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STUDIES ON LAKE RESTORATION BY PHOSPHORUS INACTIVATION

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STUDIES ON LAKE RESTORATION BY PHOSPHORUS INACTIVATION

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

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SECTION I
INTRODUCTION

Reduction of in-lake nutrient levels through nutrient inactivation is one technique being evaluated for the restoration of excessively eutrophic lakes. Such treatment may be required for numerous shallow lakes or ponds and those lakes possessing poor flushing characteristics, even though external supplies of excess nutrients are prevented from entering the system. The advantages of nutrient inactivation over other restoration methods are relatively low cost, ease of application, wide scope of applicability, and use of low or non-toxic chemical or mineral additives (as compared with the use of copper sulfate or algicides, for example). Selected metal ions have shown potential as nutrient inactivation substances. These have the disadvantage of forming flocculent hydrous oxides which may be resuspended by wave action and currents in shallow lakes. Also, bacterial solubilization of phosphates of aluminum, calcium, and iron may occur under some conditions (1, 2, 3, 4, 5). Harrison et al., (6) have shown that sediment bacteria from Upper Klamath Lake, Oregon, are able to liberate phosphate from normally insoluble phosphates under anaerobic conditions. Such activity could hamper efforts toward permanent lake restoration by nutrient inactivation using metal ions, but periodic rejuvenation could be accomplished by subsequent additional treatments. Also, such resolubilization might not constitute as significant a problem in deep, stratified lakes.

Existing technology of potential applicability to nutrient inactivation is oriented toward the removal or immobilization of phosphorus. Numerous methods, mostly based on chemical precipitation or ion-exchange mechanisms, effectively remove phosphrous from sewage effluents (7, 8). Chemical methods include treatment with lime, alum, alum-lime, and iron (1). Fly ash has been found by Tenny and Echelberger (9) to significantly decrease phosphorus concentrations in water from highly eutrophic Stone

Lake, Michigan. In 1968, Lake Langsjon, Sweden, was treated with Boliden pellets (primarily aluminum sulfate) (10, 11). The lake showed definite improvement with a reduction in algal blooms during the summer following treatment; however, a second treatment in 1970 was necessitated because of additional sewage inflow to the lake. In 1970, Horseshoe Lake, Wisconsin, appeared to be improved by treatment with alum (12). A decrease in total phosphorus was apparent, hypolimnetic phosphorus concentrations did not increase during thermal stratification, transparency increased slightly, dissolved oxygen remained higher, and nuisance algal blooms which occurred in previous years were absent following treatment.

In 1969, an investigation was begun in our laboratory to determine the practicality of nutrient inactivation by chemical methods. The studies were designed to determine the total phosphorus removal capabilities of various chemical substances in both laboratory and field situations In a 1974 publication, Peterson et al. (13) describe a more extensive laboratory evaluation of chemical inactivants which was conducted in this laboratory subsequent to the study being described in this report. Aquarium experiments were used in 1969 to test the effectiveness of aluminum, lanthanum, calcium, and zirconium hydroxides in decreasing phosphorus concentration in waters from eutrophic lakes in Oregon. In all cases, phosphorus concentration and algal production were greatly reduced. Some reduction of soluble silica was also accomplished. The chemical results of these experiments are summarized in Table 1.

In 1970, limited field tests were conducted using two nylon-reinforced polyvinylchloride (PVC) enclosures measuring 4.8 x 4.8 x 3.6 m deep (16 x 16 x 12 feet). Both enclosures were open at the bottom and, when placed in the pond, effectively isolated two water columns and contiguous bottom sediments. Aluminum sulfate (10 mg Al/l) was added to enclosure A, and enclosure B (Figure 1) served as a control. Results of

TABLE 1. REDUCTION IN TOTAL PHOSPHORUS AND SOLUBLE SILICA IN A NATURAL SOFT WATER BY TREATMENT WITH METAL SALTS (ALKALINITY 60-70 mg $CaCO_3$/l)

Metal	Solution of Chemical Added	Concentration (mg metal/l)	Total Phosphorus (mg P/l before treatment)	Total Phosphorus (mg P/l after treatment)	Soluble Silica (mg SiO_2/l before treatment)	Soluble Silica (mg SiO_2/l after treatment)
Al	Boliden Pellets	2.5	0.26	<0.01		
Al	$NaAlO_2$	5.0	0.16	0.03	32	20
Al	Boliden Pellets	50.0	0.16	<0.01	39	16
Al	$NaAlO_2$	50.0	0.16	<0.01	39	8
La	$LaCl_3$	5.0	0.15	0.06		
La	$LaCl_3$	50.0	0.12	0.04		
Zr	$ZrOCl_2$	4.4	0.26	<0.01		
Zr	$ZrOCl_2$	50.0	0.56	0.04	40	32

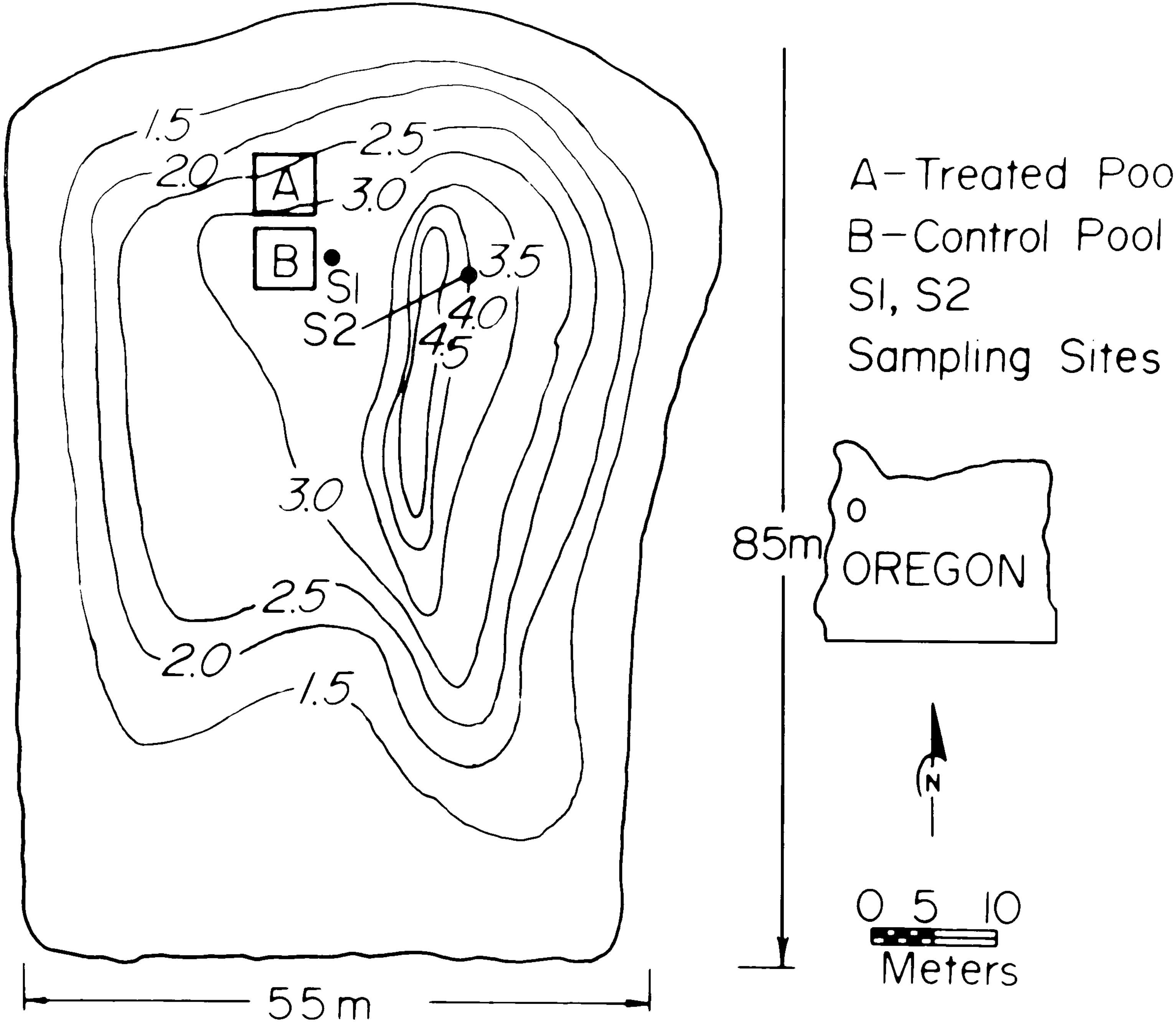

FIGURE 1. Bathemetric map of Cline's Pond showing sampling sites

these tests were inconclusive, primarily because of a tendency for the enclosed water to stagnate relative to the open pond. However, phytoplankton numbers and chlorphyll a concentrations in the treated enclosure were lower than in the control. Total carbon and total Kjeldahl nitrogen were also lower in the experimental enclosure, again indicating decreased production. Pronounced differences in phosphorus concentrations in the two enclosures were not observed.

We decided to extend our studies to a field evaluation of nutrient inactivation. The objectives were three-fold: (1) to scavenge the phosphorus, (2) to prevent the return of soluble phosphorus from the sediment interstitial water to the overlying water, and (3) to observe the effect of the treatment upon the biota of the pond.

Cline's pond, a 0.4 ha (1 acre) pond constructed in 1953 and located approximately 32 km (20 miles) north of Corvallis, Oregon, was selected as the experimental site. The pond received surface runoff from a 1 ha (2.5 acre) drainage area which is usually planted in a forage crop or sugar beets. Several small, intermittent springs supplied some subsurface water; other possible ground water infiltration was not evaluated. The maximum depth was 4.9 m (16 ft) with an average depth of 2.4 m (8 ft) (Figure 1). The pond was stocked annually by the owner with 8-10 cm (3-4 inch) rainbow trout fingerlings which were fed between 90-140 kg (200-300 pounds) of commercial fish food each year. Limnological data had been collected on the pond for three years and indicated a high degree of eutrophy; heavy growths of blue-green algae had occurred routinely, and severe oxygen depletion, high nutrient levels, and low water transparency had been the norm. Summer thermal stratification occurred in the deeper parts of the pond, and mild winter temperatures usually precluded the pond's freezing over. Limnological data for 1969, 1970, and 1971 are shown in Table 2.

TABLE 2. SUMMARY OF CLINE'S POND LIMNOLOGICAL DATA

	Depth[a,b]	1971 4/15-9/15 Avg.	1971 4/15-9/15 Min-Max.	1970 4/15-9/15 Avg.	1970 4/15-9/15 Min-Max	1969 Control 4/15-9/15 Avg.	1969 Control 4/15-9/15 Min-Max	1969 Aerated 6/30-9/15 Avg.	1969 Aerated 6/30-9/15 Min-Max	1971 6/30-9/15 Avg.
P-total (mg/l)	S	.06	.01 - .11	.29	.13 - .60	.17	.09 - .30	.19	.09 - .36	.08
	B	.09	.02 - .33	.35	.18 - .48	.56	.14 - 1.85	.44	.12 - 1.55	.09
P-ortho (mg/l)	S	.01	<.01 - .02	.03	<.01 - .09	.01	<.01 - .04	.02	<.01 - .07	.01
	B	.01	<.01 - .02	.09	<.01 - .28	.02	<.01 - .05	.03	<.01 - .06	.02
N-ammonia (mg/l)	S	.03	<.01 - .13	.22	<.01 - .84	.05	.02 - .07	.21	.04 - .10	.03
	B	.03	<.01 - .15	.56	<.01 - 1.40	.95	.08 - 4.25	.71	.04 - 4.25	.05
N-nitrate (mg/l)	SB	<.01	<.01 - .09	<.01	<.01 - .04	.04	<.01 - .10	.01	<.01 - .03	<.01
N-nitrite (mg/l)	SB	<.002	<.002- .007	.003	<.002- .009	.010	.004- .010	.010	.004- .120	<.002
N-total Kjeldahl (mg/l)	SB	1.1	.5 - 2.5	2.6	.9 - 7.0	2.5	1.3 - 9.1	2.5	1.1 - 8.9	1.5
C-total (mg/l)	SB	15	8 - 28	22	8 - 34					
C-soluble organic (mg/l)	SB	8	2 - 16	6	2 - 14					
Fe-soluble (mg/l)	SB	.16	.02 - .63	.92	.20 - 1.70					
Fe-total (mg/l)	SB	.78	.30 - 3.50	1.84	.50 - 3.70					
Mn-soluble (mg/l)	SB	.20	<.01 - 1.30	.78	<.01 - 1.95					
Mn-total (mg/l)	SB	.56	.10 - 1.58	.74	.12 - 1.35					
Si-soluble (mg/l)	SB	3.3	1.5 - 5.9	6.3	1.7 - 11.0					
Alkalinity (mg $CaCO_3$/l)	SB	32	22 - 47	46	31 - 61	46	33 - 76	46	27 - 86	38
DO (% Saturation)	S	110	77 - 152	98	22 - 200	126	73 - 197	124	30 - 125	116
	M	99	67 - 122	41	9 - 96	62	7 - 117	56	24 - 86	96
	B	32	2 - 96	9	2 - 17	19	0 - 69	17	0 - 80	25
DO (mg/l)	S	10.0	7.0 - 13.4	8.4	2.0 - 16.5	10.8	6.2 - 16.1	10.4	2.7 - 11.1	10.0
	M	9.2	6.1 - 11.1	3.7	.9 - 8.7	5.7	.6 - 10.4	5.6	2.1 - 7.6	7.8
	B	3.2	.0 - 9.7	.8	.2 - 1.7	1.7	.0 - 6.4	1.6	.0 - 7.0	2.3
pH	S	7.4	6.5 - 9.5	8.8	6.7 - 10.9	8.7	7.7 - 9.6	6.9	6.4 - 8.4	7.7
	B	7.0	6.5 - 7.5	7.2	6.4 - 8.9	6.8	6.5 - 8.2	6.6	6.3 - 7.0	7.0

TABLE 2. SUMMARY OF CLINE'S POND LIMNOLOGICAL DATA (continued)

	Depth[a,b]	1971 4/15-9/15 Avg.	1971 4/15-9/15 Min-Max.	1970 4/15-9/15 Avg.	1970 4/15-9/15 Min-Max	1969 Control 4/15-9/15 Avg.	1969 Control 4/15-9/15 Min-Max	1969 Aerated 6/30-9/15 Avg.	1969 Aerated 6/30-9/15 Min-Max	1971 6/30-9/15 Avg.
Secchi disc (cm)		117	55 -200	90	12 -180	46	30 - 75	74	40 -130	125
Temperature (°C)	S	18.6	11.0- 25.8	21.7	17.0- 28.5	21.5	15.1- 27.2	22.1	18.6- 22.5	21.6
	M	18.0	11.0- 24.8	18.7	15.5- 21.1	18.5	13.3- 22.1	19.5	18.0- 22.5	20.7
	B	15.8	10.0- 21.5	15.4	11.7- 19.8	17.6	10.4- 21.2	18.6	16.0- 22.4	18.7
Chlorophyll *a* (mg/m³)	SB	54	2 -179	187	8 -1682	56	27 -117	26	13 - 55	49
Phytoplankton										
clump count	SB	17,698		26,740		20,526		17,511		5,433
modified clump count	SB	42,561		192,563		50,188		22,995		58,005
Chloride (mg/l)	SB	12.0	9.0- 16.0	4.0	4.0- 4.0					
Sodium (mg/l)	SB	10.9	8.9- 16.0	7.0	5.0- 8.0					
Potassium (mg/l)	SB	.4	.2- .7							
Sulfate (mg/l)	SB	<10	<10 -<10	10	<10 -<10					
Total hardness (mg/l)	SB	34	25 - 55	40	34 - 46	39	33 - 52	41	34 - 58	39
Conductivity (umhos/cm)	SB	120	160 -138	117	99 -135	111	93 -157	115	101 -181	126
Volatile suspended solids (mg/l)	SB	4.7	1.0- 20.0	8.0	1.0- 28.0					
Suspended solids (mg/l)	SB	6.7	1.0- 28.0	12.0	1.0- 36.0					

[a] S, surface; M, middle; and B, bottom.
[b] SB, average of surface and bottom.

In 1969, Cline's Pond was the site of an aeration-destratification experiment; this study has been reported by Malueg et al. (14). The pond was separated into equal experimental and control sections with polyethylene sheets. The experimental section was aerated and the other was left undisturbed as a control. Unless otherwise indicated, 1969 data referred to in the present report apply only to the control section.

SECTION II
SUMMARY

Sodium aluminate effectiveness as a nutrient inactivant to control eutrophication was evaluated in Cline's Pond, a 0.4 ha farm pond near Corvallis, Oregon. Ability of the inactivant to scavenge phosphate in the water column, to prevent resolublization of phosphate, and to inhibit primary production was of primary concern. Evaluation was based on limnological comparison of the pond following inactivation with antecedent data obtained over the preceding two years. In general, total phosphate, ammonia, total Kjeldahl nitrogen, iron, manganese, and algal standing crop were lower following inactivation than during the two previous years. Increased transparency and more uniform distribution of dissolved oxygen and pH suggested an improvement in water quality. A shift in dominance from blue-green to green algae was indicated. Firm conclusions as to the effectiveness of the sodium aluminate treatment cannot be drawn, however, because of a lack of uniformity of limnological parameters in the pond during the two years before initiation of the experiment.

SECTION III
CONCLUSIONS

Data obtained from this study and others using similar techniques indicate that the use of chemical substances to immobilize algal nutrients may be a feasible and practical technique for reducing primary productivity, in eutrophic lakes. The experiment reported here suggested some reduction in both biological and chemical symptoms of advanced eutrophy, using an aluminum compound to decrease the availability of phosphorus in the system. The necessity of comparing the 1971 results with antecedent data make the results difficult to interpret. Variation in the chemical and biological data of the latter are sometimes greater than between these and the 1971 experimental data. Overall, it appears that the aluminum treatment did reduce the eutrophic status of the pond and that no obvious toxicity problems resulted. The method does appear promising for restoration of eutrophic lakes lacking significant flowthrough, where nutrient influx can be controlled. In other cases where nutrient input is not curtailed or internal recycling continues, inactivation treatment on some periodic basis might prove feasable.

SECTION IV
RECOMMENDATIONS

Further studies should be conducted using a variety of possible nutrient inactivation compounds. This will require extensive laboratory experimentation to determine efficiencies, duration of effectiveness, and possible adverse environmental effects. Field testing and prolonged observation will be necessary to determine effectiveness in the natural environment where an array of factors, impossible to duplicate in laboratory testing situations, may occur.

Nutrient inactivation appears to be a promising tool for reducing the severity of algal blooms in excessively eutrophic waters. It should be particularly valuable in situations where nutrient input has been reduced and a recycling of nutrients between the water and sediment prevents a reduction in algal productivity. Application of a low or non-toxic inactivant on a periodic basis may prove a valuable management tool where non-point sources cannot be controlled. However, use of this technique should be carefully evaluated because our present knowledge does not allow the prediction of long range environmental effects. Additions of foreign materials to a water body should be considered only when all other possibilities have been evaluated.

SECTION V

METHODS AND MATERIALS

On April 15, 1971, prior to the development of a major blue-green algal population, the pond was treated with sodium aluminate. The pond water was poorly buffered (total alkalinity approximately 30-50 mg/l as $CaCO_3$) and the sodium aluminate solution had to be neutralized with concentrated hydrochloric acid prior to its introduction into the pond to prevent drastic changes in pH. Sodium aluminate ($NaAlO_2$) was dissolved in pond water in 200 l (55 gallon) metal drums. The neutralized slurry of aluminum hydroxide and water was pumped to a second metal drum in a small boat. Distribution from the boat was initially through a 3 m (10 ft) perforated PVC manifold system clamped to the transom. The slurry was released about 0.3 m (1 ft) below the surface of the water through a series of spray nozzles. However, the nozzles clogged after about one half of the solution had been applied and the remaining slurry was sprayed directly on the water surface from an open hose. Mixing was achieved by the backwash of the boat propeller during application and by rapid traverses of the pond after application was completed. A total of 227 kg (500 lb) of sodium aluminate and 265 kg (585 lb) of hydrochloric acid were used in the treatment, corresponding to a final average concentration in the pond of 10 mg Al/l. The 1971 cost for the sodium aluminate and hydrochloric acid were $102.00 and $60.00, respectively.

Water samples were collected from two locations, S1 and S2 (Figure 1), which were three and four m deep, respectively. Samples for chlorophyll a and phytoplankton were collected from the surface, middle and bottom of each location, and samples for chemical analyses were collected only from the surface and bottom. Chlorophyll a, pH, and Secchi disc measurements were made weekly. The remaining chemical, physical and biological determinations (see Table 2) were on a biweekly schedule. All parameters were measured one week prior to treatment, the day following treatment, one week from the day of treatment, and every two weeks thereafter. Chemical analyses were conducted in accordance with EPA methods (15). Transparency was measured with a black and white 20cm Secchi disc, dissolved oxygen and temperature with an Electronic Instruments Limited Model 15A Dissolved Oxygen Meter, pH with a Beckman Zeromatic II pH meter, and conductivity with an Industrial Instruments, Inc., Model RC 16B2 Conductivity Bridge. Chlorophyll *a* analysis followed the method of Strickland and Parsons (16).

Phytoplankton were preserved as a three percent formalin mixture and the preserved samples were counted using a one ml Sedgewick Rafter counting chamber. Most organisms were identified to genus and some of the more abundant forms to species. Two different methods were used in interpreting the phytoplankton data. Originally enumeration was by the standard clump count (17), but a "modified clump count" was subsequently employed to obtain a better estimate of actual cell numbers. The standard clump count considers all organisms of one type in contact with one another as single organisms, thus generally underestimating the number of cells, particularly where filamentous or colonial forms are involved. The filamentous bluegreen *Anabaena* was the major bloom-forming organism in Cline's Pond. In order to emphasize its cell numbers rather than chain numbers, an average number of cells was determinated for approximately 100 chains. This was multiplied by the total number of chains counted in each sample to determine the number of cells present. This method is referred to as the modified clump count."

SECTION VI
RESULTS

Averages of the sampling depths (surface, bottom, or surface and bottom) at sites S1 and S2 are presented in Figures 2 through 21 and Table 2. Maximum and minimum values are also given in Table 2 to suggest the magnitude of observed variation. The data used in the comparison extend from April 15 to September 15 of each year.

Total phosphorus concentrations, which were of particular interest, did not change greatly immediately after treatment. The average for the surface at the two stations was 0.043 mg P/l one week prior to treatment and 0.041 mg P/l one day after treatment. There was an increase from 0.027 to 0.076 mg P/l in the average total phosphorus concentration in the bottom water of stations S1 and S2 during the same time periods; this increase was confined almost totally to the bottom of the deeper east station where the total phosphorus increased from 0.020 to 0.104 mg P/l. In the shallower west station, levels were 0.034 mg P/l before treatment and 0.048 mg P/l after treatment. Total phosphorus concentration in 1971 remained lower and did not fluctuate to the degree observed in the previous two years (Figures 2 and 3).

The 1971 orthophosphate-phosphorus values showed little difference before or immediately after treatment. Surface samples collected on April 8, one week prior to treatment, averaged <0.01 mg P/l as did those collected April 16, the day following treatment. A comparison of averages of the sampling period indicates practically no differences in orthophosphate-phosphorus between the 1971, 1970, and 1969 seasons except for the 1970 bottom samples. Surface orthophosphate-phosphorus concentrations for three years were 0.01, 0.03, and 0.01 mg P/l, respectively: bottom concentrations were 0.01, 0.09, and 0.02 mg P/l. Figure 4 indicates the relative similarity of surface orthophosphate-phosphorus values during

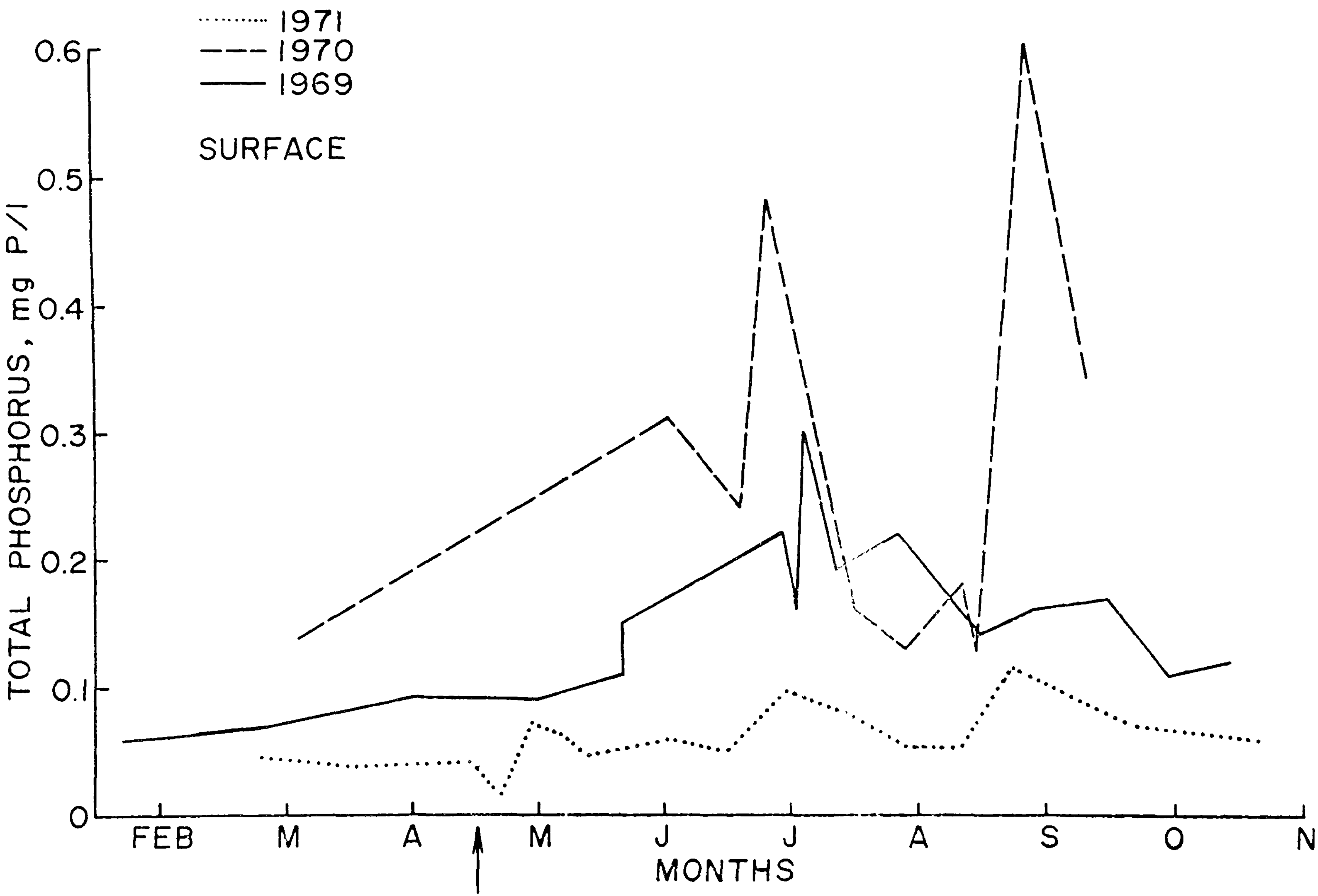

FIGURE 2. Total phosphorus-surface

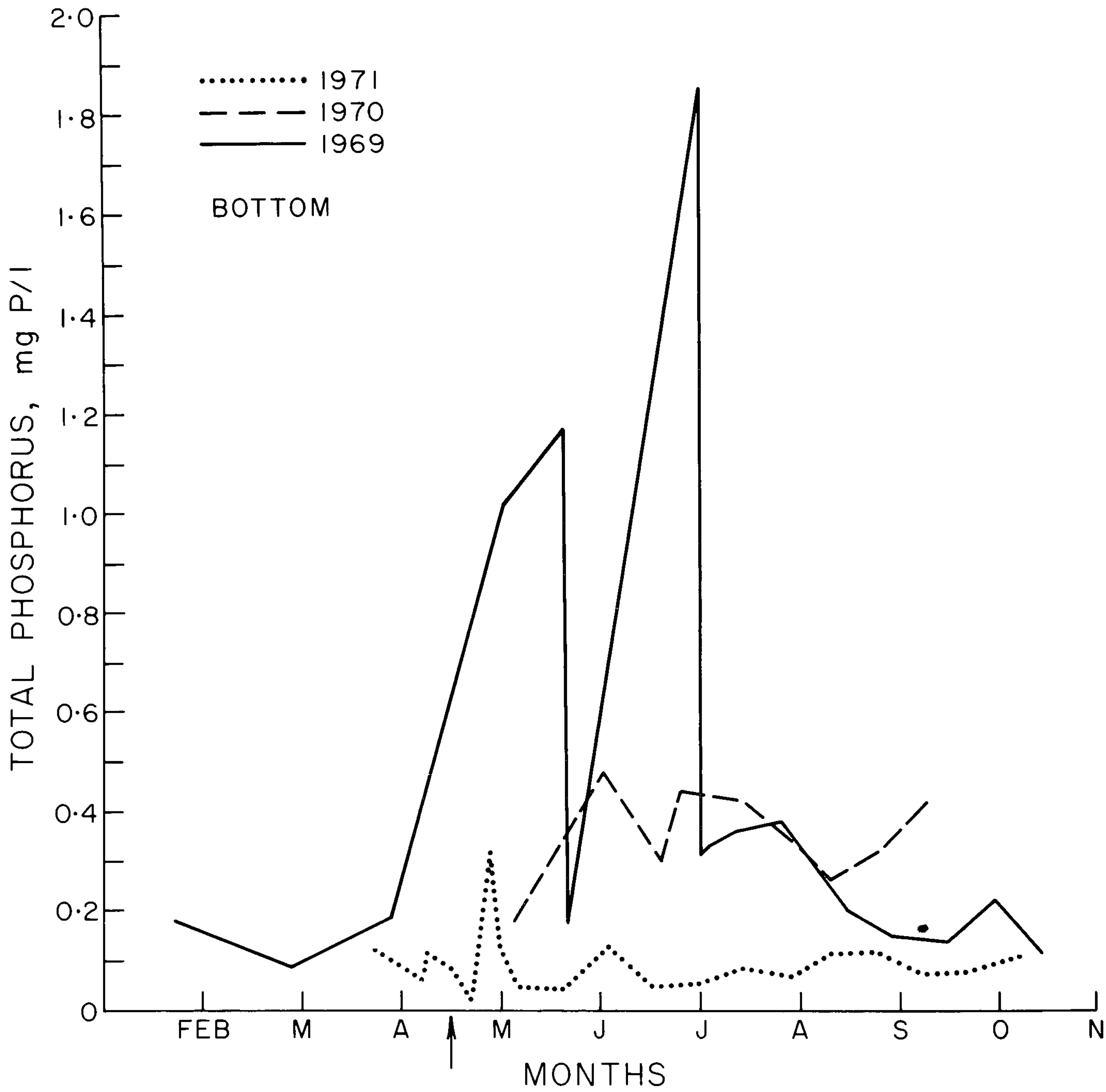

FIGURE 3. Total phosphorus-bottom

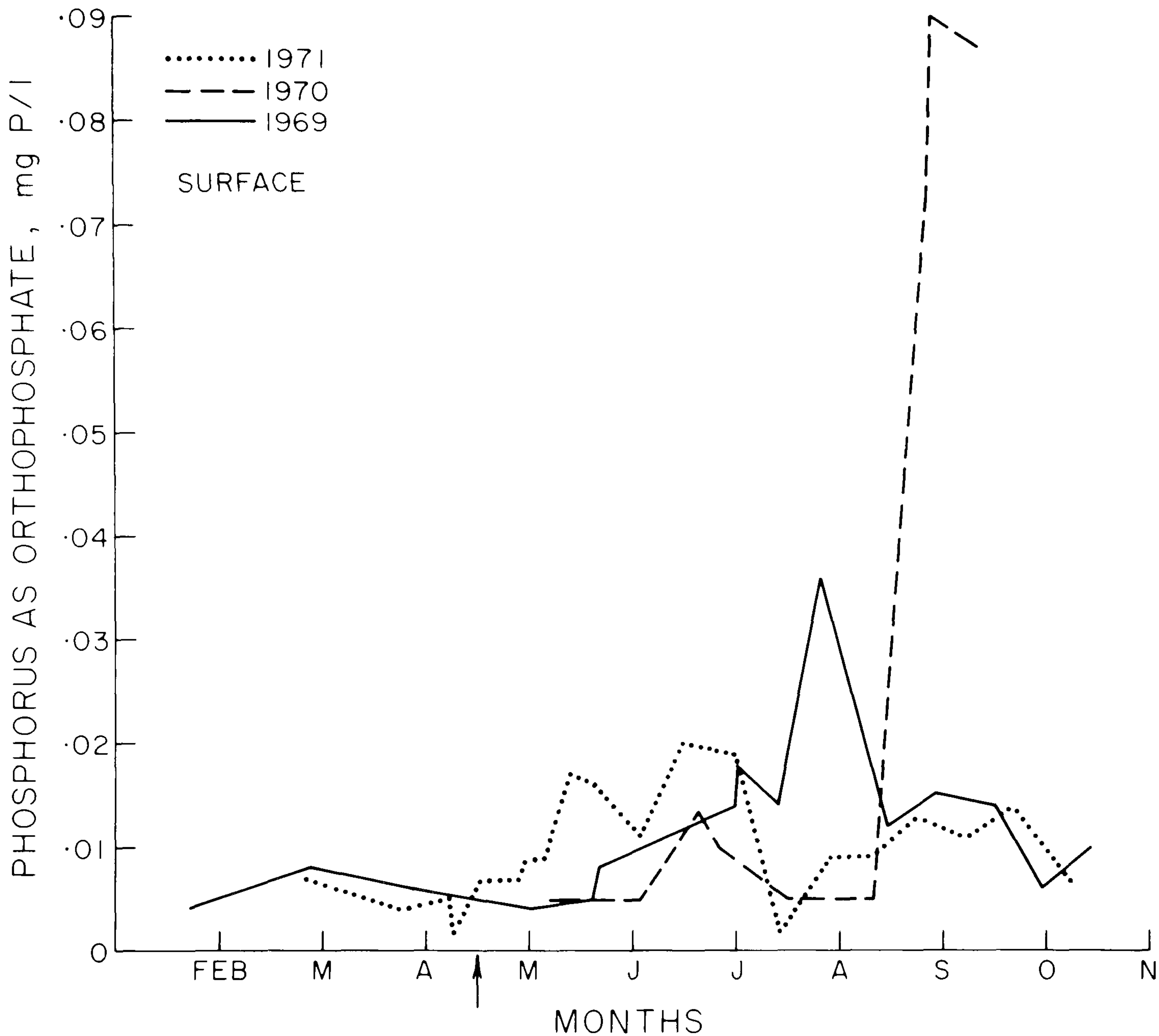

FIGURE 4. Orthophosphate-phosphorus-surface

most of the growth season; Figure 5 shows that bottom values were generally lower and more stable in 1971.

Ammonia concentrations were generally lower following nutrient inactivation. No changes were observed immediately after treatment; values remained between 0.01 and 0.04 mg N/l for the first month. Both surface and bottom values remained relatively constant throughout 1971 (Figures 6 and 7), never exceeding 0.16 mg N/l throughout the growth season. The extreme variation in bottom concentrations that occurred in 1969 and 1970 should be noted; on several occasions, the bottom concentration exceeded 1.00 mg N/l. Average values for the three years illustrate the same trend: 0.03, 0.22, and 0.05 mg N/l, respectively, for 1971, 1970, and 1969 surface concentrations and 0.03, 0.56 and 0.95 mg N/l for the bottom.

Nitrite, nitrate, and organic nitrogen did not change greatly after treatment; nitrite remained <0.001 mg N/l and nitrate varied from <0.01 to 0.03 mg N/l during the initial two months after treatment. Organic nitrogen decreased from 0.70 to 0.54 mg N/l on the surface and from 0.95 to 0.84 mg N/l on the bottom following sodium aluminate application. Average nitrite and nitrate concentrations were low during all three years. Nitrite was <0.002, 0.003, and 0.010 mg N/l, respectively, for 1971, 1970, and 1969, and nitrate was <0.01, 0.04, and 0.01 mg N/l. Total Kjeldahl nitrogen (Figures 8 and 9) followed a pattern similar to organic nitrogen, dropping slightly immediately after treatment with an increase in surface values during mid-July (Figure 8). The surface and bottom total Kjeldahl nitrogen averages were lower in 1971 than in either 1970 or 1969: 1.1, 2.6, and 2.5 mg N/l, respectively, for the three years.

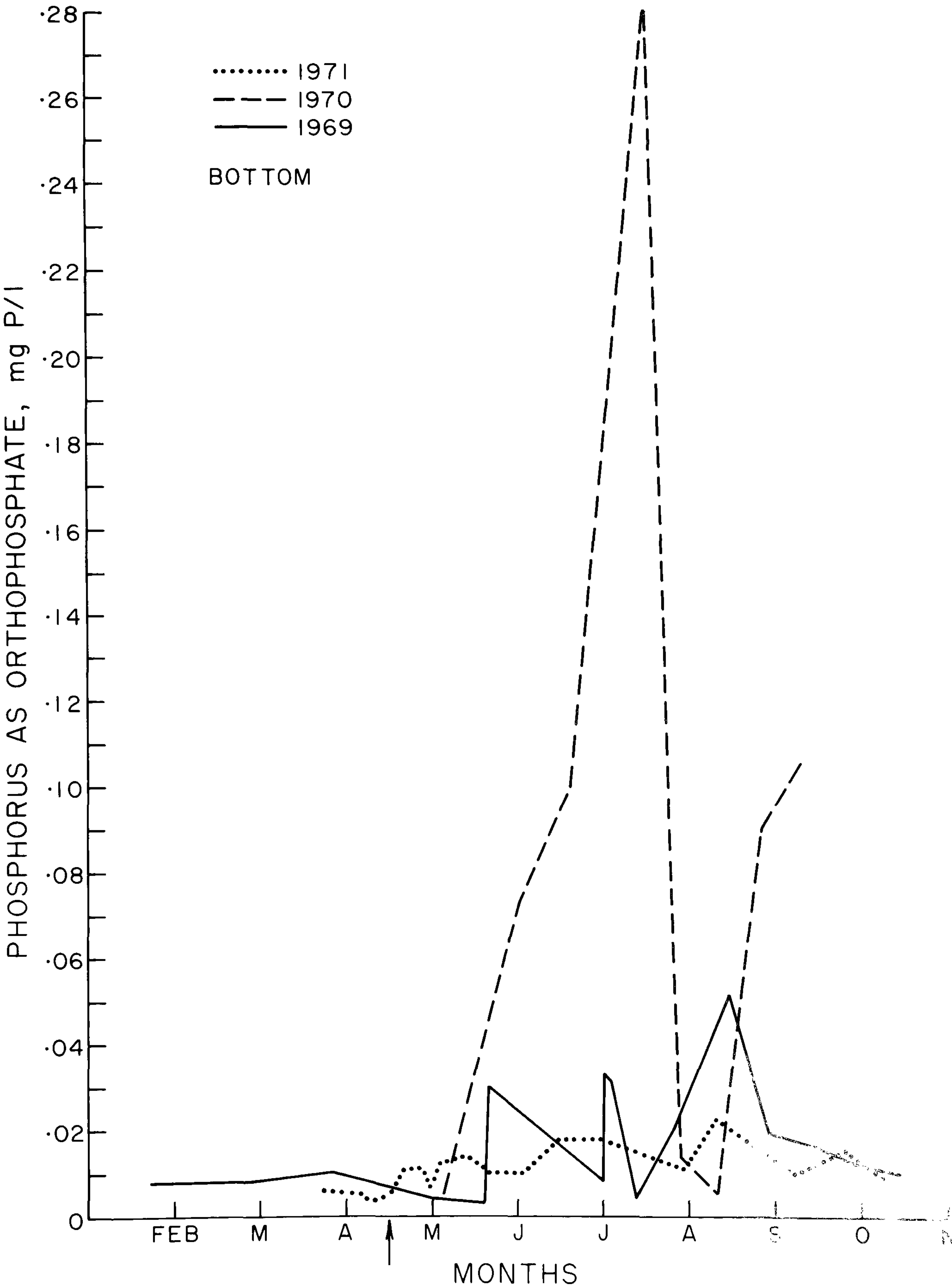

FIGURE 5. Orthophosphate-phosphorus-bottom

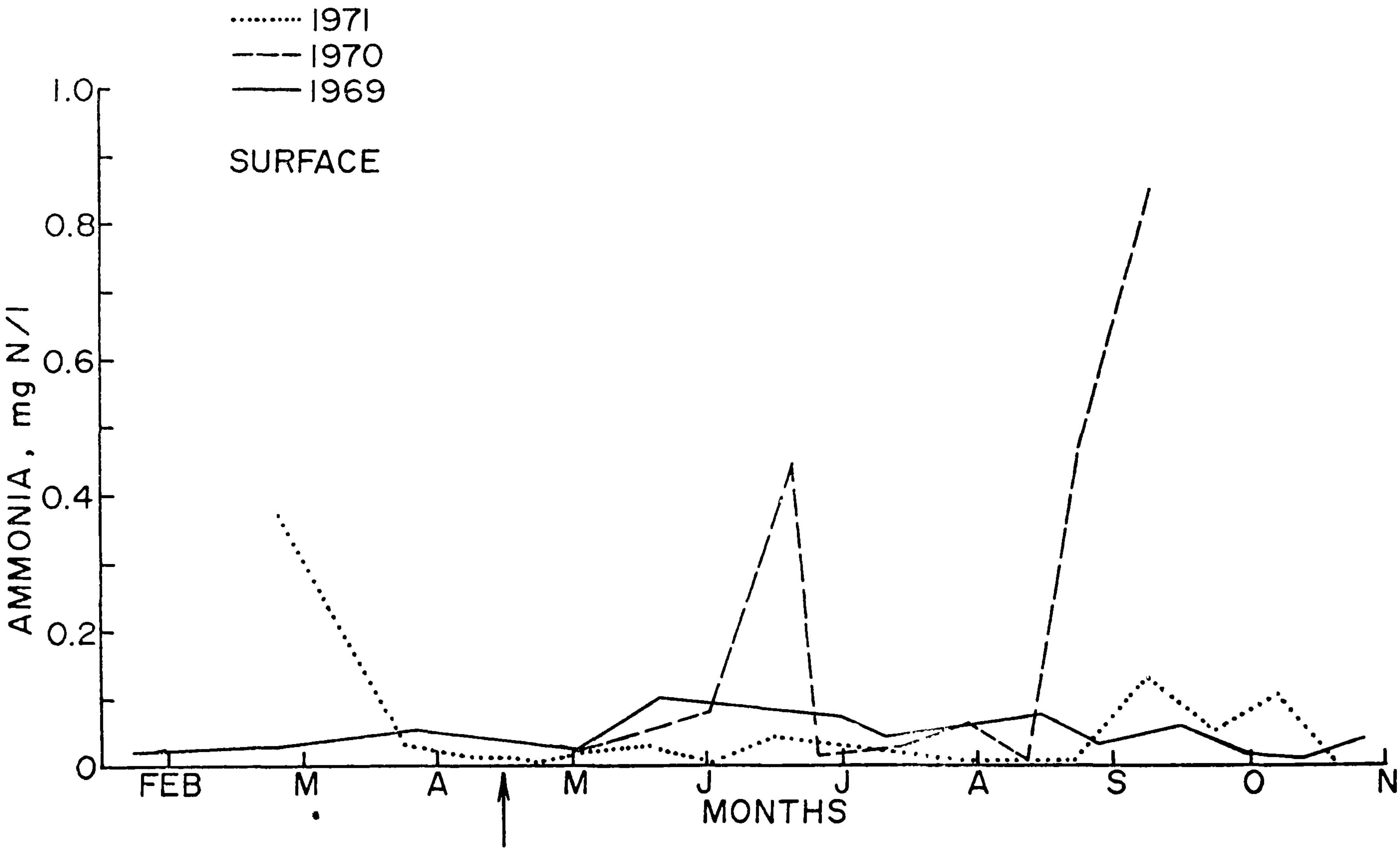

FIGURE 6. Ammonia-surface

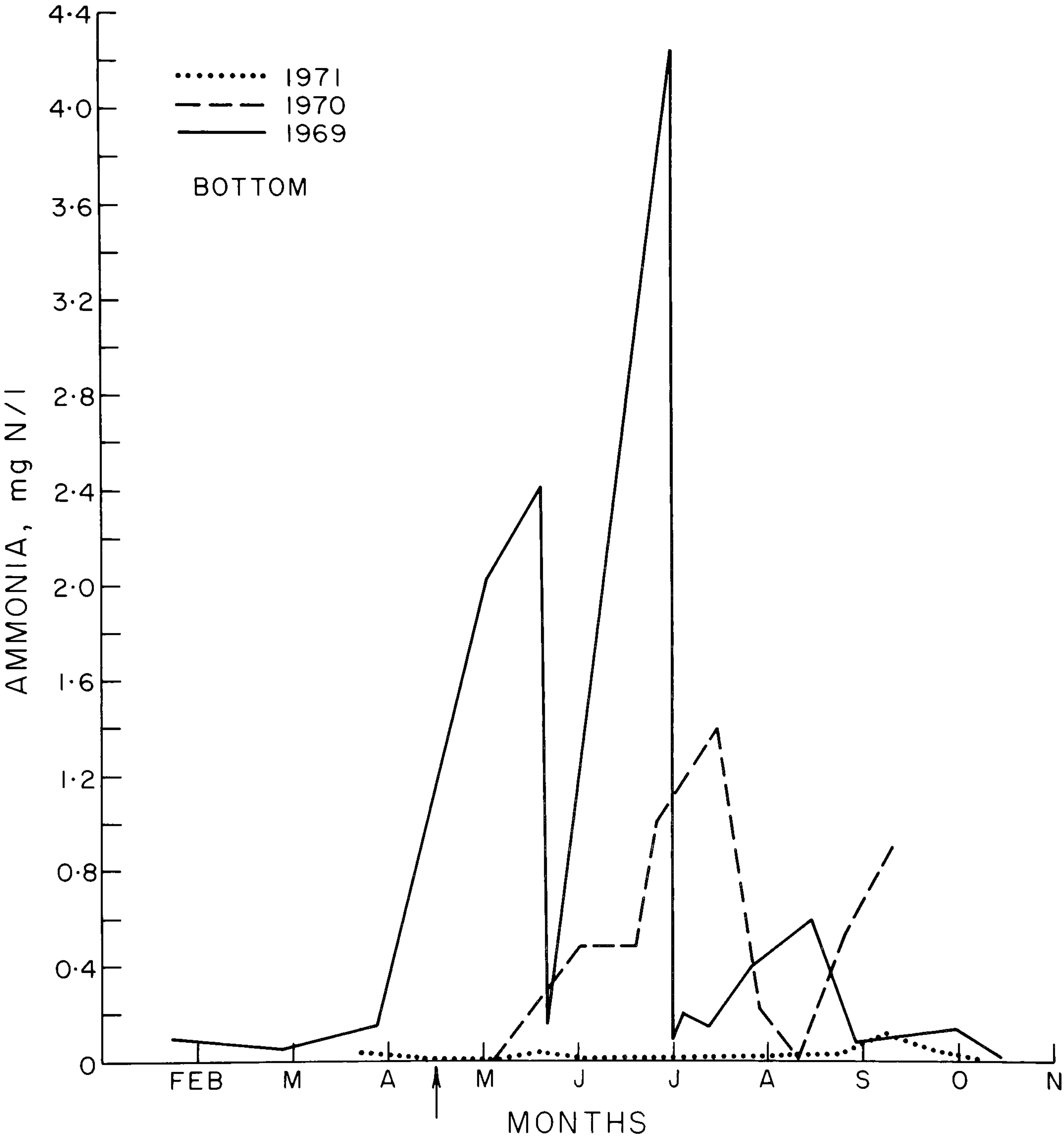

FIGURE 7. Ammonia - bottom

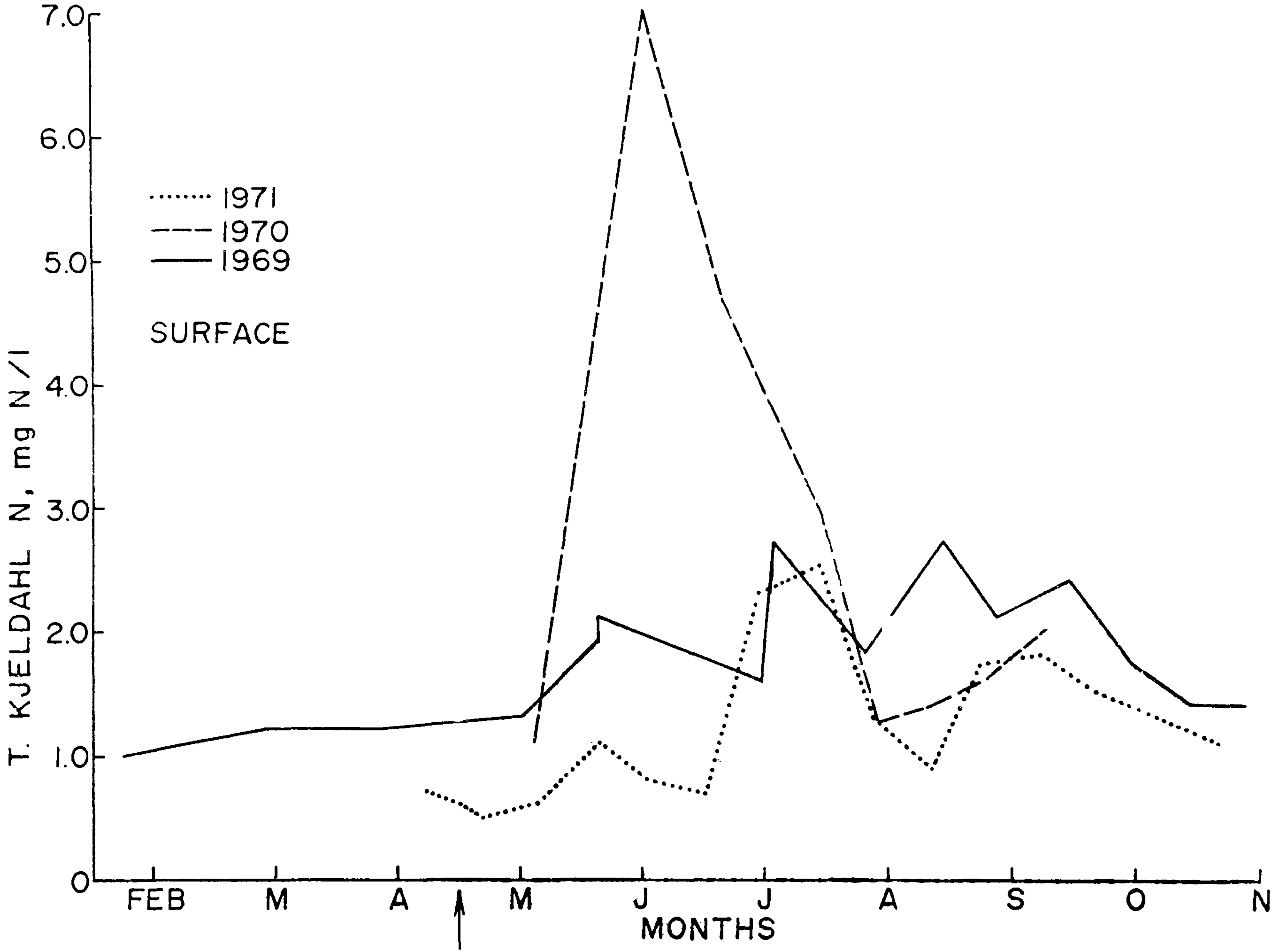

FIGURE 8. Total Kjeldahl nitrogen-surface

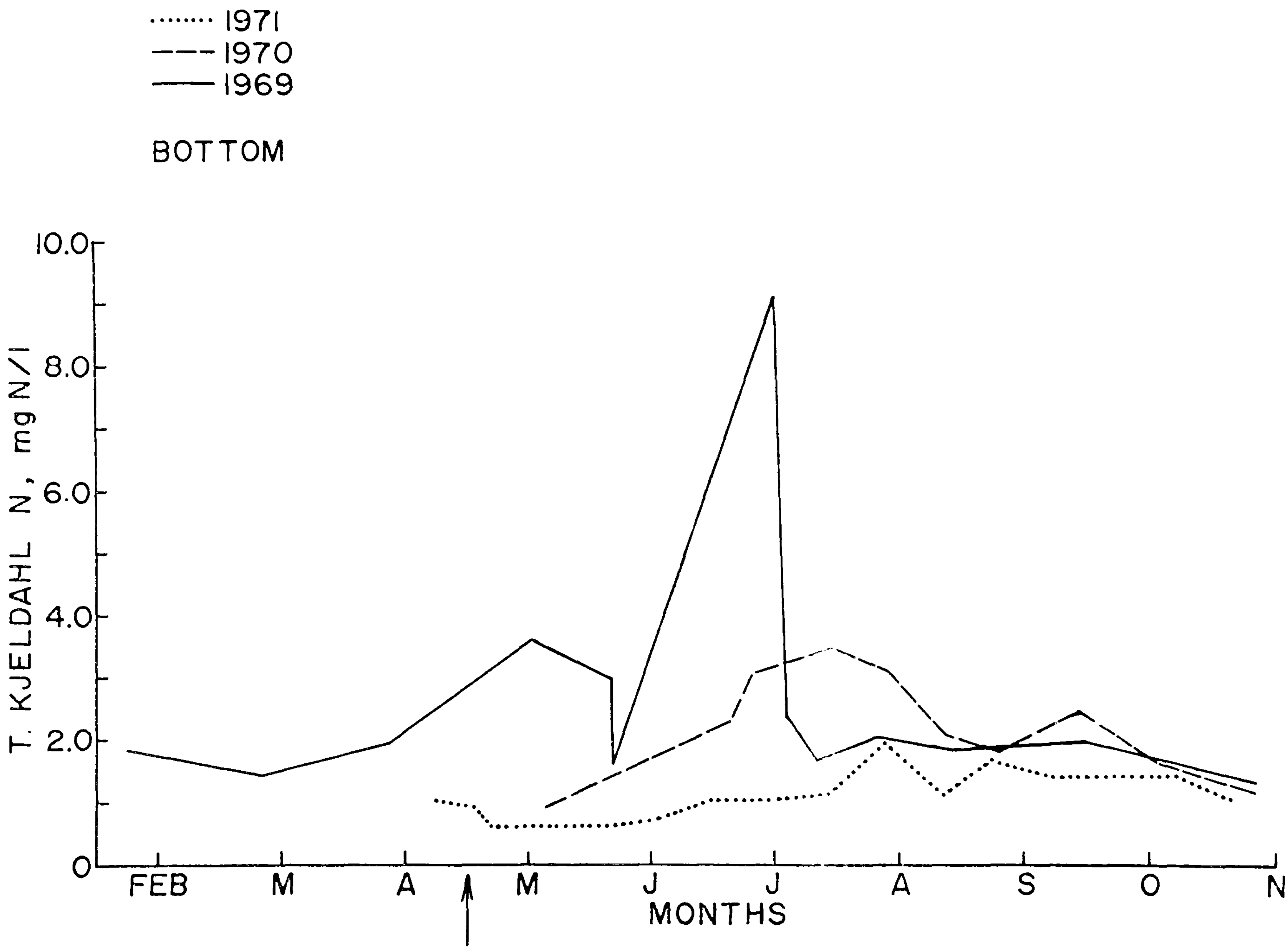

FIGURE 9. Total Kjeldahl nitrogen-bottom

Total carbon and soluble organic carbon were measured in 1971 and 1970. Concentrations did not change significantly after treatment, but did increase gradually during the season. Surface and bottom averages for total carbon were 10 mg C/l before and 9 mg C/l one week after treatment. A peak of 25 mg C/l was reached on September 7, 1971. Surface and bottom averages for soluble organic carbon followed a similar trend; 6 mg C/l before treatment 5 mg C/l after treatment, and a peak of 12 mg C/l on September 7. Average total carbon concentrations were 8.3 mg C/l in 1971 and 6.0 in 1970.

Iron and manganese measurements were not obtained immediately before or after treatment, nor at any time in 1969. Averages for 1971 were consistently lower than those for 1970 (Figures 10 and 11). Average soluble iron was 0.16 mg Fe/l in 1971 and 0.92 in 1970. Total iron averaged 0.78 mg Fe/l in 1971 and 1.84 in 1970. Manganese followed a trend similar to iron. Average soluble manganese was 0.20 mg Mn/l in 1971 and 0.78 in 1970. Average total manganese was 0.56 mg Mn/l in 1971 and 0.74 in 1970. The discrepancy in the average soluble and total manganese values for 1970 cannot be reconciled. The estimated resolution of the analytical method is 0.01 mg Mn/l.

A slight decrease in soluble silica occurred immediately after the addition of the sodium aluminate. The surface concentration decreased from 4.7 mg SiO_2/l to 3.7 following treatment. The surface-bottom average for 1971 was 3.3 mg SiO_2/l and 6.3 for 1970. Soluble silica was not measured in 1969.

Total alkalinity averaged 24 mg/l as $CaCO_3$ before inactivation at both the surface and bottom. It remained at that level for about one month (Figures 12 and 13), increasing to about 40 mg/l by the end of the summer. The seasonal averages for 1971, 1970, and 1969 were 32, 46, and 46 mg/l as $CaCO_3$ indicating a slight overall reduction after treatment of the pond.

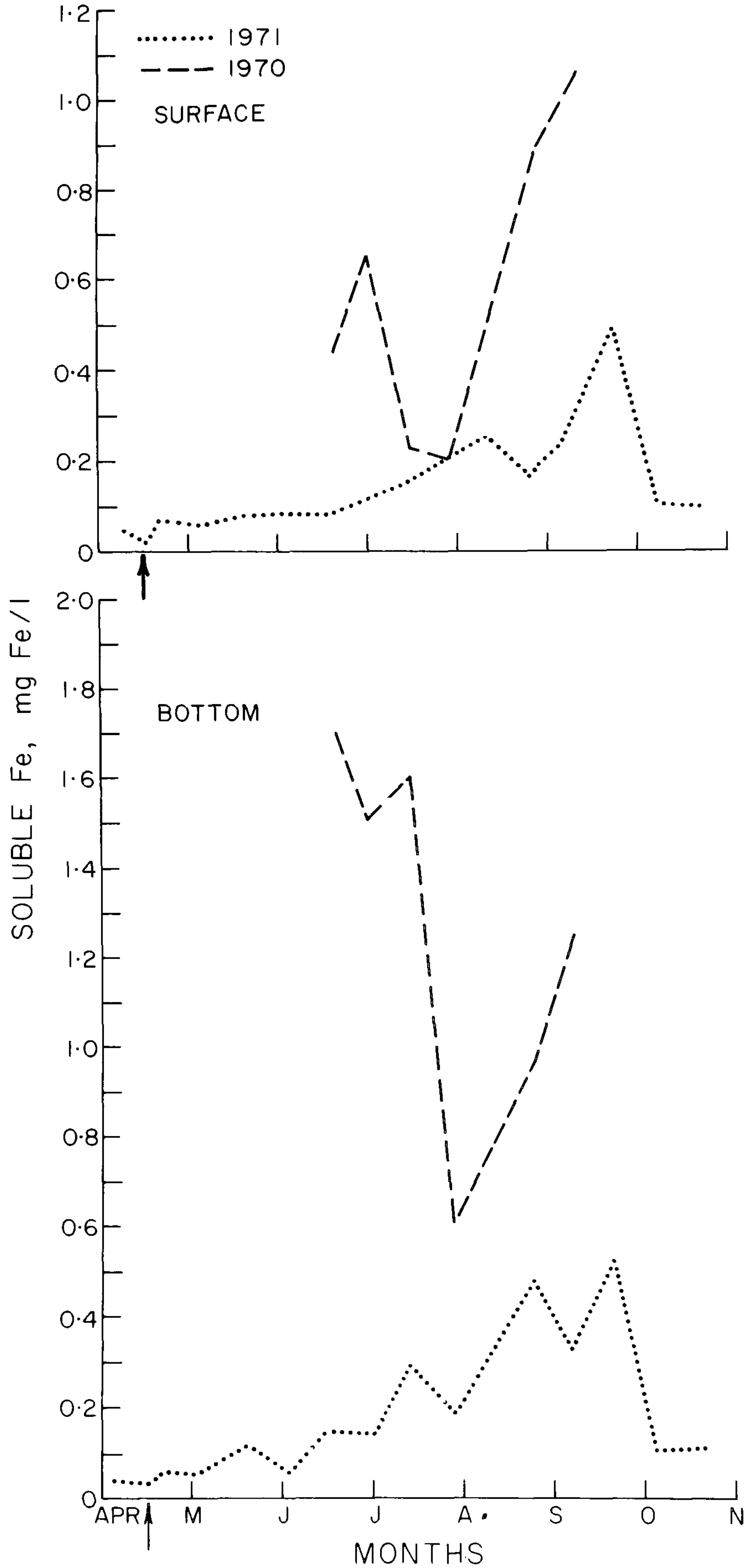

FIGURE 10. Soluble iron-surface and bottom

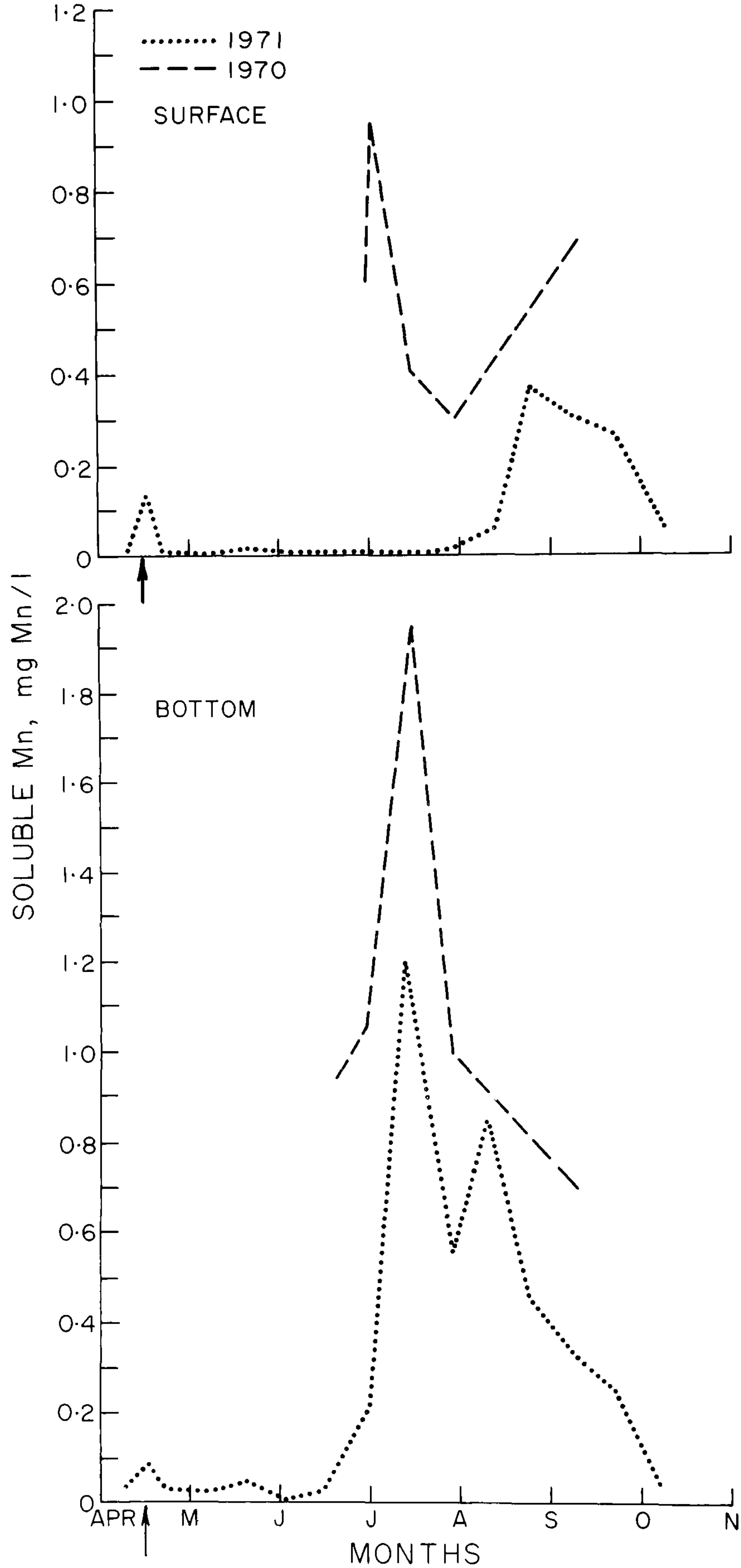

FIGURE 11. Soluble Manganese-surface and bottom

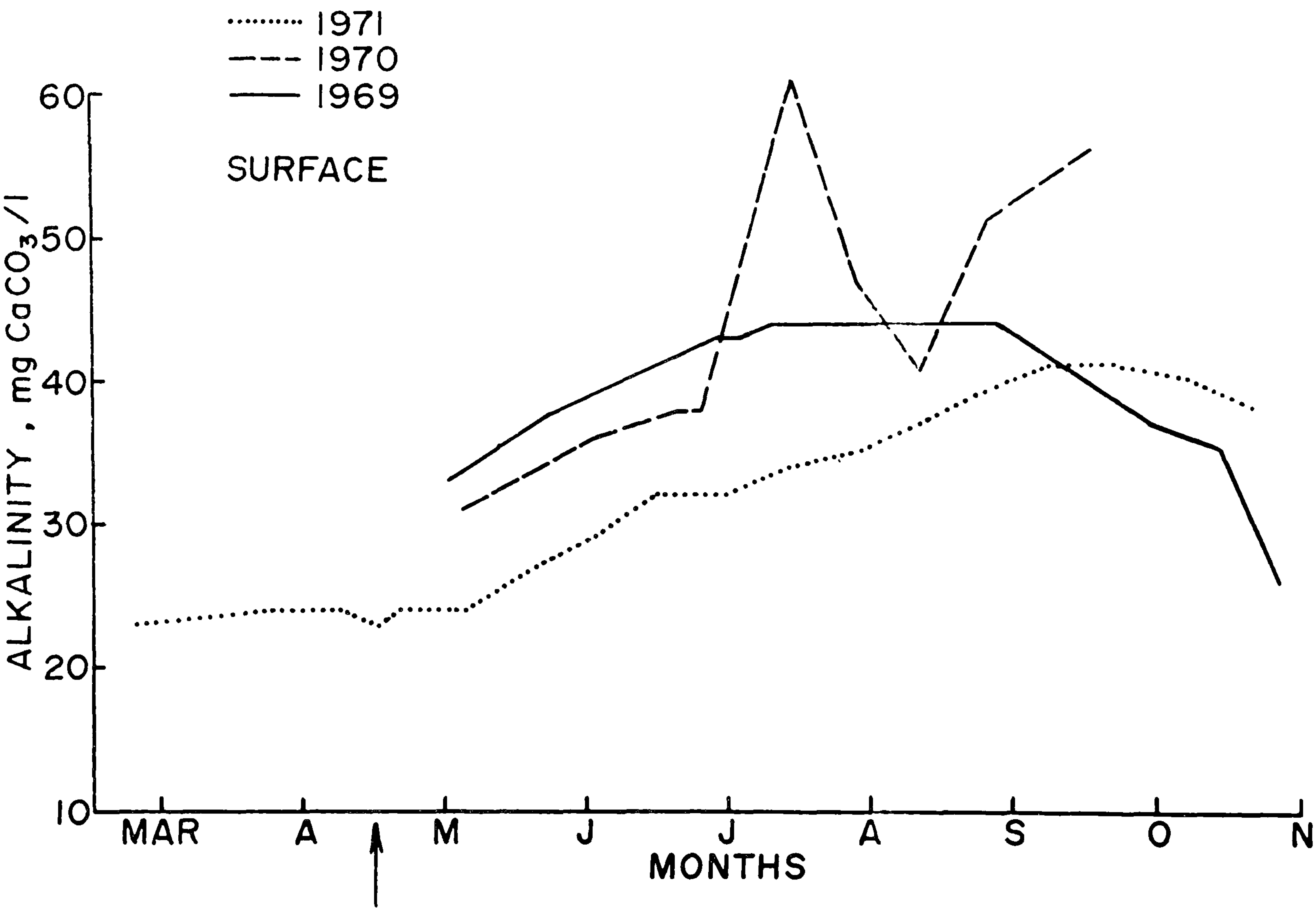

FIGURE 12. Alkalinity-surface

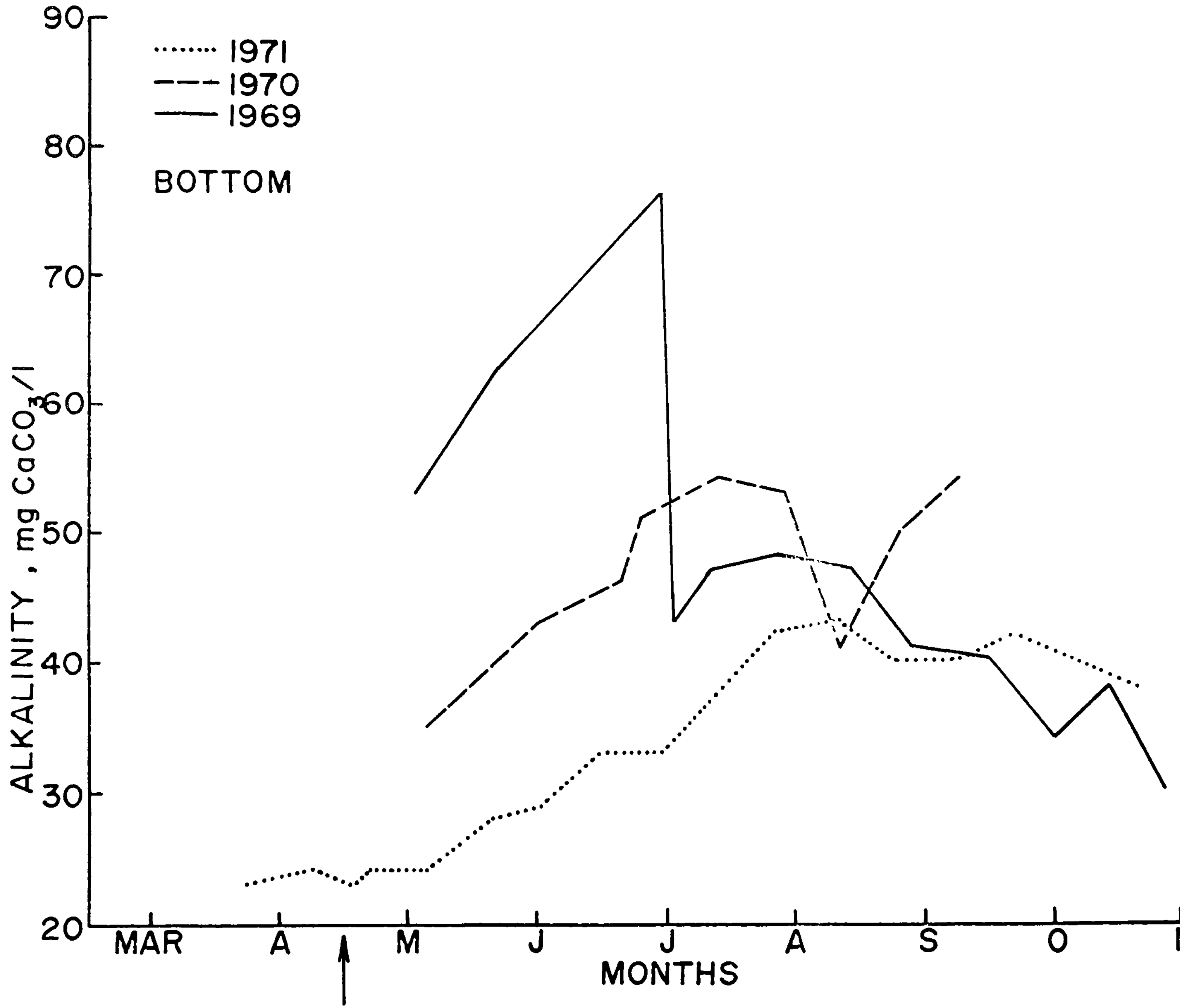

FIGURE 13. Alkalinity-bottom

The percent saturation of oxygen differed between 1971 and the previous years (Figures 14, 15, and 16). Surface and mid-depth saturation levels were more uniform after treatment and did not exhibit the extremes observed in 1970 and 1969. Average saturation values for the surface, middle, and bottom in 1971 were 110, 99, and 32 percent, respectively. Average values for the same period and depths in 1970 were 98, 41 and 9 percent, and for 1969, they were 126, 62, and 19 percent.

The hydrogen ion concentration (pH) of the water did not change significantly after treatment with neutralized sodium aluminate. The pH was 7.0 before treatment and 6.9 the day following. Surface pH remained nearly constant (between 7.0 and 7.5) well into June (Figure 17). The data for 1970 and 1969 showed higher averages than 1971. Average surface values for 1971, 1970, and 1969 were 7.4, 8.8, and 8.7; those for the bottom were 7.0, 7.2 and 6.8.

Transparency was somewhat increased in 1971, particularly compared to 1969 (Figure 18). The Secchi disc reading immediately before treatment was 177 cm and decreased to 100 cm four hours after treatment. It increased slightly the following day to 115 cm, and one week following treatment had increased to 160 cm. The summer average in 1971 was 117 cm as compared to the 1970 average of 90 cm and the 1969 average of 46 cm (Figure 18).

Average water temperatures were similar during the three years, although the 1971 values were somewhat less. Surface, middle, and bottom average temperatures (°C) were 18.6, 18.0, 15.8 for 1971; 21.7, 18.7, 15.4 for 1970; and 21.5, 18.5, 17.6 for 1969.

Biological data suggested a slight reduction in standing crop in 1971 compared to the previous years. Chlorophyll a (Figure 19) did not change greatly immediately after treatment. Surface and bottom values

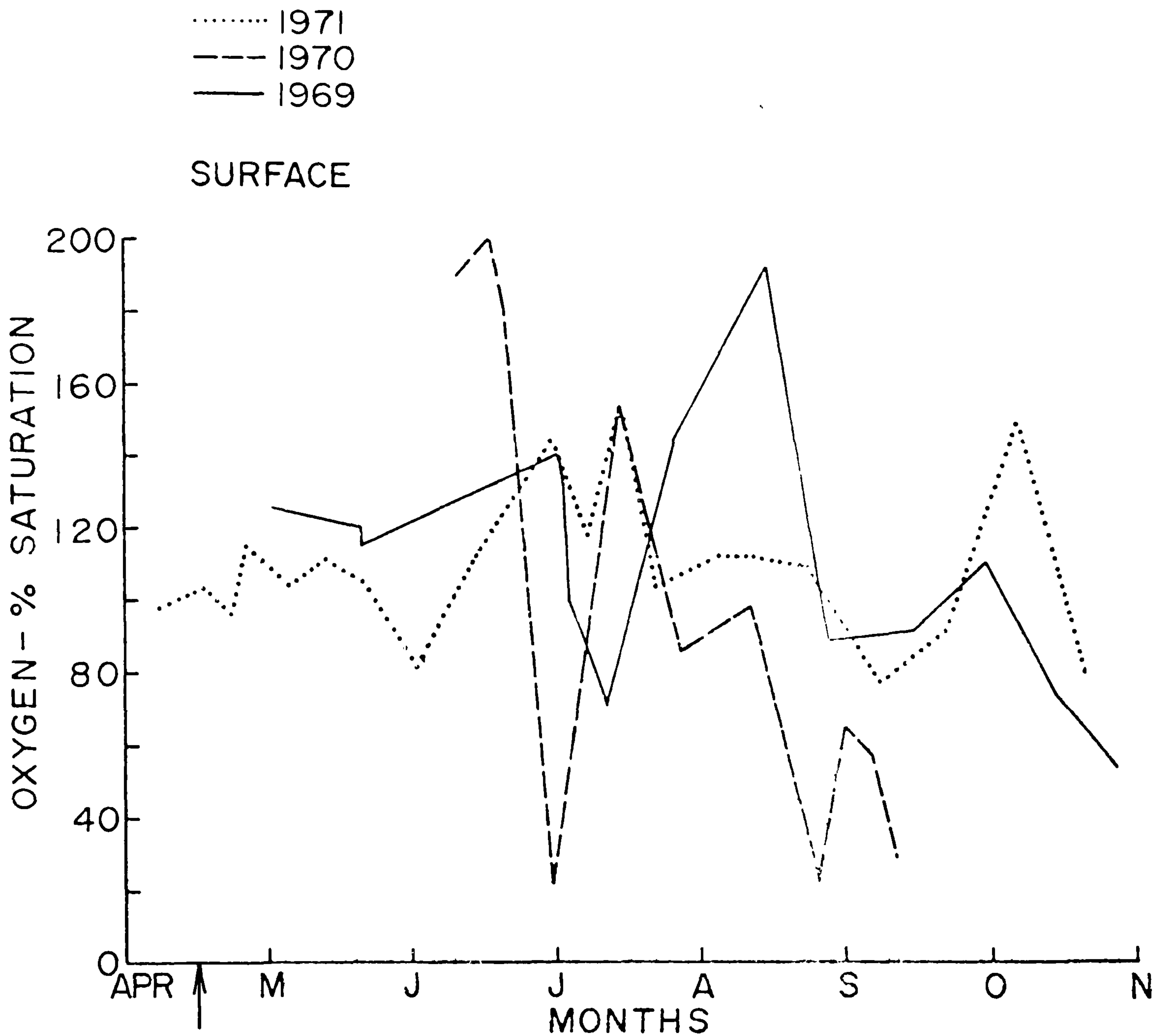

FIGURE 14. Oxygen (% saturation) -surface

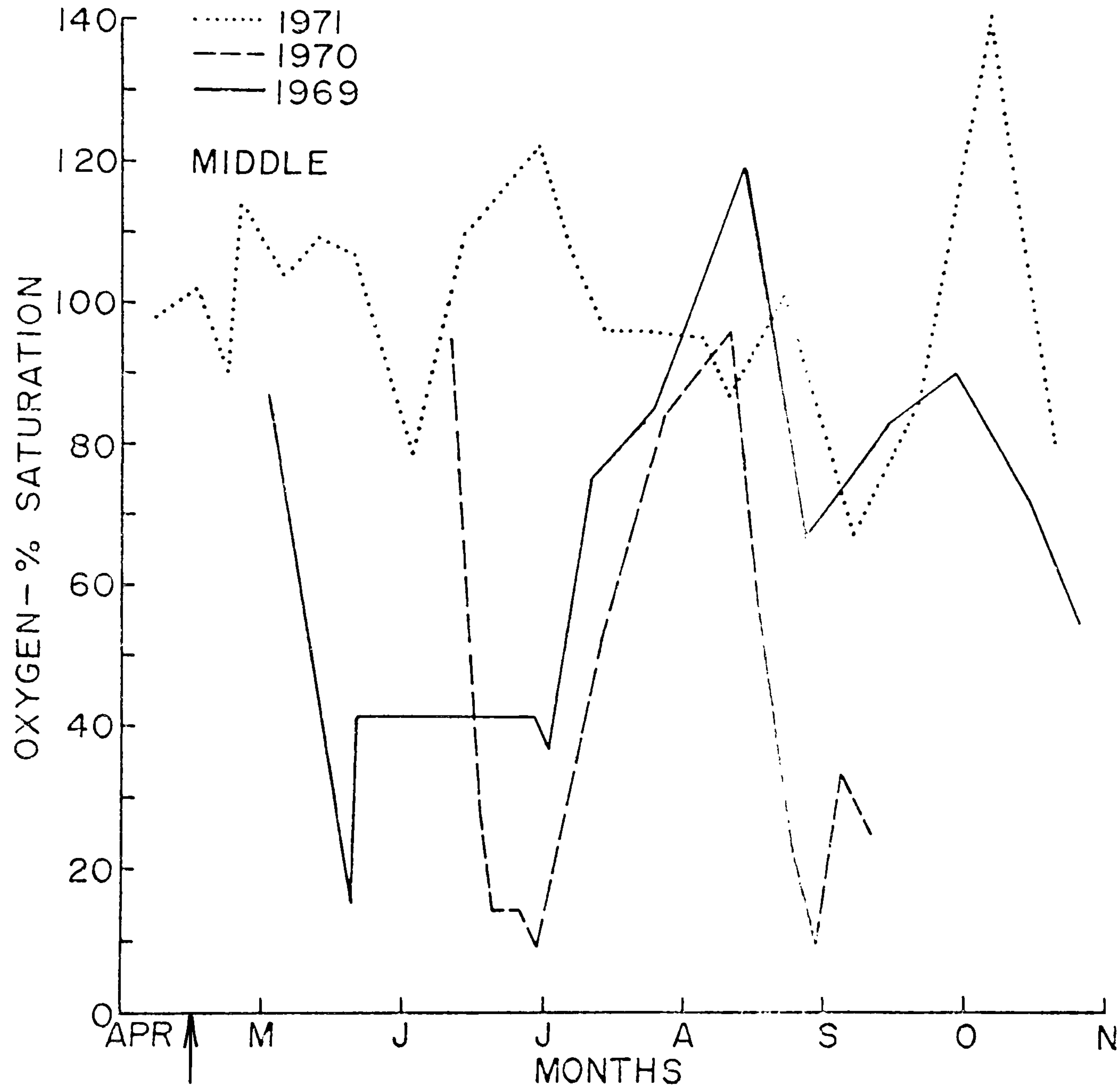

FIGURE 15. Oxygen (% saturation) -middle

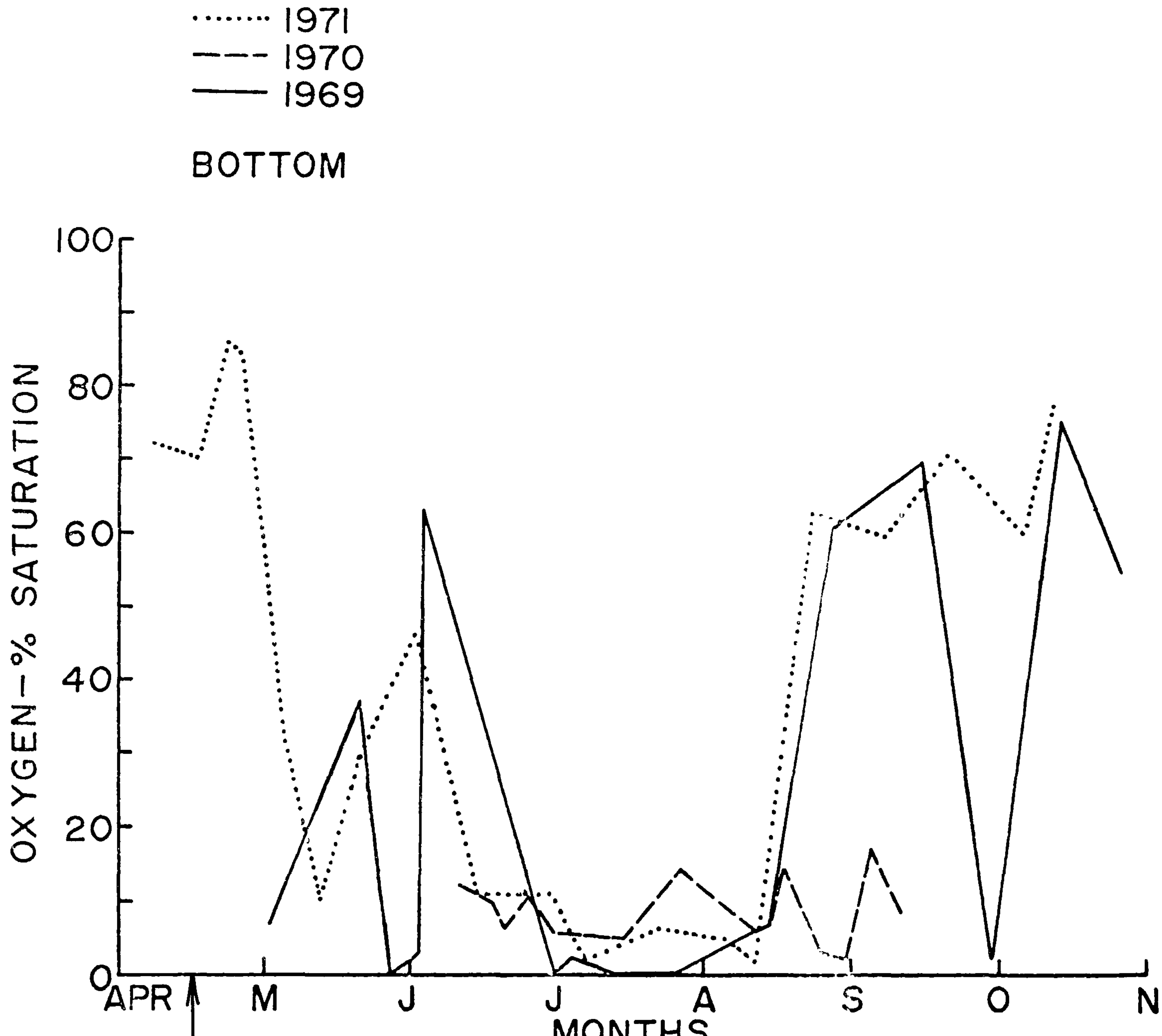

FIGURE 16. Oxygen (% saturation) -bottom

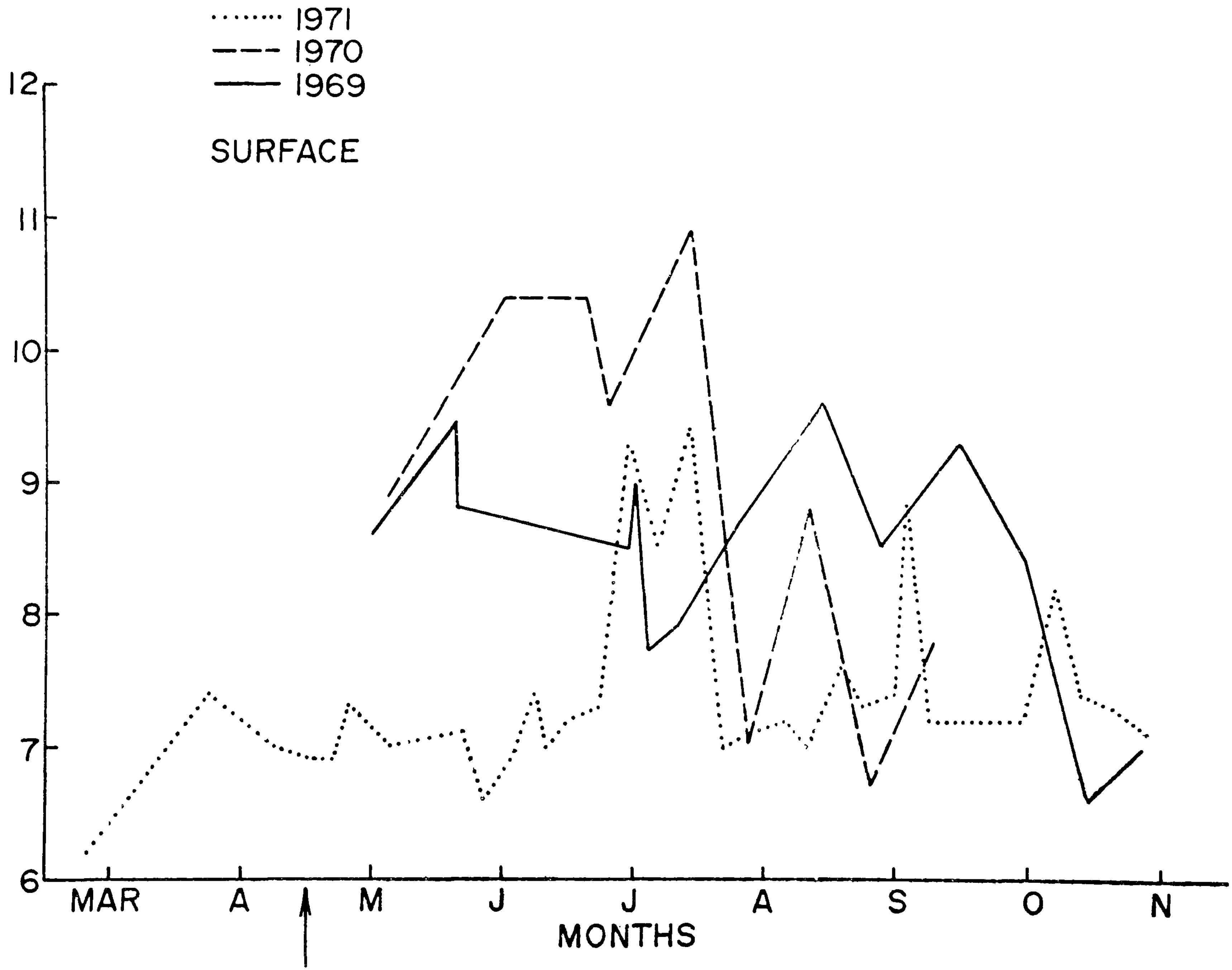

FIGURE 17. pH - surface

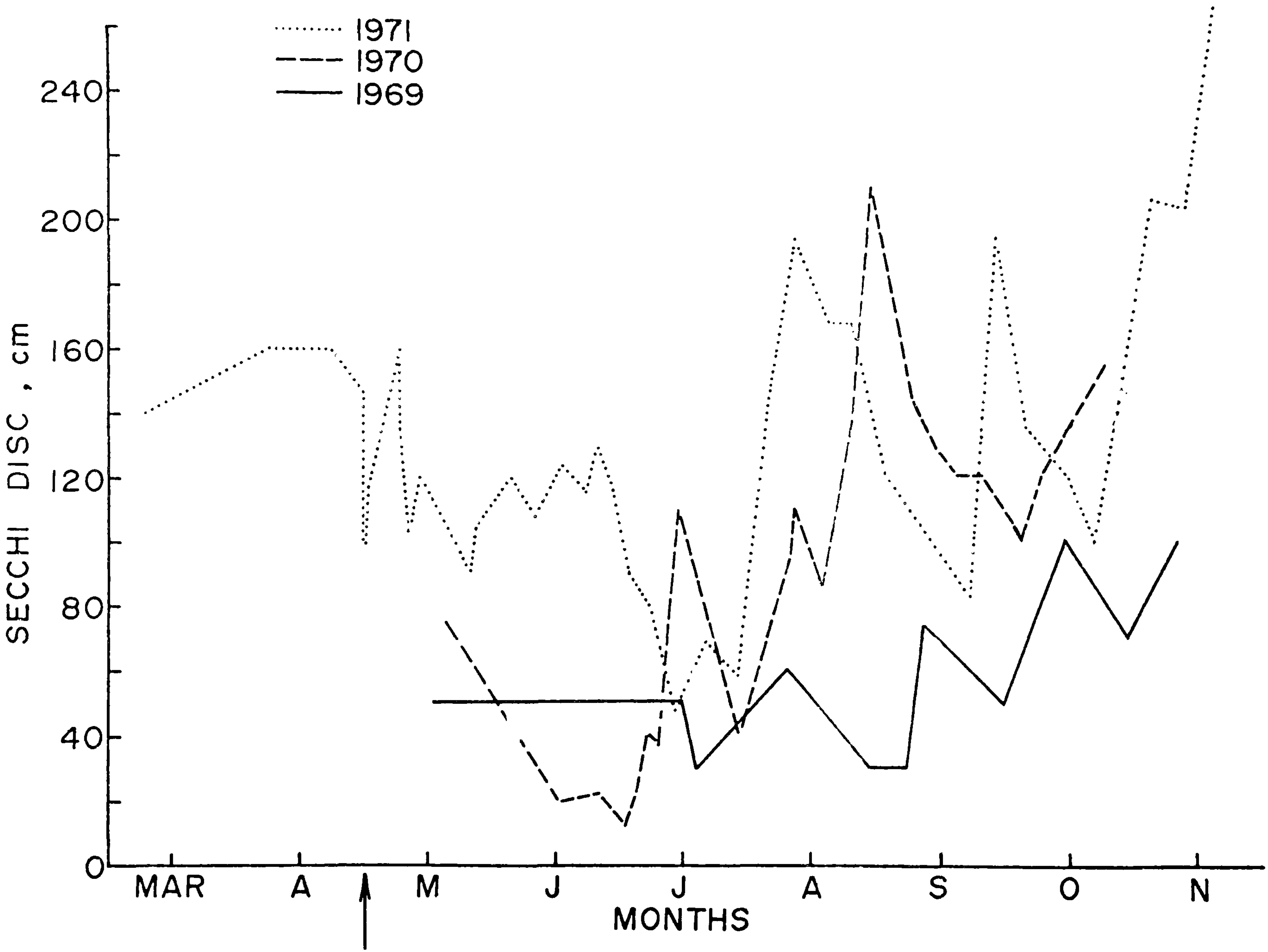

FIGURE 18. Water transparency

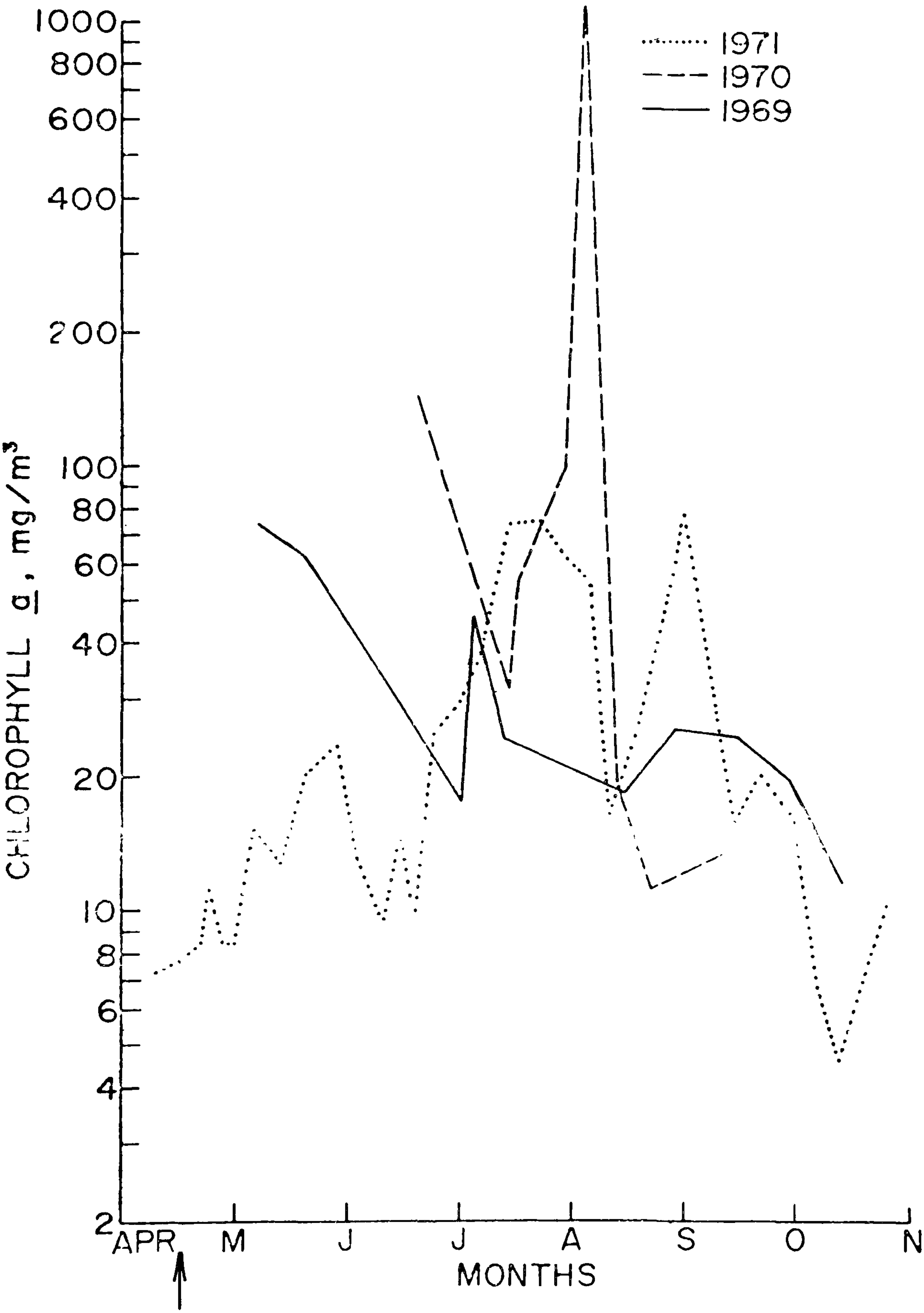

FIGURE 19. Chlorophyll a-average of surface and bottom

one week prior to treatment were 7.3 and 7.2 mg/m^3, respectively, and one day after treatment decreased to 6.4 on the surface, but increased to 9.1 near the bottom. Surface and bottom averages for the three year period were 43 mg/m^3 (1971), 187 mg/m^3 (1970), and 54 mg/m^3 (1969). Concentrations of chlorophyll *a* were greatly reduced during the two months immediately following the application of the sodium aluminate as compared to the same time interval in 1970 and 1969 (Figure 19).

Indications of a somewhat reduced standing crop were also found in the phytoplankton counts. Neither the clump count nor the modified clump count showed a sizable reduction in phytoplankton immediately after treatment (Figures 20 and 21). On a seasonal basis, however, both methods of counting suggested a reduction in cell numbers for 1971. The averages of surface and bottom clump counts for 1971, 1970, and 1969 were 17,000, 26,700, and 20,500 cells/ml, respectively. For the modified clump count, averages for the same period were 42,500, 192,600, and 50,200 cells/ml.

Figures 20 and 21 indicate the peak algal growth periods. *Anabaena* was the predominant blue-green; each year a spring bloom of *A. affinis* and a late summer bloom of *A. helicoidea* occurred. The magnitude of the blooms was not as great in 1971 as previously. Speciation apparently changed with the treatment; *Catena viridis* and *Planktosphaeria* were present in 1971, but were not recorded during the previous two years. Green algal peaks of *Ankistrodesmus*, *Kirchneriella*, and *Scenedesmus* occurred during midsummer of all years, but the magnitude was greater in 1970 than either 1969 or 1971.

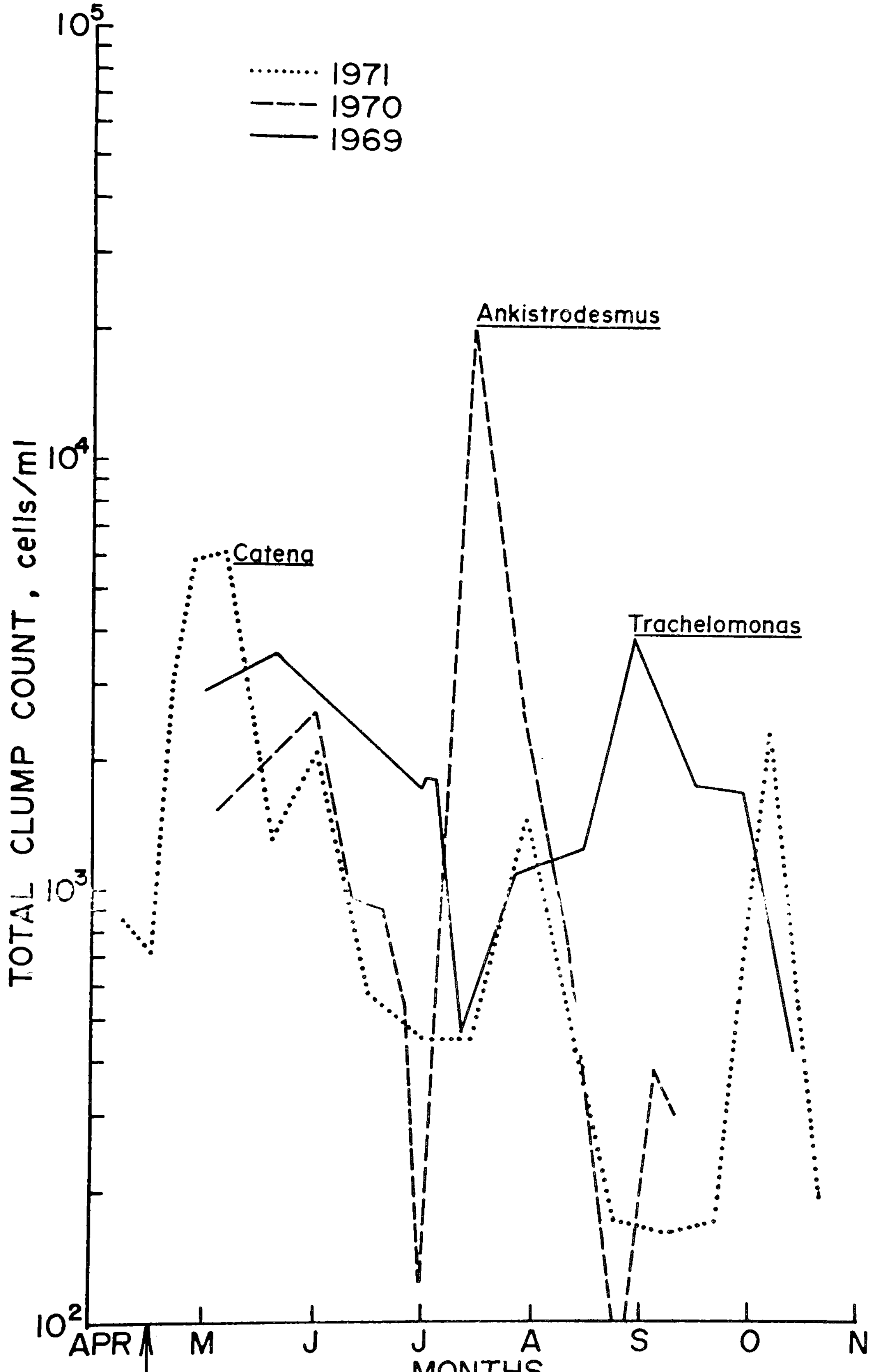

FIGURE 20. Phytoplankton-total clump count-average of surface and bottom

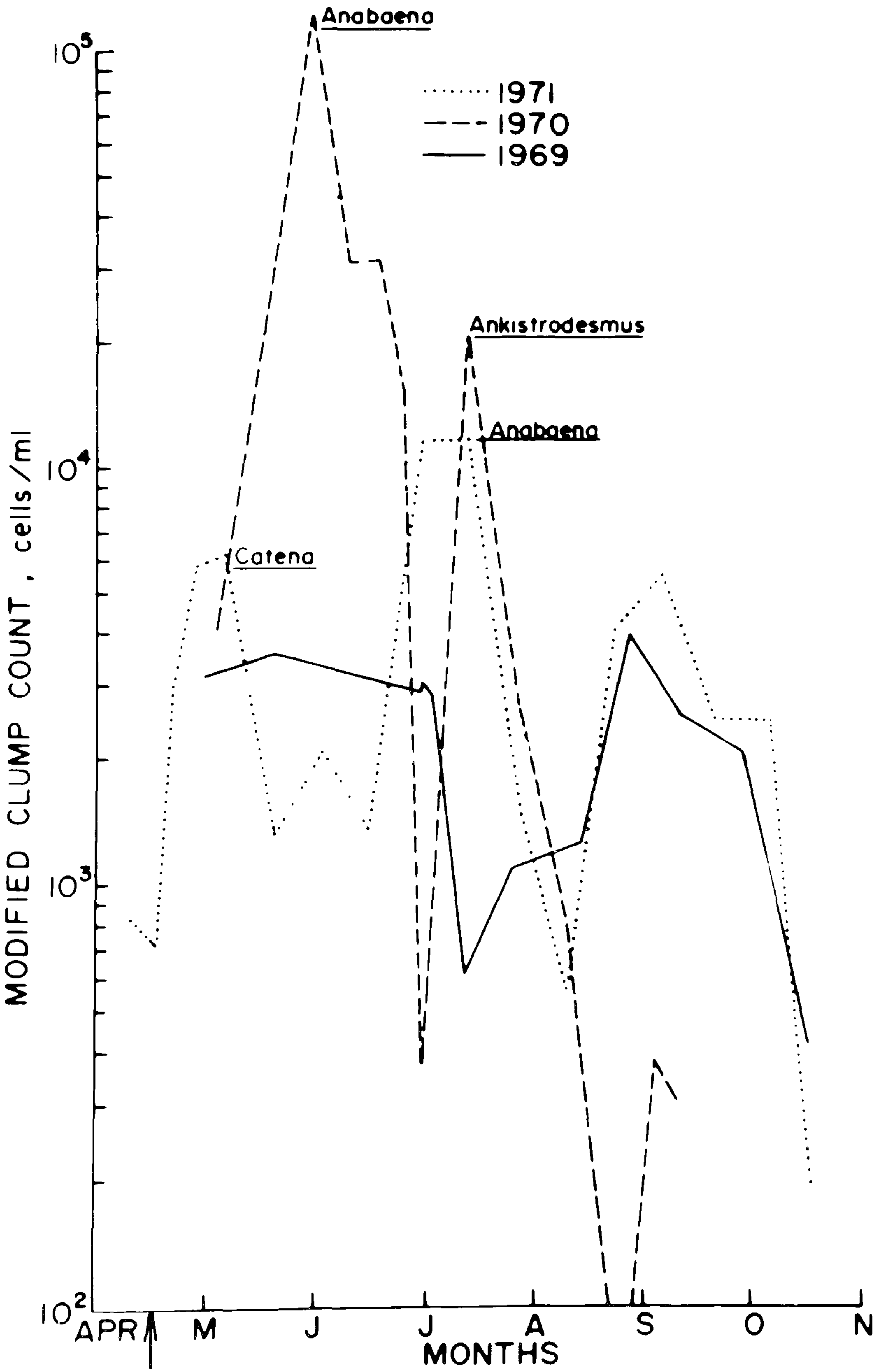

FIGURE 21. Phytoplankton-modified clump count-average of surface and bottom

SECTION VII
DISCUSSION

The chemical, physical, and biological criteria suggested improvement in the water quality of Cline's Pond following addition of sodium aluminate. Chlorophyll a, phytoplankton counts and organic nitrogen seem to indicate a reduced algal standing crop when compared to 1970 and 1969. Secchi disc measurements showed a moderate increase in transparency in 1971. Dissolved oxygen did not exhibit the large fluctuations, associated with heavy algal blooms, observed in previous years.

The sodium aluminate addition to Cline's Pond was expected to directly reduce phosphorus concentrations. Average total phosphorus decreased markedly following sodium aluminate addition and remained at low levels throughout the year. This was probably the result of adsorption or bonding of phosphorus to the aluminum hydroxide floc and precipitation of the particulate matter. However, orthophosphate-phosphorus levels in 1971 were about the same as those observed in the previous two years, except that increases that occurred in the mid and late summer in 1970 and 1969 were not observed in 1971.

The substantially lower ammonia levels observed during the 1971 season suggested a reduced level of production, in that there appeared to exist relatively little decomposable organic matter. Kjeldahl-N was likewise lower in 1971 than in the preceding two years.

Although a short-term bloom of *Anabaena* occurred in August after the sodium aluminate treatment, spring blue-green blooms of *Anabaena* and *Aphanizomenon* as in 1969 and 1970 were not repeated. In 1971, the spring peak consisted of a filamentous green alga, *Catena viridis*, and several other green coccoid forms. As shown by the chlorophyll a values, the algal biomass during the 1971 spring pulse was less than in previous years. Midsummer levels however, exceeded those which occurred in 1969. This may be partially explained because the chlorophyll a analytical technique employed in 1971 varied somewhat from that in 1969. The higher midsummer phytoplankton counts can be partially explained by lack of an accurate conversion factor in 1969. The conversion factor was calculated after the samples had been stored for two years.

Some changes in algal species composition were noted following treatment of the pond. *Catena viridis*, which constituted the 1971 spring pulse, had not been recorded previously as was the case for *Planktosphaeria*. *Aphanizomenon* was important in 1969, decreased in 1970, and was not observed in 1971.

Application of the aluminum hydroxide floc did not appear to result in any deleterious effects on the observable biota. Rainbow trout exhibited no signs of stress, and those taken from the pond after treatment were in excellent condition. None of the trout appeared to die as a result of treatment and some remained for harvesting in the spring of 1972. Data were not collected on the benthos.

One possible adverse effect of neutralized sodium aluminate addition is an increase in conductivity due to the introduced Na^+ and Cl^- ions. If sufficient buffering capacity is present, addition of a second substance to neutralize the first may be unnecessary and increases in the conductivity may not represent a serious problem. In soft water bodies, particularly where outflow is slight, significant increases in conductivity might occur if repeated application is necessary.

SECTION VIII

COMPARISON OF RESULTS WITH THE 1969 AERATION STUDY

The aeration experiment, referred to earlier, started on June 30, 1969, when aeration of the experimental section began. Mechanical difficulties delayed the experiment farther into the growing season than had been intended; therefore, results were not as clearcut as desired.

Table 2 summarizes data relating the findings of the aeration study. Comparison of results with those of the present nutrient inactivation study over a comparable period (6/30 to 9/15) yield some interesting insights into the dynamics of the two techniques. Quantitatively, standing crop was not affected by the aeration process. A pronounced qualitative difference in algal forms occurred, but standing crop measurements were about the same in both the experimental and control sections. Nutrient inactivation seemed to reduce algal biomass and changed the species composition. In both cases, the apparent change was toward an increase in the number of green algal forms at the expense of the blue-greens. Total phosphorus and ammonia were reduced more by the sodium aluminate addition than by aeration, and orthophosphate-phosphorus remained lower. The pH of the system, however, was more stable during aeration. Dissolved oxygen remained at higher levels during the present study than during aeration; this effect could have been a result of delaying the aeration study until after the occurrence of the spring algal bloom. This delay may have resulted in an excessive oxygen demand of the settled and decomposing organic material or resuspension of the sediment during the aeration process.

SECTION IX
ADDENDUM-1972

A much reduced sampling schedule was continued into 1972 in an effort to determine the long term effectiveness of the sodium aluminate treatment. Samples were collected on a monthly basis from December, 1971, until the termination of the study in July, 1972. Data collection beyond this time was impossible because necessary physical modifications of the pond required draining and removal of accumulated sediments. Chlorophyll *a*, Secchi disc and phytoplankton measurements indicate the pond returned to a state of relatively high productivity the year following treatment. The maximum chlorophyll *a* concentrations occurred one month earlier in 1972, but were of the same magnitude as the 1971 values. A very qualitative description by one of the project personnel indicated that the *Anabaena* bloom observed in 1972 was equal in magnitude to any previously observed in the pond. The minimum Secchi disc measurements for 1972 were 45 cm, about the same as observed during the maximum growth period the previous year.

Phytoplankton data also suggested a shift toward greater eutrophy the second year; an increase in the number of organisms and a shift toward a blue-green algal population occurred. Qualitatively, the spring bloom of green coccoid forms observed during the three previous years was apparently replaced by a green flagellate population. *Catena viridis*, a large portion of the April-June 1971 population, did not appear in significant numbers in 1972.

Chemical parameters indicated a similar trend. The 1972 nutrient levels were either comparable to the 1971 levels or somewhat greater. Total phosphorus values were greater in 1972, but orthophosphate-phosphorus, soluble silica and inorganic nitrogen were approximately the same. Data interpretation is difficult because of samples were collected once a month in 1972 as opposed to an average of three times each month in 1971. Changes resulting from biological processes were impossible to assess because phytoplankton could develop into bloom populations and then disintegrate within the sampling interval of 1972.

The infrequency of sampling combined with any modification of the growth pattern resulting from climatic variation could partially account for the observed chemical and biological differences between 1971 and 1972. However, the sodium aluminate treatment apparently did not significantly reduce algal standing crop the second year. The increased standing crop could have resulted from a number of factors, but the most likely are: (1) renewal of nutrients from slope runoff and ground water from surrounding fertilized fields (2) bacterial degradation of the precipitate, (3) mixing of the precipitate and sediment so that a seal no longer covered the bottom sediments or (4) a dilution and loss of the precipitate resulting from heavy winter rains. Further research will be necessary before a definitive conclusion can be reached as to the prolonged effectiveness of the sodium aluminum treatment.

A concluding observation should note that no long term acute aluminum toxicity problems developed. Rainbow trout survived into the second year and a few survived into 1974. A large population of zooplankton and frogs have remained. Although no quantitative samples were collected, visual observation suggests a minimal modification of the fauna resulting from the sodium aluminate addition.

SECTION X
REFERENCES

1. Alexander, M. Introduction to Soil Microbiology. New York, John Wiley and Sons, 1961. p. 358-361.

2. Wood, E. J. F. Marine Microbial Ecology. New York, Reinhold Publishing Corp., 1965. p. 114-115.

3. Wood, E. J. F. Microbiology of Oceans and Estuaries. New York, Elsevier Publishing Co., 1967. p. 102, 267.

4. Johnson, H. W. The Solubilization of "Insoluble" Phosphates. V. The Action of Some Organic Acids on Iron and Aluminum Phosphates. New Zealand Journal of Science (Wellington). 2(2):215-218, June, 1959.

5. Sperber, J. I. Solution of Apatite by Soil Microorganisms Producing Organic Acids. Australian Journal of Agricultural Research (Melbourne). 9(6):782-787, November 1958.

6. Harrison, M. J., R. Y. Morita, and R. E. Pacha. Solubilization of Inorganic Phosphate by Bacteria from Upper Klamath Lake Sediments. Limnology and Oceanography. 17(1):50-57, January 1972.

7. Federal Water Pollution Control Administration. Nutrient Removal and Advanced Waste Treatment. U.S. Department of the Interior, Portland, Oregon. February 1969. 226 p.

8. Ames, L. L. Alumina Columns for Selective Removal of Phosphorus from Wastewaters. Federal Water Pollution Control Administration, U.S. Department of the Interior, Cincinnati, Ohio. 1969.

9. Tenny, M. W. and W. F. Echelberger. Fly Ash Utilization in the Treatment of Polluted Waters. Presented before: Second Ash Utilization Symposium. Pittsburg, Pennsylvania. March 10-11, 1970. 69 p.

10. Jernelov, A. Phosphate Reduction in Lakes by Precipitation with Aluminum Sulfate. In: Fifth International Conference in Water Pollution Research. New York, Pergammon Press Ltd., 1:I 15/1-I 15/6, 1971.

11. Landner, L. Personal Communication. Swedish Water and Air Pollution Research Laboratory, Stockholm, Sweden. 1970.

12. Peterson, J. O., J. P. Wall, T. L. Wirth and S. M. Born. Eutrophication Control: Nutrient Inactivation by Chemical Precipitation at Horseshoe Lake, Wisconsin. Department of Natural Resources, Madison, Wisconsin. Technical Bulletin No. 62. 1973. 20 p.

13. Peterson, S. A., W. D. Sanville, F. S. Stay, and C. F. Powers. Nutrient Inactivation as a Lake Restoration Procedure-Laboratory Investigations. U. S. Environmental Protection Agency. Corvallis, Oregon. Publication EPA-660/3-74-032. October 1974. 118 p.

14. Malueg, K. W., J. R. Tilstra, D. S. Schults, and C. F. Powers. The Effects of Induced Aeration Upon Stratification and Eutrophication Processes in an Oregon Farm Pond. Geophysical Monograph Series Vol. 17, Man-Made Lakes: Their Problems and Environmental Effects. W. C. Ackerman, G. F. White, and E. B. Worthington (Eds.). American Geophysical Union, Washington D.C. 1973. p. 578-587.

15. Methods for Chemical Analysis of Water and Wastes. U.S. Environmental Protection Agency, Cincinnati, Ohio. 16020--07/71. 1971. 312 p.

16. Strickland, J. P. H. and T. R. Parsons. A Manual of Sea Water Analysis, Second Edition. Fisheries Research Board of Canada, Ottawa. 1965. p. 117-124.

17. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Inc., New York. 1966. p. 662-665.

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16. ABSTRACT

Cline's Pond, a 0.4 ha farm pond 32 km north of Corvallis, Oregon, was treated with sodium aluminate to evaluate a nutrient inactivation technique to control excessive eutrophication. Primary consideration was given to the evaluation of its ability to scavenge phosphate in the water column, to the prevention of resolubilization of phosphate during the growth season, and to the inhibition of primary production. Interpretation of the results was based on a comparison of limnological data collected after nutrient inactivation with antecedent information obtained the two years prior to the present study. This made some of the results rather ambiguous. However, total phosphate, ammonia, total Kjeldahl nitrogen, iron and manganese were generally lower and dissolved oxygen, transparency and pH suggested some improvement in water quality. The algae appeared to shift from a predominantly blue green to a green population and there was an indication of a reduced algal standing crop. A comparison is given of the results of an aeration study conducted on the same pond two years earlier. Continued observation into a second growth season indicated a reduced effectiveness as compared with the year of treatment.

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Eutrophication*, Algal Control*, Nutrient Removal*, Aluminate, Aluminum, Aeration	Inactivation, Cline's Pond	06 06

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