays and mid lake sites.

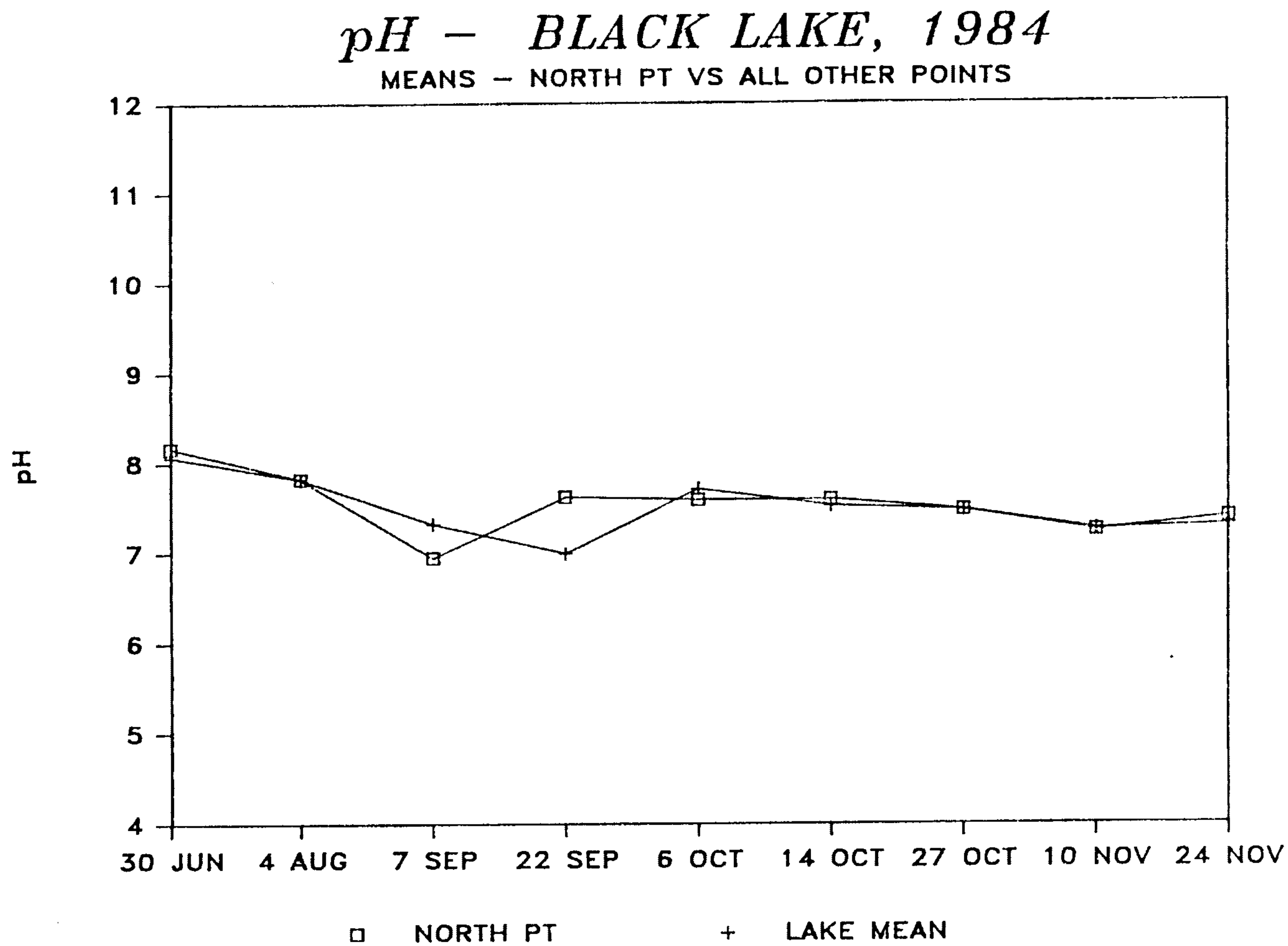

Figure 14. pH compared between north point and all other points.

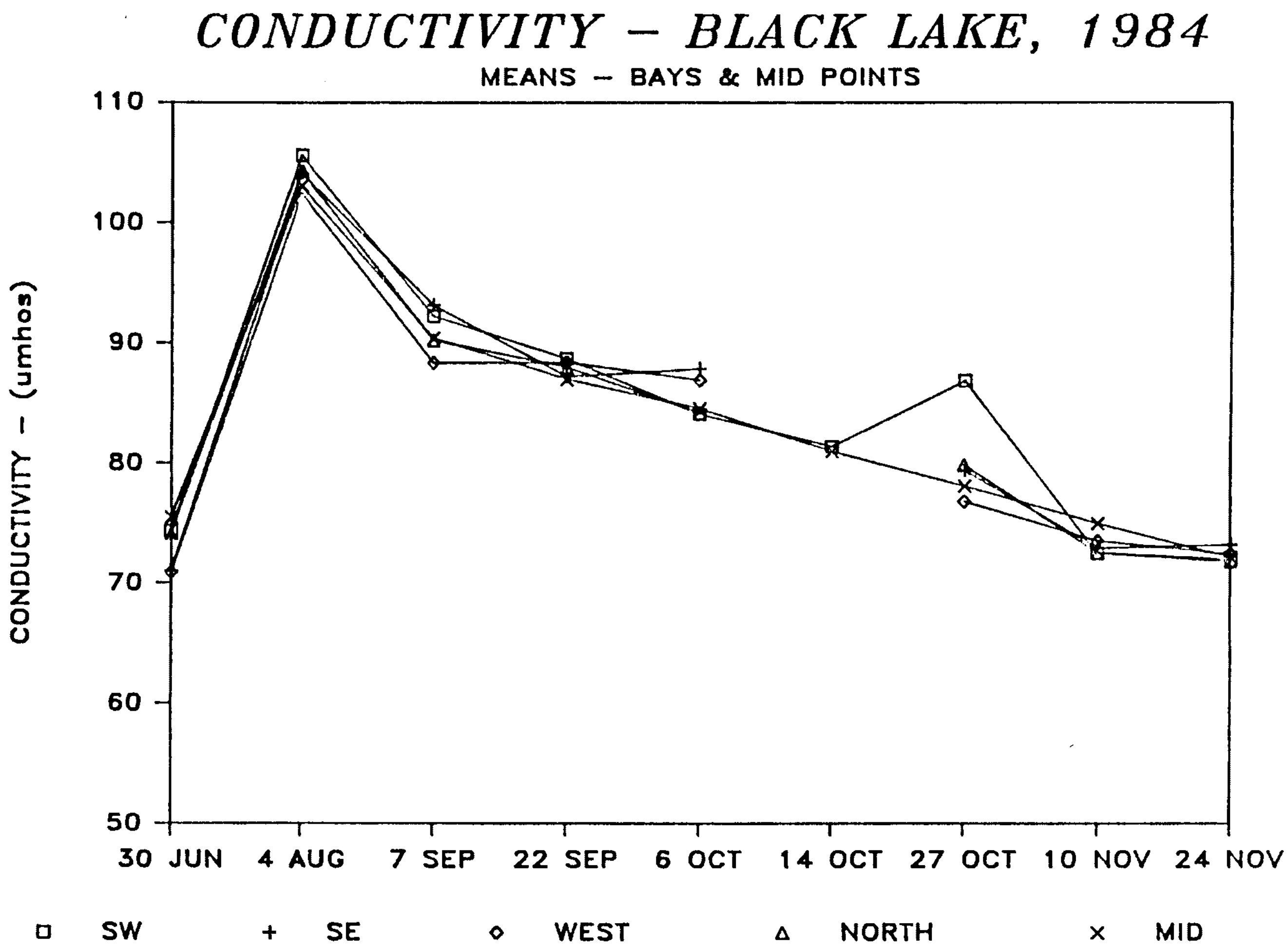

Figure 15. Mean water column conductivity compared between all sites.

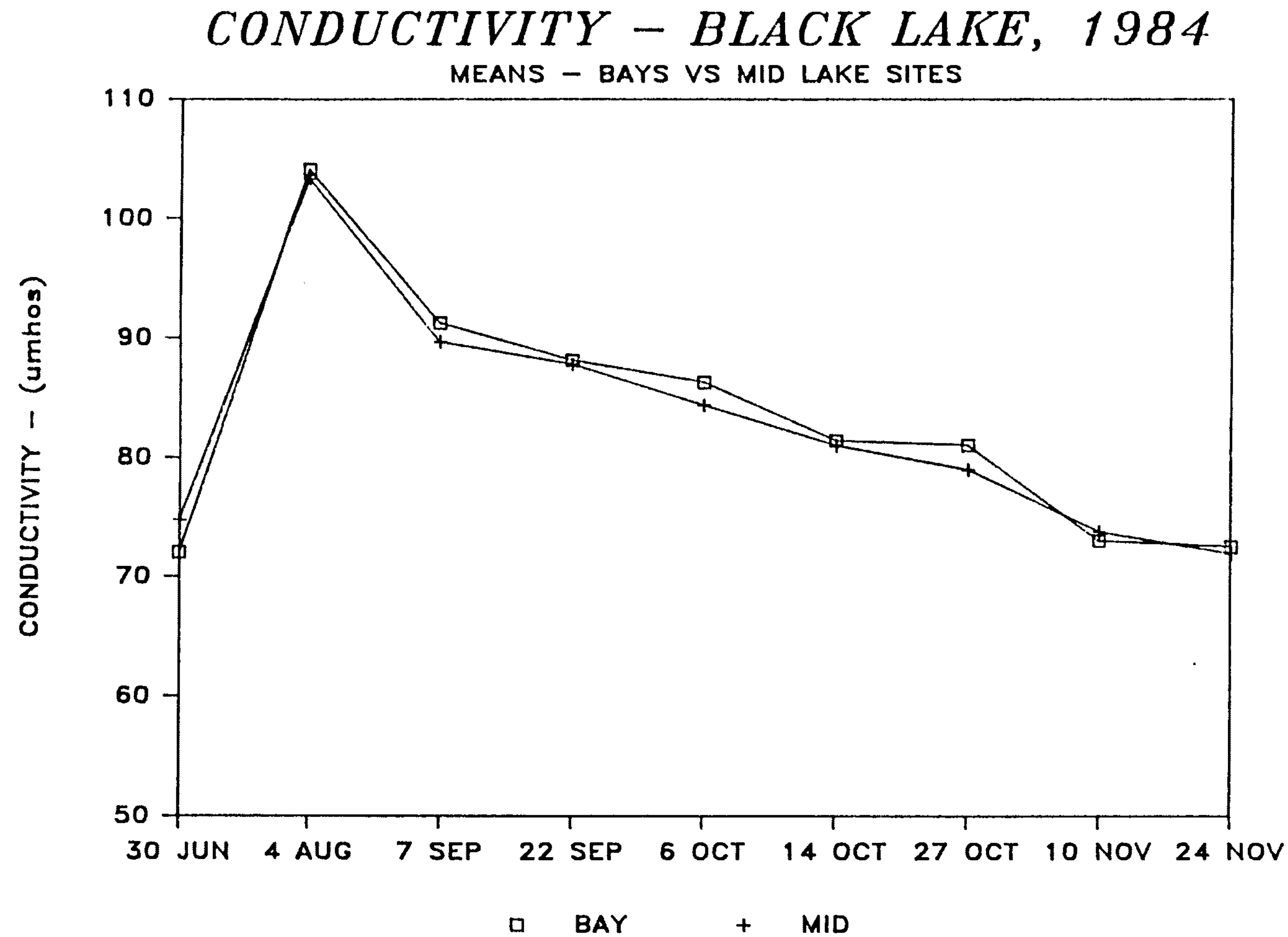

Figure 16. Mean water column conductivity compared between bays and mid lake sites.

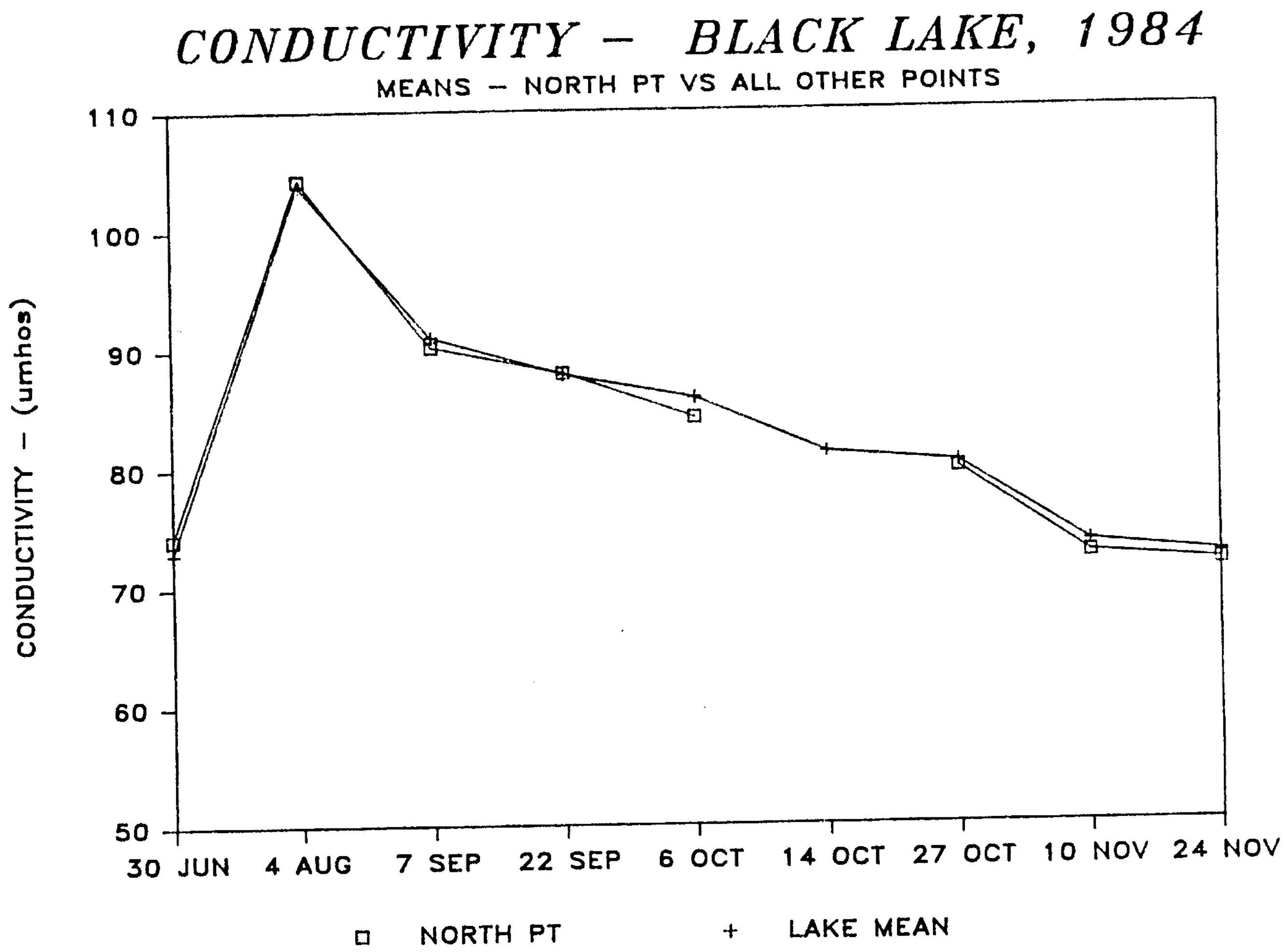

Figure 17. Mean water column conductivity compared between North point and all other points.

Turbidity and Transparency

Turbidity fluctuated through the season from October highs of ca. 8 NTU's to August lows of ca. 1 NTU (Figure 18). The SE Bay tended to sustain higher values than other sites during peaks (Figure 18). Fluctuations seemed to correlate with both productivity and rainfall events. North point sustained slightly lower values than the rest of the lake during the Fall (Figure 19), while combined bays vs mid sites showed no differences (Figure 20).

Transparency inversely correlated with productivity and rainfall, with a season high secchi reading (3.8 meters) occurring in August when phytoplankton numbers and chlorophyll "a" content were at annual lows (Figure 21). Low secchi readings occurred during peaks in algal productivity (Figure 21).

Total Nitrogen and Total Phosphorus

Nutrient parameters of total nitrogen and total phosphorus (analyzed by the Idaho Department of Health and Welfare Laboratory) are presented in Figures 22 and 23. Total nitrogen values ranged from a low of ca. 0.3 mg/l in August to highs of ca. 0.6 mg/l in June and October. Total phosphorus values ranged from a low of 0.01 mg/l in August to a high of 0.07 mg/l in November. The variability in total nitrogen values between SW Bay and Mid Point on 8 September and 6 October is most likely due to error in analysis. The average N:P ratio is 16:1 for composited mid sites, with a range of 8:1 to 38:1 occurring over the year.

Algal Assays

Algal assay test results are presented in Tables 2 and 3. All

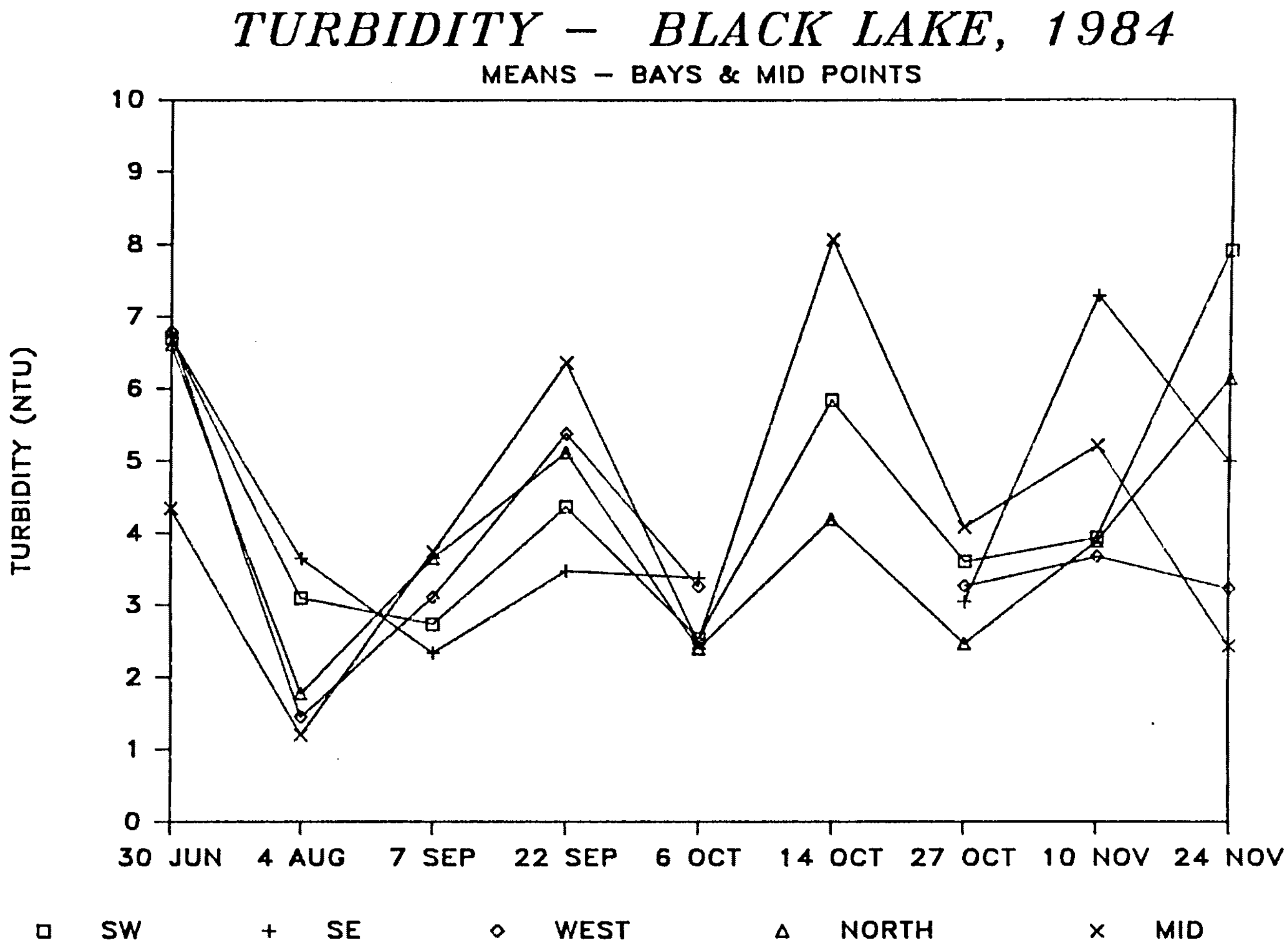

Figure 18. Mean water column turbidity compared between all sites.

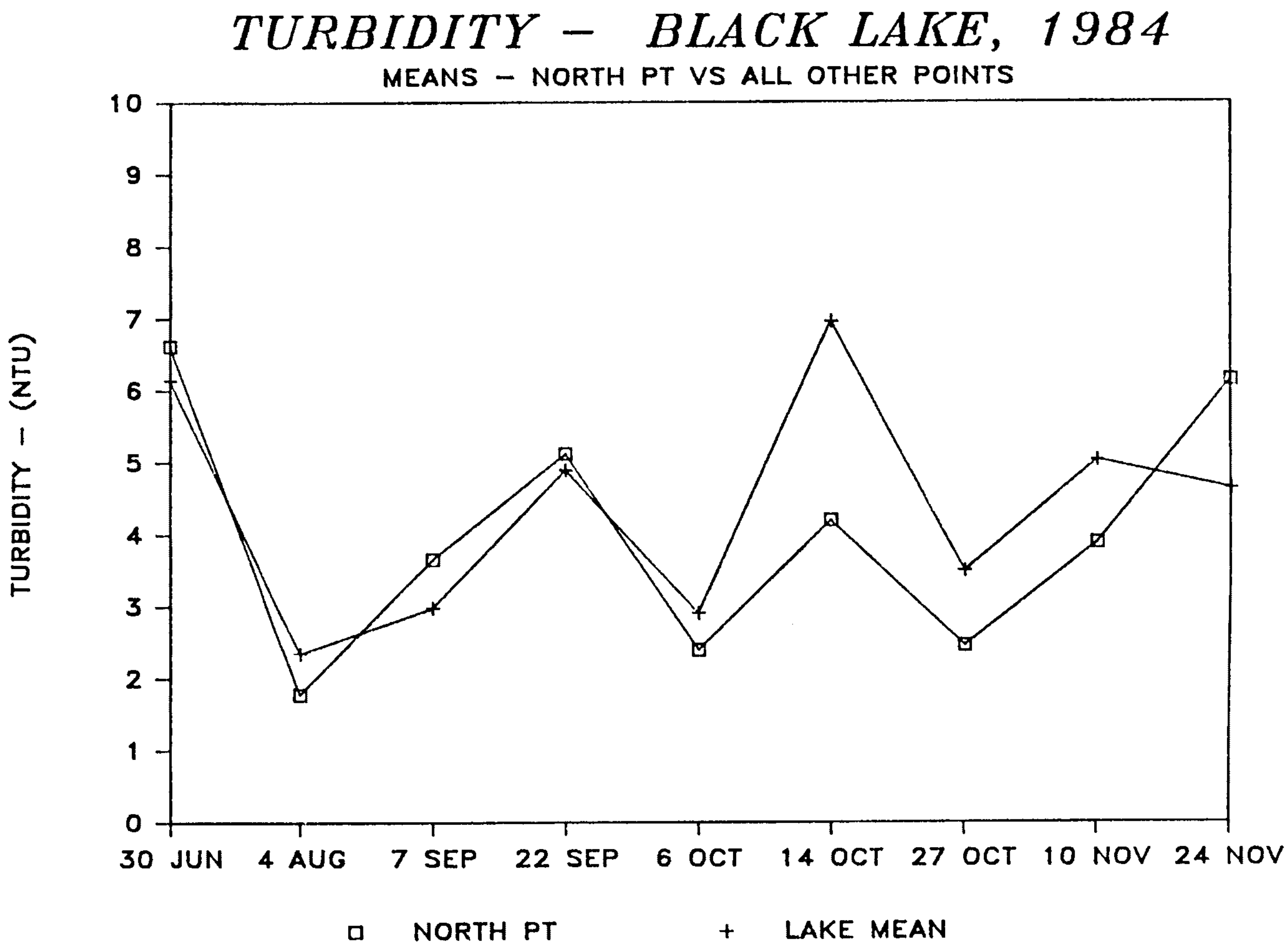

Figure 19. Mean water column turbidity compared between North point and all other points.

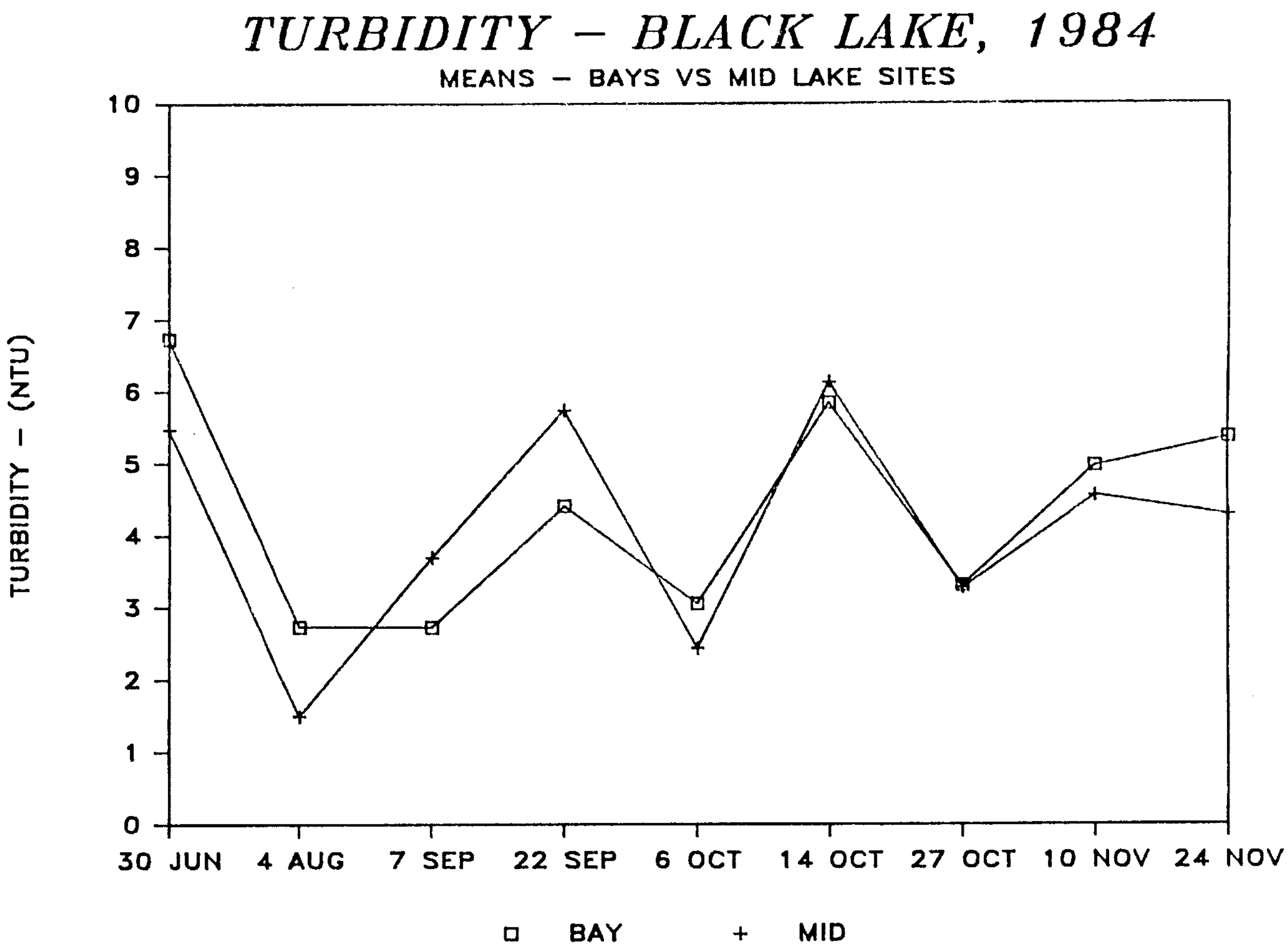

Figure 20. Mean water column turbidity compared between bays and mid lake sites.

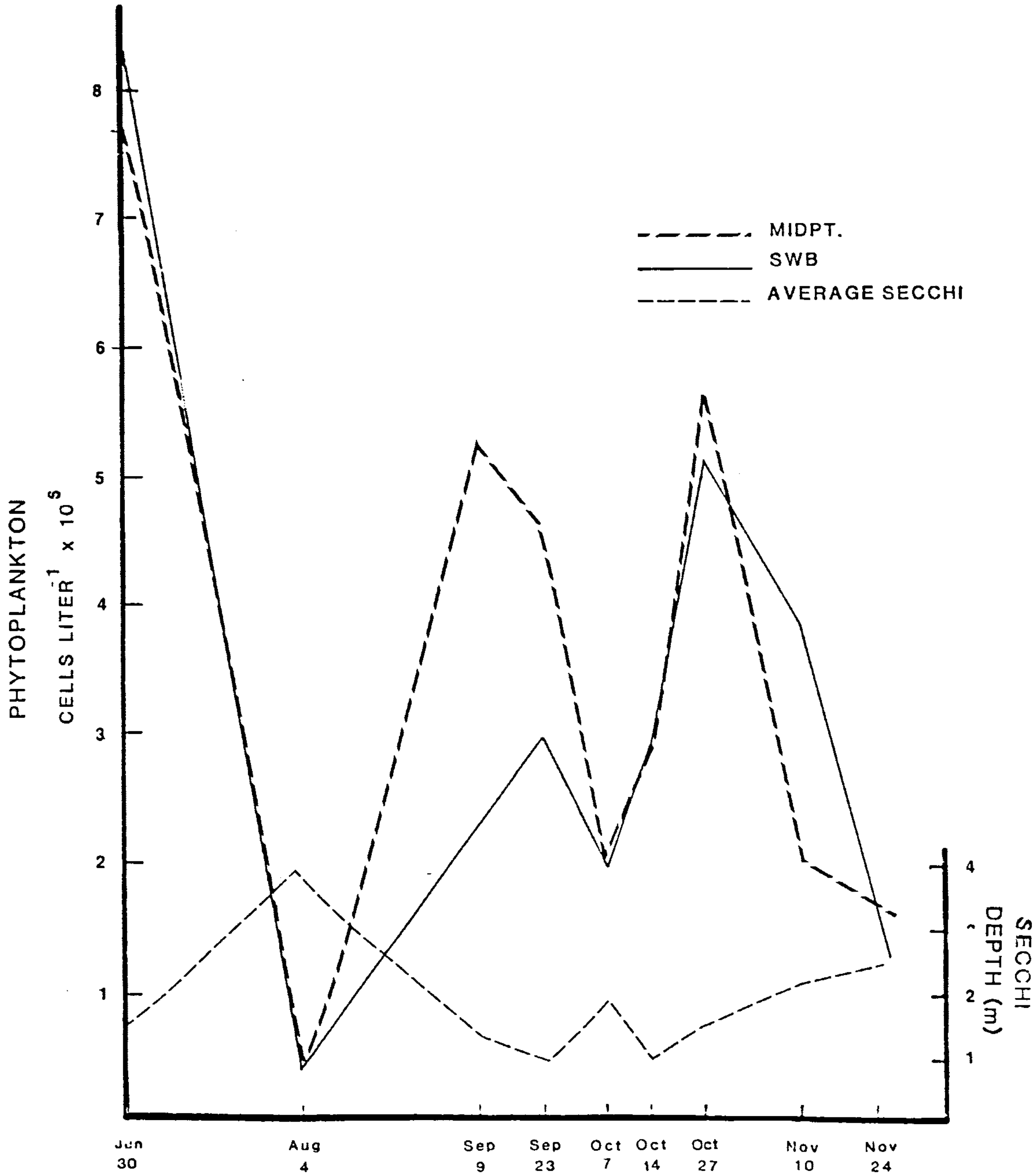

Figure 21. Phytoplankton numbers at Southwest bay and Midpoint compared to water transparency - Black Lake, 1984.

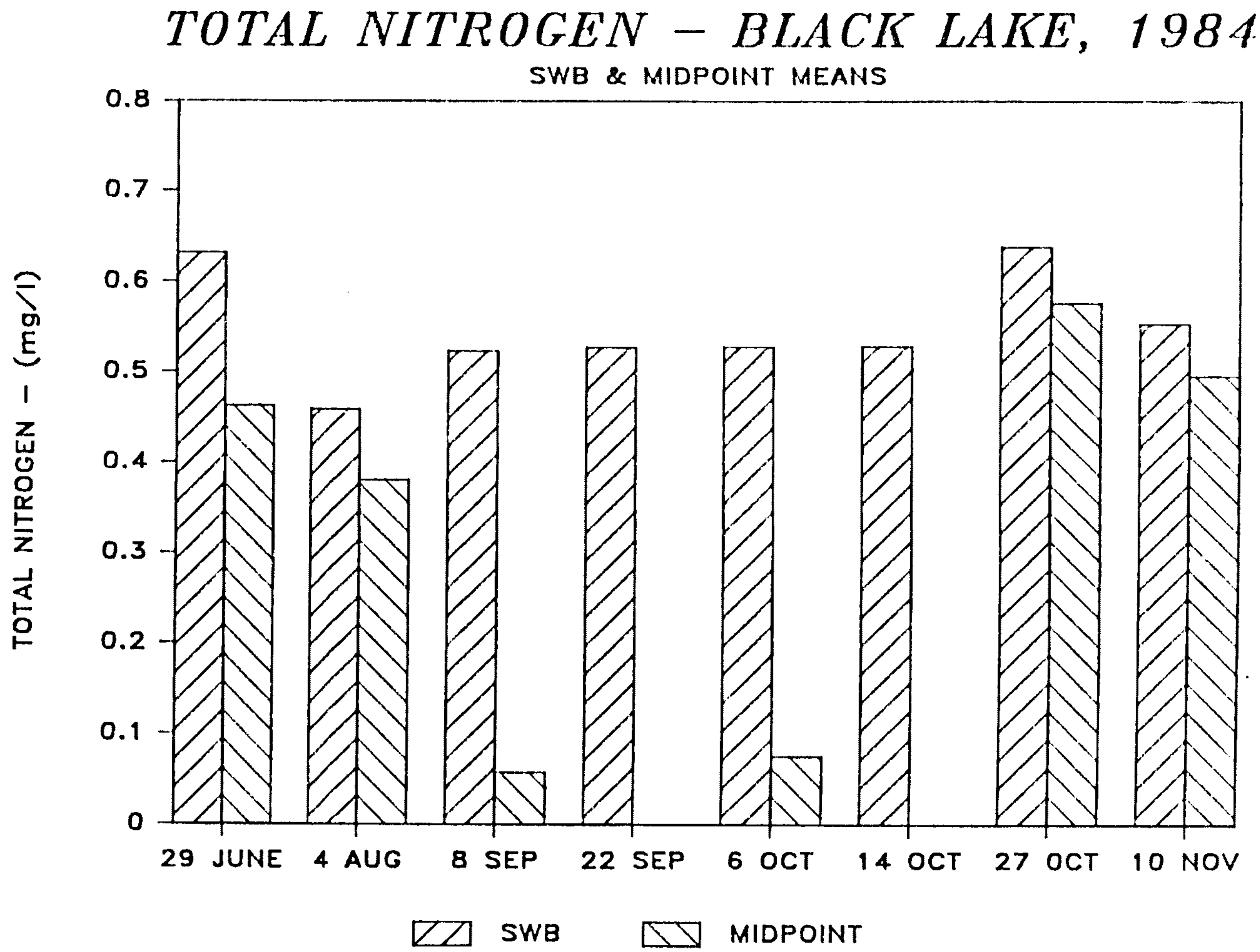

Figure 22. Total nitrogen compared between Southwest bay and Midpoint.

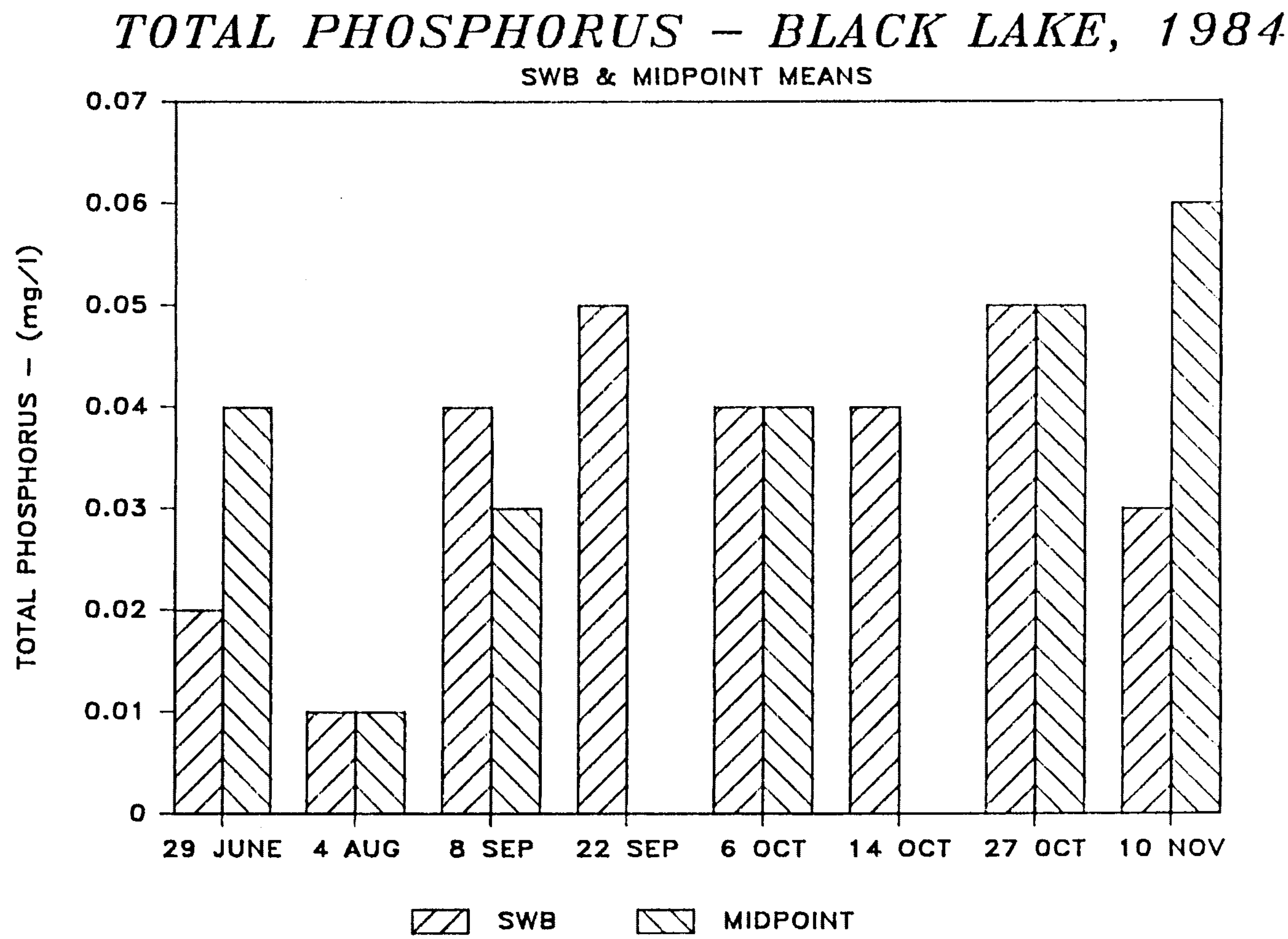

Figure 23. Total phosphorus compared between Southwest bay and Midpoint.

samples collected from August 8 to October 14 were primarily algal growth-limited by phosphorus and secondarily limited by nitrogen (U.S. E.P.A. 1985). From October 27 to November 24, 1984 the order of the limiting nutrients was reversed with nitrogen being the primary- and phosphorus being the secondary-limiting growth nutrient in Black Lake waters.

According to the productivity group classification of algal biomass, the control yield of 0.62 mg dry weight Selenastrum/liter falls within the "moderate" productivity subgroup of 0.11 to 0.80 mg dry weight/liter (U.S. E.P.A. 1985). Samples collected from September 9 to October 14 fell within the "moderately high" productivity subgroup of 0.81 to 6.00 mg dry weight/liter (Table 3). Samples from October 27, November 10, and November 24 were examined more closely as the primary limiting nutrient switched to nitrogen for these dates. Although samples from October 27 and November 24 fall within the high productivity subgroup (6.00 mg dry weight/liter) (Table 3), lake growth potential is best defined by analysis of yields produced in the nitrogen-spiked flasks, which will be discussed in more detail later.

Zinc concentrations were at background levels (0.007 - 0.008 mg/1), and did not inhibit algal growth in these tests (Table 3). Chromium, nickel, cadmium and mercury were below the level of detection. Calcium, magnesium, and sulfur were within detection limits (Table 2), but were not inhibitory to algal growth.

Phytoplankton and Cholorphyll "a"

Phytoplankton composition and numbers varied seasonally as shown in Figures 21 and 24. During this seasonal variation the algal

TABLE 3. 14-DAY ALGAL GROWTH POTENTIAL TEST - BLACK LAKE, 1984 (composite of 3 central deep points taken from 1 and 3 meters at each point.) (EPA 1985).

SAMPLE DATE	CONTROL	NUTRIENT SPIKES (mg/1) 1.00 N	0.05 P	N+P	1.00 E	N+E	P+E	N+P+E	LIMITING FACTORS	ZINC (mg/1)
5 Aug 84	0.62	0.41	3.26	27.79	1.31	0.45	3.50	25.56	P/N	-
9 Sep 84	3.44	4.23	8.98	34.89	4.23	3.47	9.34	37.40	P/N	0.008
7 Oct 84	4.21	5.25	5.78	37.40	4.17	4.81	5.47	27.23	P/N	-
14 Oct 84	2.47	3.73	2.57	21.47	1.91	2.41	2.90	21.86	P/N	0.007
27 Oct 84	6.97	11.01	7.75	42.19	5.06	5.42	7.03	40.48	N/P	-
10 Nov 84	5.70	9.60	5.88	40.94	5.00	5.44	6.01	35.03	N/P	0.008
24 Nov 84	7.96	12.16	9.21	42.65	7.69	9.68	9.20	46.13	N/P	0.008

P = PHOSPHORUS; N = NITROGEN; E = EDTA; M = HEAVY METALS INHIBITION productivity showed high production in late June, a decline in early August, and successive increases in early September and in late October. Phytoplankton community composition changed from early summer dominants of Fragilaria sp., Tabellaria sp., Asterionella sp., and Melosira sp., to a late summer early fall community of Melosira sp. Cyclotella sp., Nostoc commune, and Asterionella sp. Early August was the only time Nostoc* was the dominant form, representing 99% of all Cyanophyta present (Figure 24). Although Nostoc was dominant in August, in terms of overall numbers it only represented 15% to 50% of total numbers of Chrysophyta species present throughout the rest of the season (Figure 24). Late fall constituents (during the time the toxic bloom has usually occurred) shifted back to diatoms, with Melosira sp., Fragilaria sp. and Asterionella sp. the dominants. Aside from the dominance of Cyanophyta in August, the Chrysophyta accounted for the major proportion of phytoplankton phyla throughout the rest of 1984, with the Chlorophyta, Cyanophyta and Euglenophyta relatively minimal in abundance (Figure 24).

Seasonal trends in chlorophyll "a" values correlated well with trends in phytoplankton numbers (Figures 21 and 25). During this seasonal variation, chlorophyll "a" ranged from highs of 15 to 31 ug/l to lows of 0 to 5 ug/l (Figure 25). Slight differences existed between

*N. commune is considered to be a "super species" which includes various ecological expressions or ecophenes known to be blooming algae such as Anabina circinalis and A. flos-aquae (Drouet 1978). Because the blue-green algae have only recently been revised, many authors continue to use the ecophene names as species names. This lumping of many ecophenes into the super species (N. commune) may lead to confusion in bloom assessment, as A. flos-aquae may merely be an ecological expression of N. commune, but in our work, we are continuing to follow the system of Drouet.

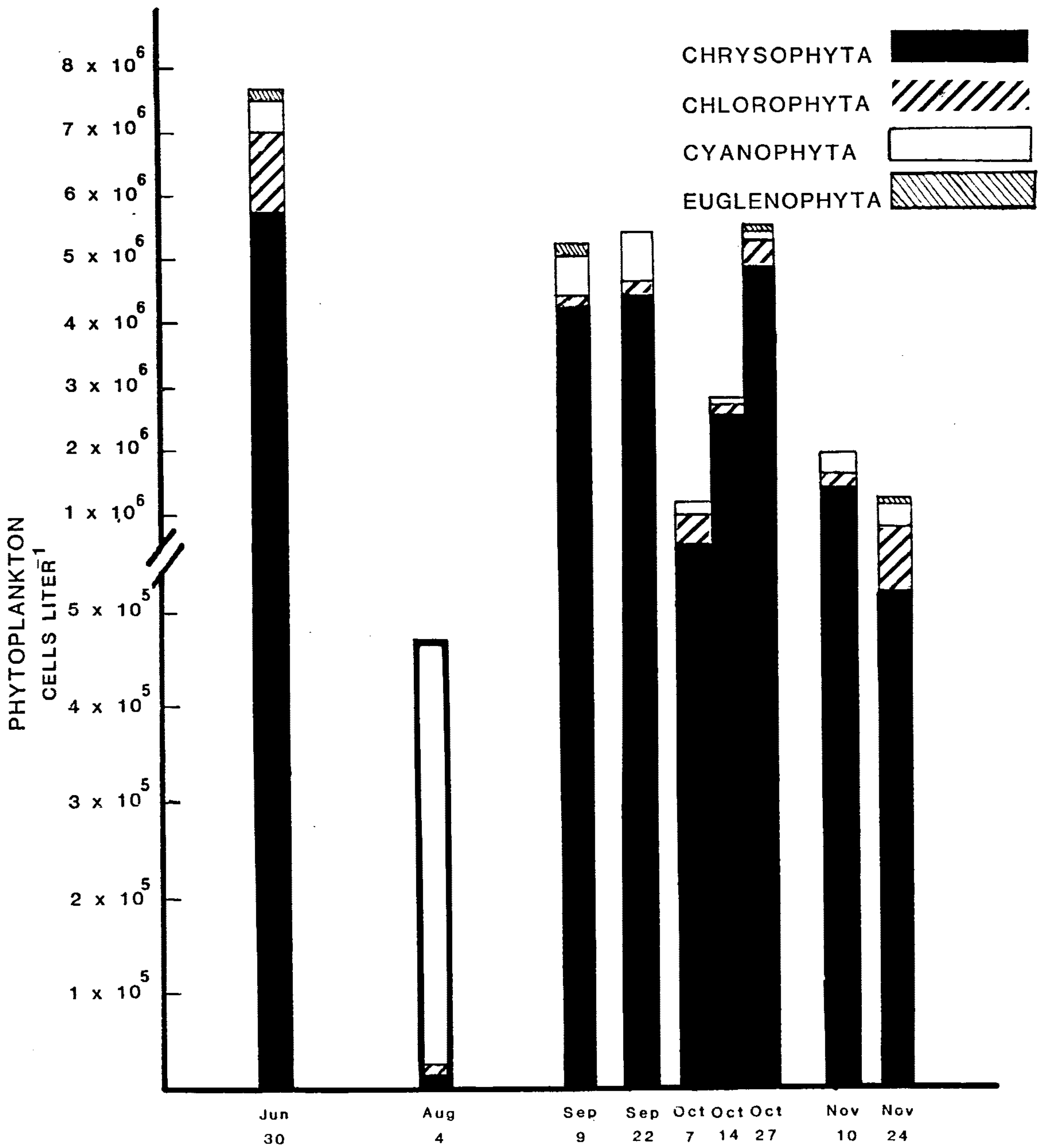

Figure 24. Algae phyla and numbers - Black Lake, 1984.

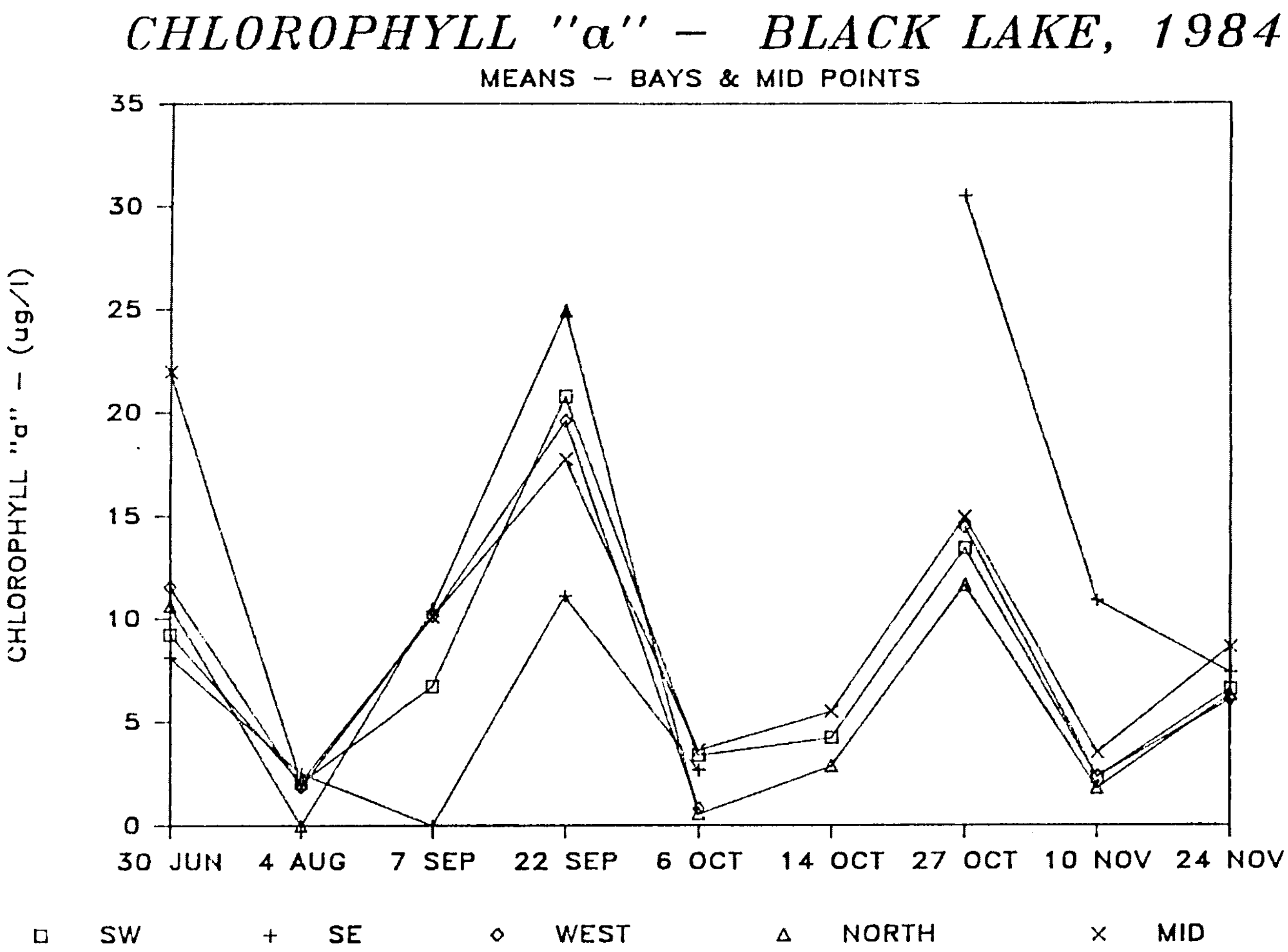

Figure 25. Mean water column chlorophyll "a" compared between all sites.

sites; however, no trends are apparent as sites sustaining highs and lows vary by date (Figure 25). Again, no trends are apparent when comparing North Point to the rest of the lake, or when comparing bays to mid sites (Figures 26 and 27). A relatively high autotrophic index (algae biomass: chlorophyll "a" ratio) occurs throught the season, with peaks in October and November (Figure 28).

Aquatic Macrophytes

Aquatic macrophytes were found in dense mats throughout the littoral zone of the lake, but were thickest in the SW and SE bays. The dominant species were: *Ceratophyllum demersum*, *Elodea canadensis* and *Myriophyllum spicatum* var. *exalbescens*. Macrophytes continued growing until die-back in late October.

Zooplankton

Zooplankton total numbers/liter and seasonal trends are presented in Figure 29. Mid Point sustained higher numbers of zooplankton/liter throughout 1984, with the high occurring in November at ca. 300 organisms/liter. Seasonal highs and lows coincided with those of the phytoplankton with the exception of November 10 (Figures 24 and 29). Dominant species include: *Daphnia rosea*, *Cyclops bicuspidatus*, *Diaptomus tyrrelli* and nauplius larvae. The Cladocerans account for an average of 30% of the total species present during 1984.

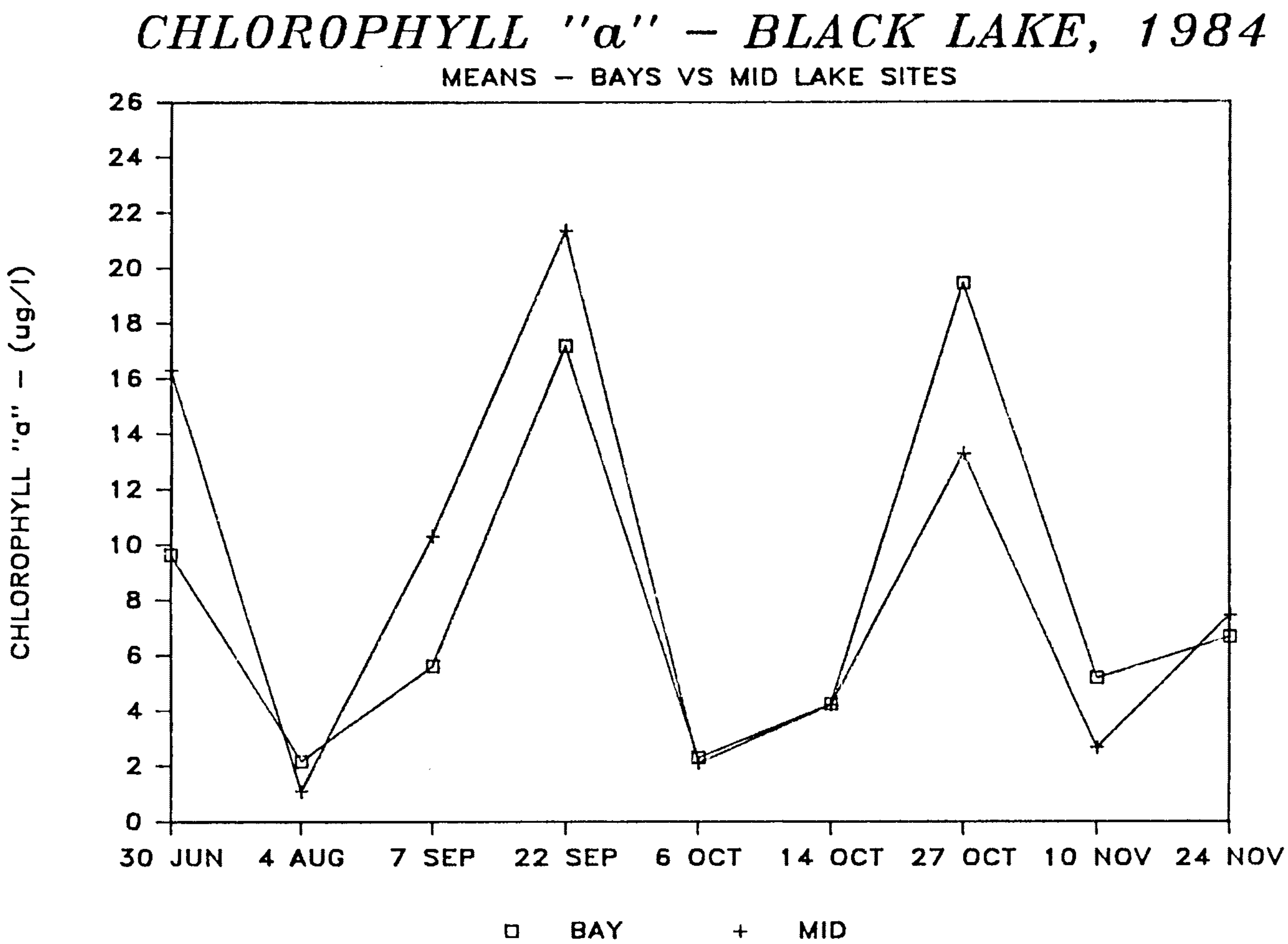

Figure 26. Mean water column chlorophyll "a" compared between all sites.

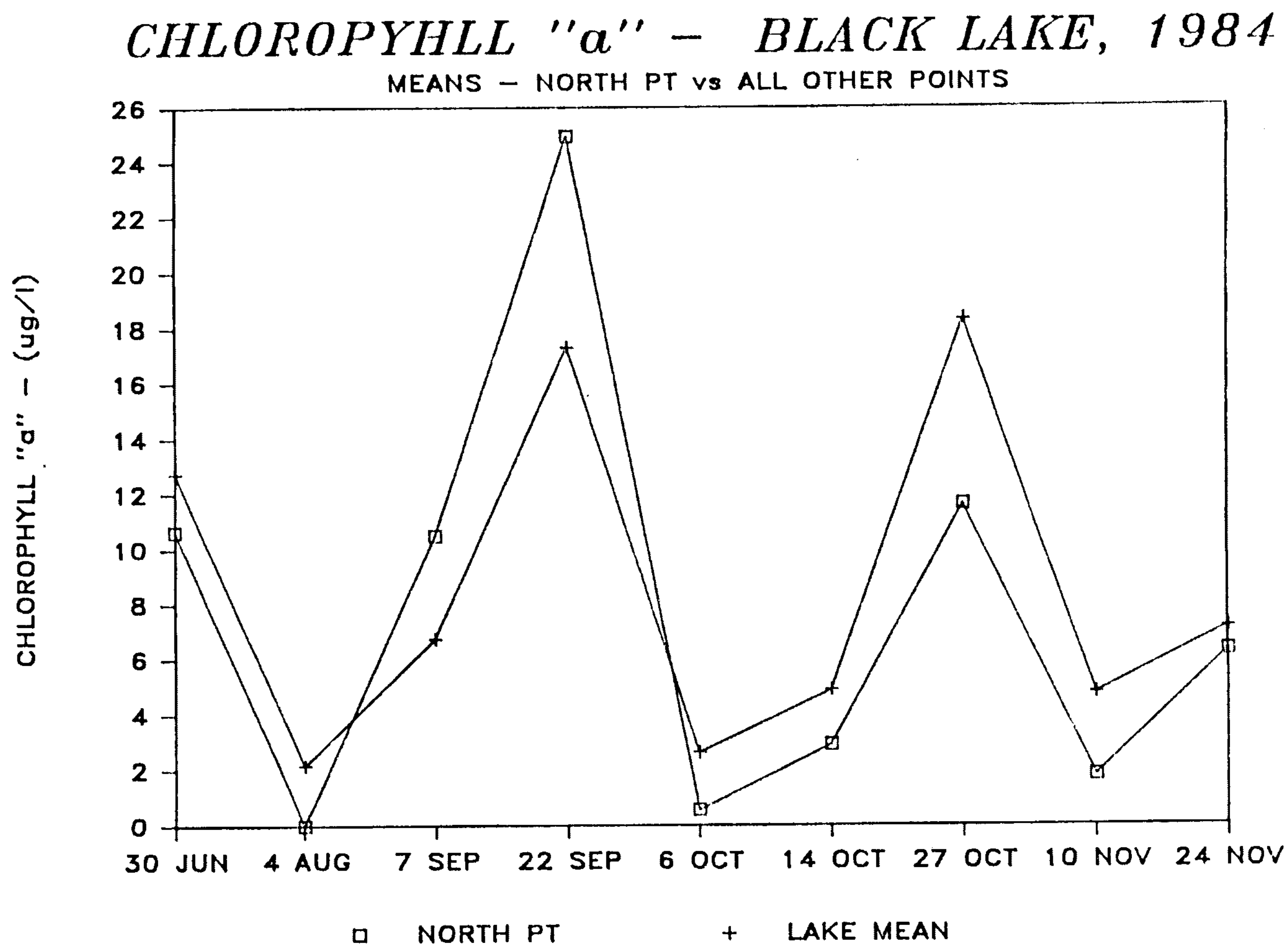

Figure 27. Mean water column chlorophyll "a" compared between North point and all other points.

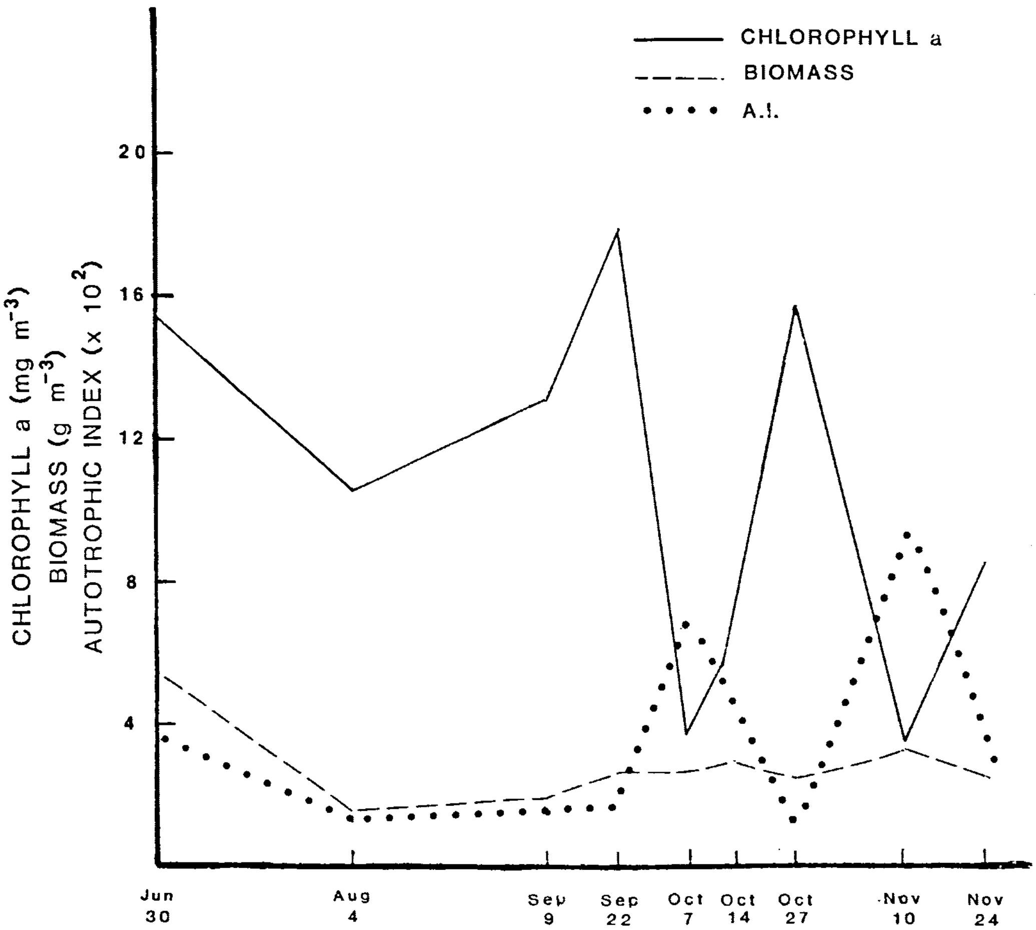

Figure 28. Chlorophyll "a", ash free dry weight (biomass), and autotrophic index at Midpoint - Black Lake, 1984.

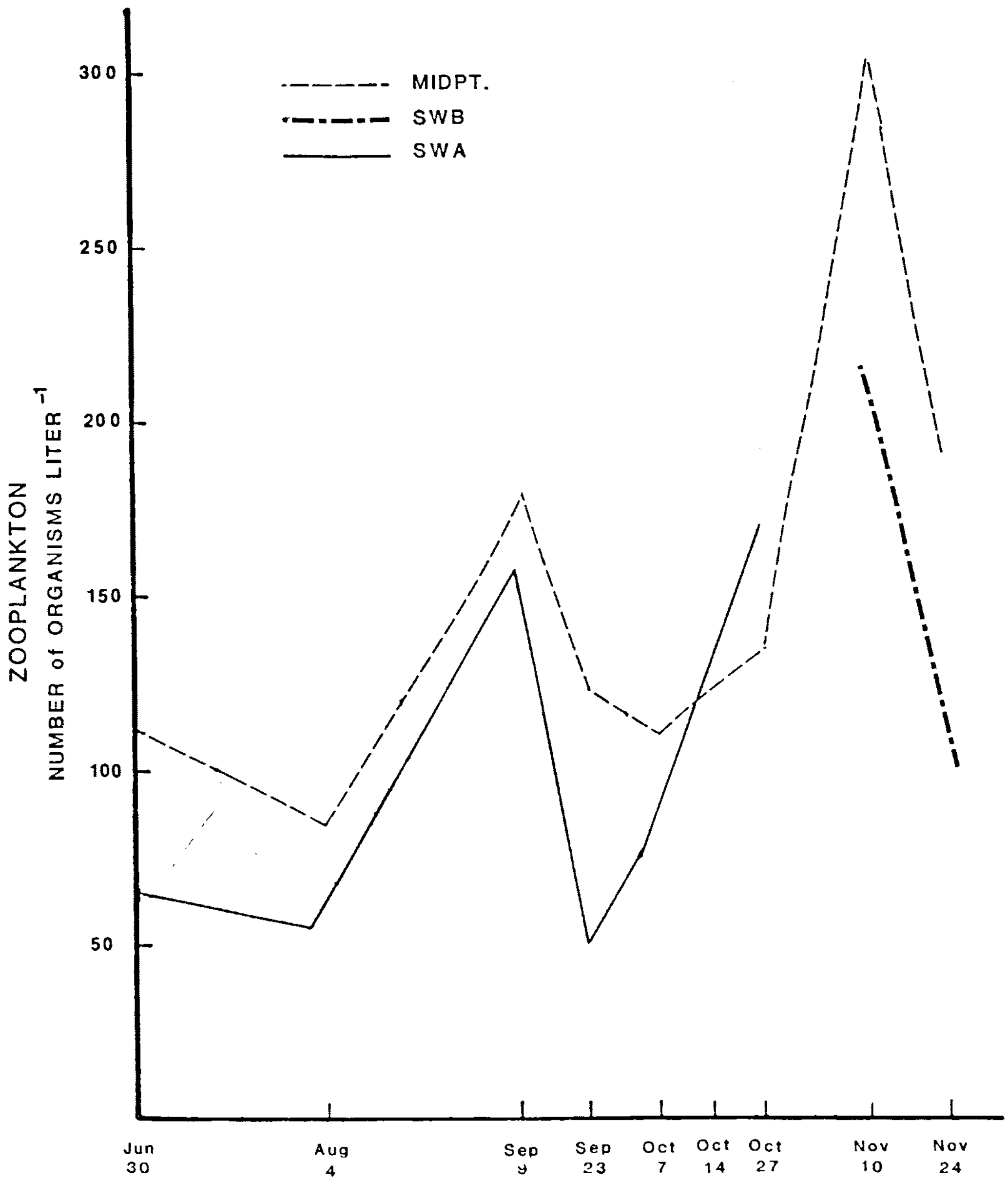

Figure 29. Mean zooplankton numbers in Black Lake, Midpoint and Southwest bay, 1984.

DISCUSSION

In 1984, Black Lake remained highly productive throughout the sampling regime. All indicators showed very high productivity. Water transparency ranged from 0.8 to 3.4 m with a June-October average of 1.2 m. Phytoplankton numbers, chlorophyll "a" content, pH, temperature, nutrient content, and the presence of extensive rooted aquatic macrophytes, all characterize a eutrophic lake. Super saturated near surface dissolved oxygen values also indicate high productivity, as eutrophic lakes can vary from virtual anoxia to 250% saturation (Goldman and Horne 1983). Bay sites were consistently higher in dissolved oxygen than Mid sites due to the presence of aquatic macrophytes. Also, CO_2 was generally not present at these sites during the summer months.

Although conditions seemed favorable, and other blooms were intermittent through the summer-fall, Nostoc did not develop to bloom proportions and toxicity did not occur. The fact that Nostoc was dominant in August showed that it was present, but due to certain environmental factors was not able to proliferate to bloom levels.

Algal growth potential was shown to be high in the algal assay results. Since the test alga is a non-nitrogen fixing green alga, actual potential can be underestimated if one does not also look at the nitrogen spiked flasks. This is especially true in fall, when nitrogen switched to the limiting nutrient. By adding nitrogen to the test flasks the green alga's nitrogen requirements are satisfied and it will produce yields similar to what one would expect from nitrogen fixing algae such as Nostoc commune (E.P.A. 1985). Based on these determinations the algal growth potential of Black Lake during the period of October 27 to November 24 ranged between 9.60 to 12.16 mg dry weight/liter rather than the lower control growth potentials of 5.70 to 7.96 mg dry weight/liter. This indicates that the potential for a massive bloom of nitrogen fixing blue-green algae (such as N. commune) existed in the fall of 1984.

The fact that the primary limiting nutrient switched from phosphorus to nitrogen during the fall months also would indicate conditions which favor Nostoc, as Anabaena is favored by low N:P ratios (Schindler 1977). Black Lake sustained phosphorus levels of 0.01 to 0.07 well within the eutrophic range in Vollenweider's (1968) productivity classification system. High nitrogen also has been shown to favor chlorophytes over cyanophytes (Barica et al 1980).

Since Black Lake is clearly eutrophic, and the potential for a blue-green bloom was present but did not materialize, may possibly be explained by two factors...climatological trends and stratification patterns. Weather patterns (rainfall and solar radiation) are important in determining the new season's algal composition and growth (May 1981). Black Lake sustained a prolonged wet spring (greater flushing of nutrients) in 1984, with spring water loading into the lake 20% higher than the preceeding three years. In addition, there was the lack of a protracted calm, bright, and warm fall in 1984. Juday et al. (1981) noted that precipitation was below normal during the year when a toxic bloom of Anabaena flos-aquae occurred in Hegben reservoir, Montana. May (1981) also noted that blue-greens are favored in excessive drought like conditions, and that Anabaena is removed more efficiently in flood conditions.

Stratification patterns may also play an important role in determining bloom formation. Black Lake never became completely stratified in 1984, as it lacked the presence of a true hypolimnion. A hypolimnion began forming in June but then never developed throughout the summer (seen by relatively little vertical differences in oxygen and temperature within the profile). This may be due to weather and flow patterns, and also to Black Lake's low mean depth (4.8 m) and saucer-like shape resulting in a propensity to be easily mixed. According to May (1981) blue-greens tend to be favored by conditions encountered in hypolimnial anoxia. Blue-greens also grow best in low O_2 and high CO_2, with both conditions occurring in the hypolimnial layer. Also, nutrients are high near the thermocline in lakes with an anoxic hypolimnion (Fay 1983), these nutrients could then become available to blue-greens as they are favored in low oxygen conditions and may be present at this high nutrient layer.

Since environmental parameters are most likely to dictate both blooms and development of toxicity (van der Westhuizen and Eloff 1982), climatological and stratification differences may well account for the lack of a toxic bloom of *Nostoc commune* even when other environmental parameters were favorable. This picture will be better understood following more complete data analysis and another season's study. Since toxic blooms did develop in the previous three years, it is more likely they will occur in 1985, a year of low spring runoff and warm, low runoff summer conditions. If so, the contrast in environmental conditions between the two years of "no toxicity" and "toxicity" could explain much of the causal mechanism.

CONCLUSIONS

1. Limnological and productivity variables were very similar between bay and open water sites in this shallow basin, especially since the study year was exceptionally cool and windy, resulting in well-mixed conditions.

2. The North sampling point adjacent to loading from the cattle feedlot effluent did not show limnological conditions different from other lake stations.

3. Although no toxic bloom of N. commune occurred in 1984, Black Lake did produce high algae levels throughout the sampling season. This is shown by high chlorophyll "a" content, relatively high phytoplankton numbers, moderately high nutrient levels, and low water transparency.

4. Limnological conditions, however, indicated a great potential for a toxic blue-green bloom to occur, as seen by optimal algal growth conditions of fall N:P ratios, pH, water temperature, and algal assay results.

5. Stratification patterns may be important in dictating whether N. commune can out-compete other algal species, thereby increasing its numbers, and float to the surface causing toxicity.

6. Weather patterns, namely solar radiation and precipitation, may be important in setting the stage for the occurrence of blue-green blooms and ensuing toxicity.

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