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Evidence of Eutrophication in Wall Lake Barry County, Michigan

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EVIDENCE OF EUTROPHICATION IN WALL LAKE
BARRY COUNTY, MICHIGAN

by

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INTRODUCTION

Wall Lake is a popular recreation lake in southwestern Michigan. In recent years lakeside summer homes have become increasingly desirable and at Wall Lake there has been increased development of lake property. There are more homes, more boats, and more people staying at the lake for larger portions of the year. The lake is almost completely surrounded by private homes, and 46 percent of these are occupied throughout the year.

The lake is small, and as such it can absorb the effects of man's activities for only a short period of time before drastic changes in water quality become evident. Recently, the residents have noted that weed beds of Potamageton spp. and Nymphaea odorata Ait. and other aquatic plants are becoming more widespread. Nusiance algae have begun to appear in large quantities and are probably lasting for longer periods of time. Increases in plankton have already caused a significant oxygen debt in the hypolimnion reducing the fish population to only the more hardy warm water varieties and, if this trend continues, decreasing the value of the lake to the sport-fisherman.

Often, water quality becomes poor because people fail to realize the extent of the problem and fail to take the necessary precautions until the situation is desperate. If the problem is recognized soon enough it can be prevented or at least trends can be reversed or halted. To do this, though, a limnological study of the lake must be made to establish the condition of the lake at the present. This paper will present the earliest data on Wall Lake and will include the first studies of the phytoplankton, fecal coliform bacteria and several physical and chemical parameters.

Wall Lake

Wall Lake is located in Hope township of Barry County 3.7 km (2.3 mi.) northeast of Delton, Michigan (Sections 28, 29, 32, and 33, T.2N. R.9W.) (See Figure 1). The catchment area is largely rolling country 283 to 305 m. (927' - 1000') above sea level. Geologically Wall Lake is situated in the northern portion of an outwash plain guarded to the north by a stagnation moraine and flanked by Kame topography (Folson, 1971). The lake is situated 283 m. (927') above mean sea level. Its area is 221.9 ha (547.8 acres) with 54 percent of that less than 3 m. (10') deep. The lake has a maximum depth of 11 m. (36') and a mean depth of 4.2 m. (14'). Wall Lake has no inlet. The outlet leaves the east end of the lake and flows 0.96 km (0.6 mi.) to Shallow Lake. On February 8th, 1951, a discharge rate of 0.03 cubic feet per second was measured in the outlet, 1000 feet downstream from the lake. A low concrete wall lies across the outlet downstream from the lake but this is thought to have little effect on the lake levels (Miller and Thompson, 1970).

The climate is typical for the continental United States although it is greatly modified by the Great Lakes. The average

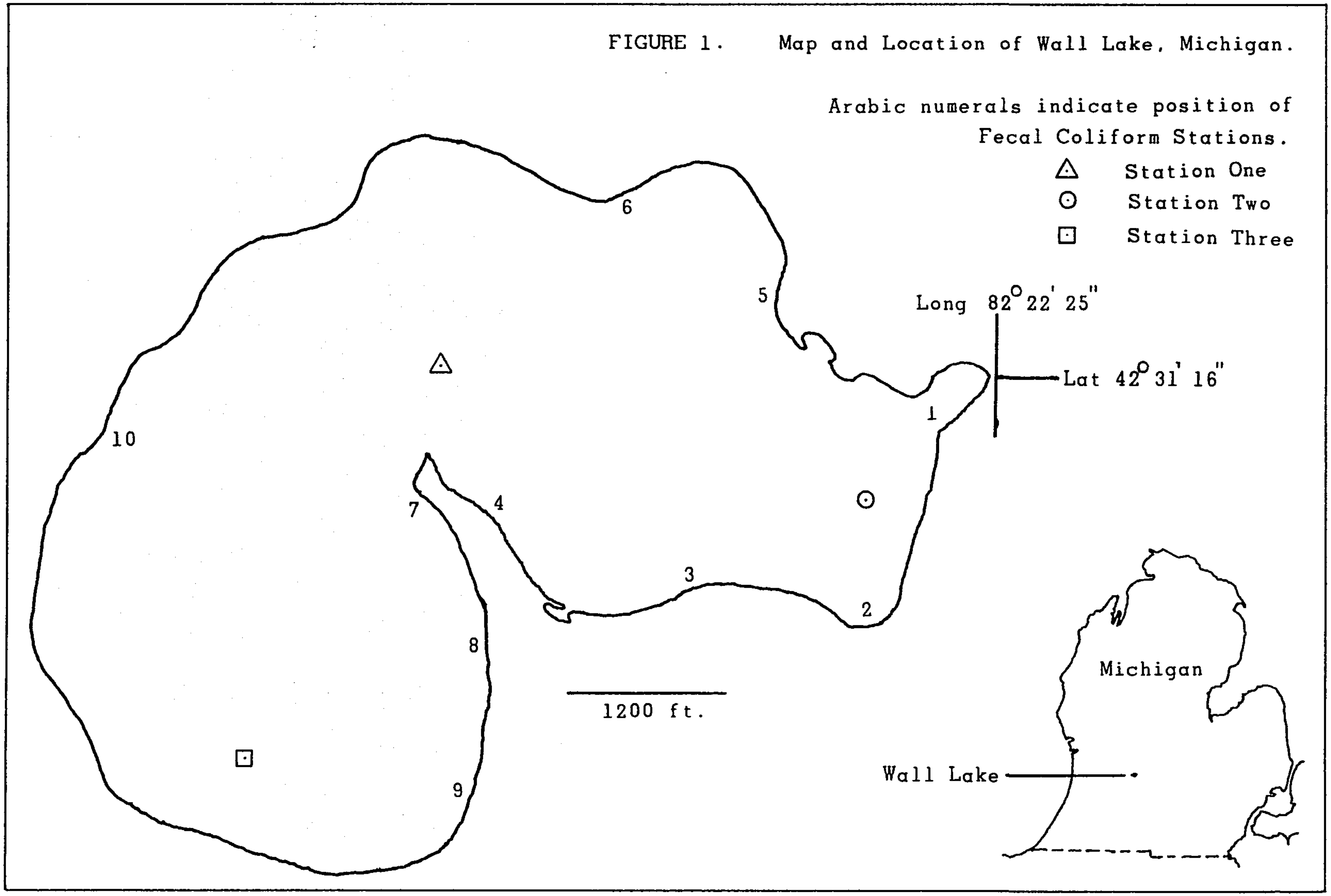


FIGURE 1. Map and Location of Wall Lake, Michigan.

July temperature is 22.5°C (72.5°F) and the average January temperature is -3.3°C (26°F). The mean annual rainfall is 83.8 cm (33 in.) and the mean annual snowfall is 102 cm (40 in.) (Senninger, 1970).

Until about 1850 the area was occupied by the Potowatomi Indians (Bernard, 1967). From that time on there has been a steady increase in the number of residents around the lake. At the present, there are approximately 200 homes. In recent years more of the homes are being winterized for year-around living. Most of the homes are in a single line around the lake although on the peninsula there is a double line of homes.

METHODS

Data was taken from March 1st to October 1st, 1973, at three sampling sites approximately equidistant from one another (Figure 1). Station One was over the deepest portion of the lake, just northwest of the peninsula, and water samples were taken at the surface, 2, 6, and 11 meters. Station Two was at the east end of the lake in four meters of water. At that station samples were taken at the surface, 2, and 4 meters. Station Three was at the southern end of the lake and water samples were taken at the surface and at the bottom (2 m.). At each elevation phytoplankton, ortho plus metaphosphate, nitrate plus nitrite nitrogen, turbidity, apparent color, oxygen, pH, and temperature measurements were taken.

Each phytoplankton sample was carefully siphoned into 500 milliliter bottles and killed on the spot with 15 milliliters of formaldehyde. The sample was left undisturbed for several days so the plankton could settle to the bottom. Then all but 109 milliliters were siphoned off the top and the remaining sample was shaken to resuspend the plankton. One milliliter was drawn off and the phytoplankton counted in a Sedgewick-Rafter counting chamber. Counts of all but very infrequent species lie within $\pm$ 8.5 percent of the true value with a 95 percent probability. Every attempt was made to express counts as cells per milliliter, however, in some cases this was impossible and either trichomes, filaments, or colonies per milliliter was substituted. These exceptions are noted in the text as they become important.

A second set of 500 milliliter bottles was used to collect samples for later analysis of phosphate, nitrogen, turbidity, and apparent color. Prior to use each of these bottles was washed in hot HCl, rinsed in distilled water, and 20 mg. of HgCl preservative were added (A.P.H.A., 1965). After the water samples were added to each bottle they were individually packed in ice. Analysis of these parameters was done with a Hach kit (Hach Chemical Company, Ames, Iowa) in the laboratory the same day the samples were gathered.

Oxygen was determined by the Winkler method (Needham and Needham, 1962). On July 20th, an error was found in the sampling technique. Prior to that date all samples were collected using a weighted bottle with a cork that could be removed at the desired level from the surface. From that day forward all samples were gathered via a long plastic tube hooked to a hand vacuum pump.

The pH was determined colormetrically with a LaMotte pH kit in the field. The temperature was determined at each elevation with an electric temperature probe (Yellow Springs Instrument Co. Model 43TB), and toward the middle of June, at meter intervals. Secchi disk readings were made beginning May 11th.

Fecal coliform bacteria was studied periodically during the warmer portion of the summer, principally during the time the lake was in greatest use by the residents. Ten stations were chosen (Figure 1) and surface samples were treated in accordance with Millipore instructions (Application Manual A.M. 302).

RESULTS

Biological Parameters

In the course of the study 79 phytoplankton species from five different algal divisions were recognized (See Table 1). Of these 19 proved impossible to identify even to genus. They either were not in the right stage in their life cycle or existed in such low densities that they were seen too infrequently to be identified. Their densities were recorded, however, and used in determining relative density and the diversity index.

Several algae were seen from plankton tows that never appeared in the counting chamber. These few included: Rhizoclonium sp., Spirogyra sp., Volvox aureus, Xanthidium sp., Synura uvella and Gleotrichia echinulata.

The divisions which dominate the plant community in both individual species and in numbers of individuals were: Chrysophyta, Cyanophyta, and Chlorophyta. The Euglenophyta and the Pyrrhophyta contributed only four species and these never attained a dominant role in the ecosystem.

Two major blooms of Chrysophyta developed in the course of the season: one in the early spring and one in mid-July. These two blooms resulted from growth of three different species of golden algae: Asterionella formosa, Dinobryon divergens and Tabellaria sp.

Dinobryon divergens reached its maximum density shortly after the ice melted during the first week of March. Figure 2 shows that

Table 1. Phytoplankton identified in Wall Lake, 1973.

CHRYSOPHYTA

Asterionella formosa Hass
Cocconeis sp.
Cymbella sp.
Dinobryon bavaricum Imhof
Dinobryon divergens Imhof
Fragilaria spp.
Frustulia sp.
Gyrosigma sp.
Mallomonas sp.
Navicula spp.
Pinnularia sp.
Stauroneis spp.
Synura uvella Ehrenberg
Tabellaria sp.

CYANOPHYTA

Anabaena flos-aquae (Lyngb.) DeBrebisson
Aphanocapsa sp.
Coelosphaerium sp.
Gleocapsa sp.
Gleothecea sp.
Gleotrichia echinulata (J. E. Smith) P. Richter
Gomphosphaeria aponina Kuetzing
Lyngbya sp.
Merismopedia sp.
Microcystis aeruginosa Kuetz.; emend. Elenkin
Microcystis incerta Lemmermann
Microcystis sp.
Oscillatoria limnetica Lemmermann
Oscillatoria sp.
Spirulina sp.
Tolypothrix sp.

CHLOROPHYTA

Ankistrodesmus falcatus (Corda) Ralfs
Ankistrodesmus sp.
Arthrodesmus sp.
Chroococcus sp.
Closterium sp.
Cosmarium sp.
Eudorina elegans Ehrenberg
Gonium sp.
Micractinium sp.
Oocystis sp.
Pandorina sp.
Pediastrum boryanum (Turp) Meneghini
Pediastrum obtusum Lucks
Pediastrum sp.
Quadrigula closterioides (Bohlin) Printz
Rhizoclonium sp.
Scenedesmus sp.
Selenastrum sp.
Spirogyra sp.
Spondylasium sp.
Staurastrum sp.
Tetraedron gracile (Reinsch) Hansgirg
Treubaria setigerum (Archer) G. M. Smith
Volvox aureus Ehrenberg
Xanthidium sp.
Zygnema sp.

PYRRHOPHYTA

Ceratium hirundinella (O. F. Muell.) Dujardin
Peridinium gatunensa Nygaard

EUGLENOPHYTA

Phacus longicauda (Ehrenb.) Dujardin
Trachelomonas sp.

in early March, at the surface of Station One, *Dinobryon divergens* was the only planktonic alga found, in this case at 500 cells/ml. (Relative density is equivalent to that fraction of the community made up of that species.) Also, the density exceeded 200 cells/ml or 60 percent of the phytoplankton on May 8th. See Figures 2, 3, and 4.

Asterionella formosa increased significantly in abundance about April 13th. At the same time *D. divergens* was beginning its first decline. Two growth peaks were also observed in *A. formosa*, each of which substantially affected the phytoplankton community. During the interval from the 29th of March to the 13th of April, *A. formosa* had at times as many as 500 cells per milliliter and represented between 75 and 88 percent of the phytoplankton community. On June 22nd, at lower levels, *A. formosa* had a density of 10.9 cells per milliliter and this represented between 35 and 43 percent of the cells observed on that date. See Figures 5, 6, and 7.

Tabellaria sp. became a substantial portion of the phytoplankton community from the 22nd of June to the middle of July. Figures 8, 9, and 10 show the upsurge of *Tabellaria* toward the end of the sampling period. Its greatest concentrations were around 6 meters where it had a maximum density of 339 cells per milliliter and a relative density between 40 and 50 percent.

The remaining species of golden algae never achieved the degree of dominance that was demonstrated by *A. formosa*, *D. divergens*, or *Tabellaria sp.* There was a tendency for infrequently found species to increase substantially in samples taken near the bottom. At 11 meters *Navicula spp.* had a frequency of 0.81 and on the 20th of July

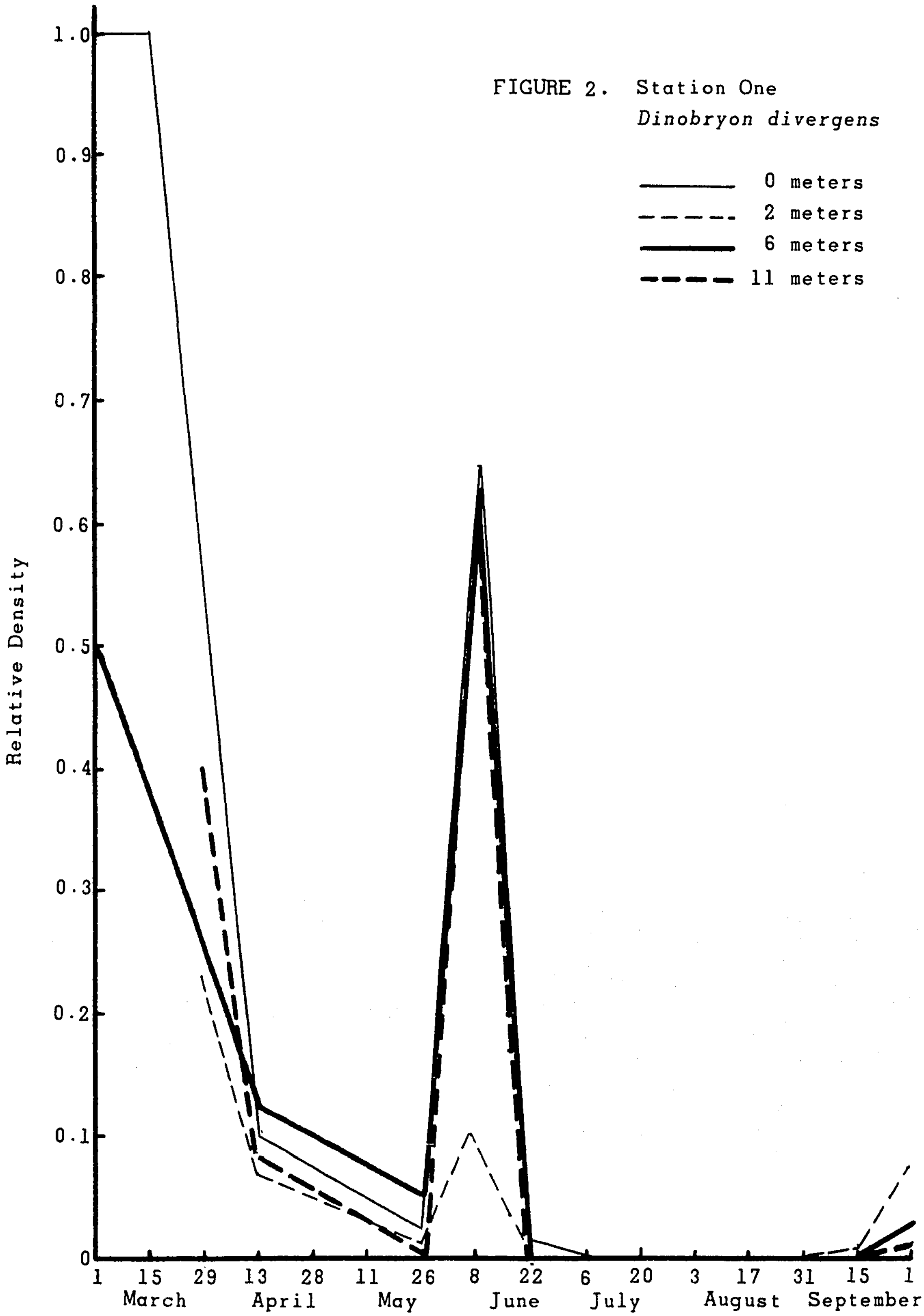


FIGURE 2. Station One
Dinobryon divergens
0 meters
2 meters
6 meters
11 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

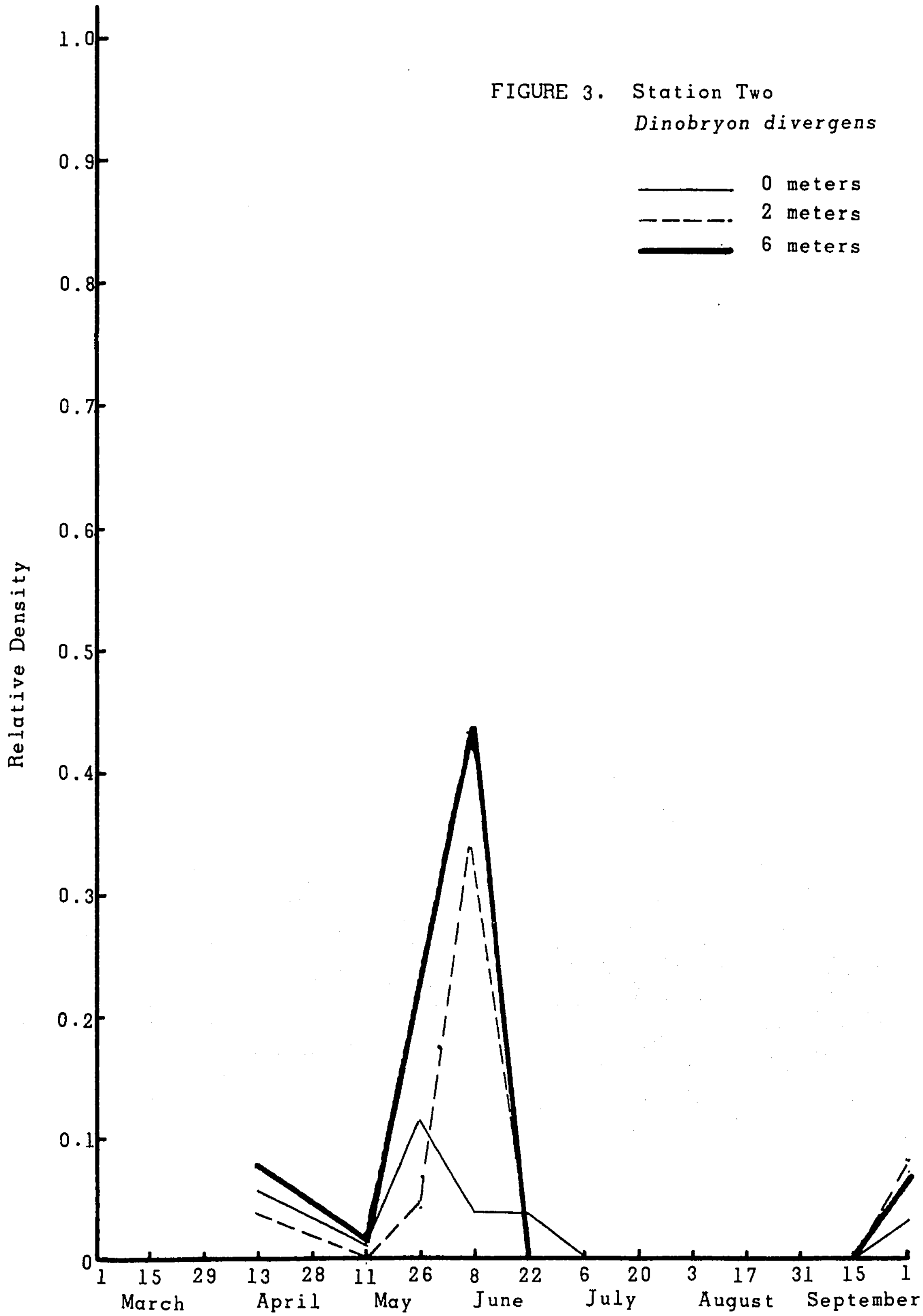


FIGURE 3. Station Two
Dinobryon divergens
0 meters
2 meters
6 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

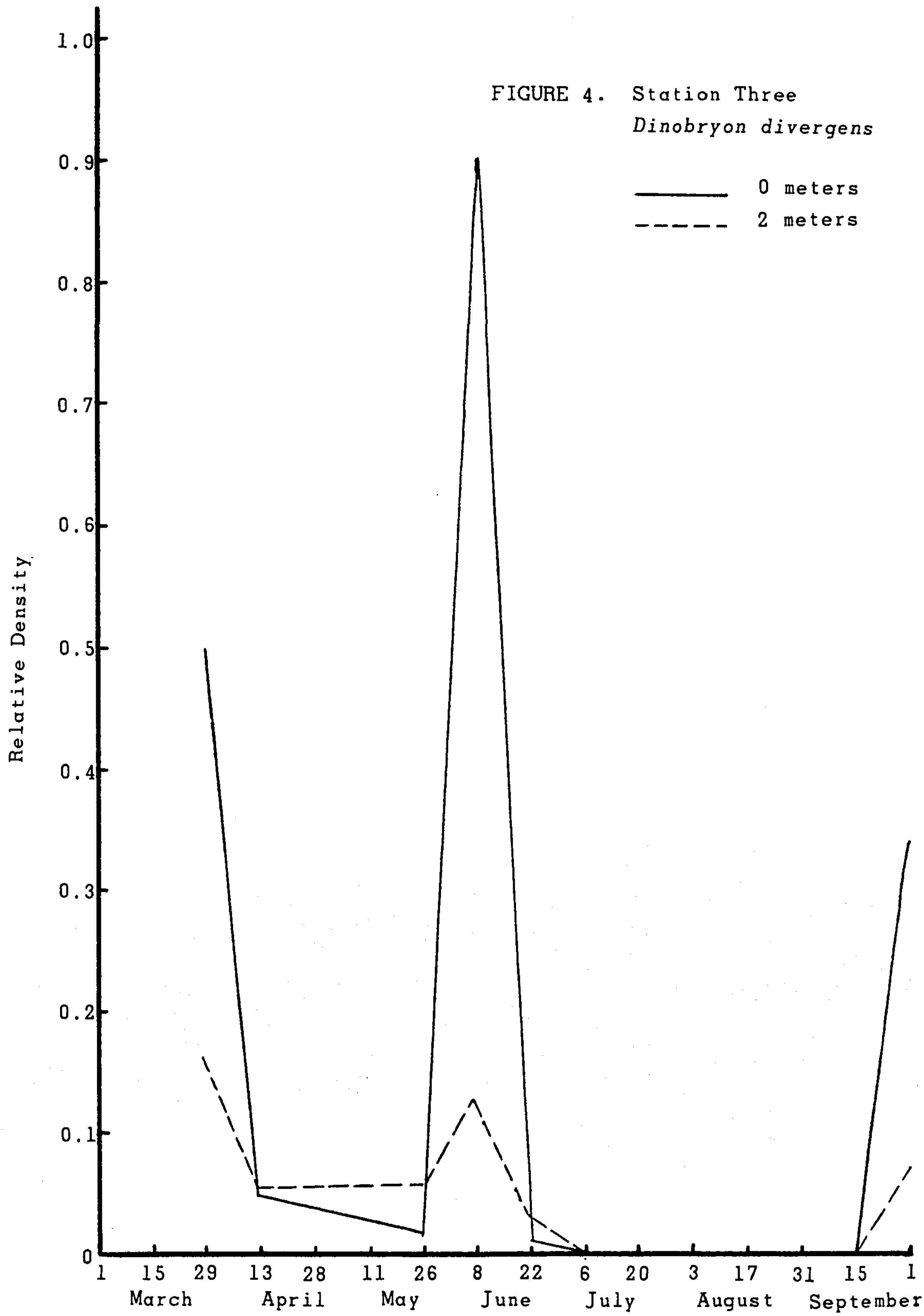
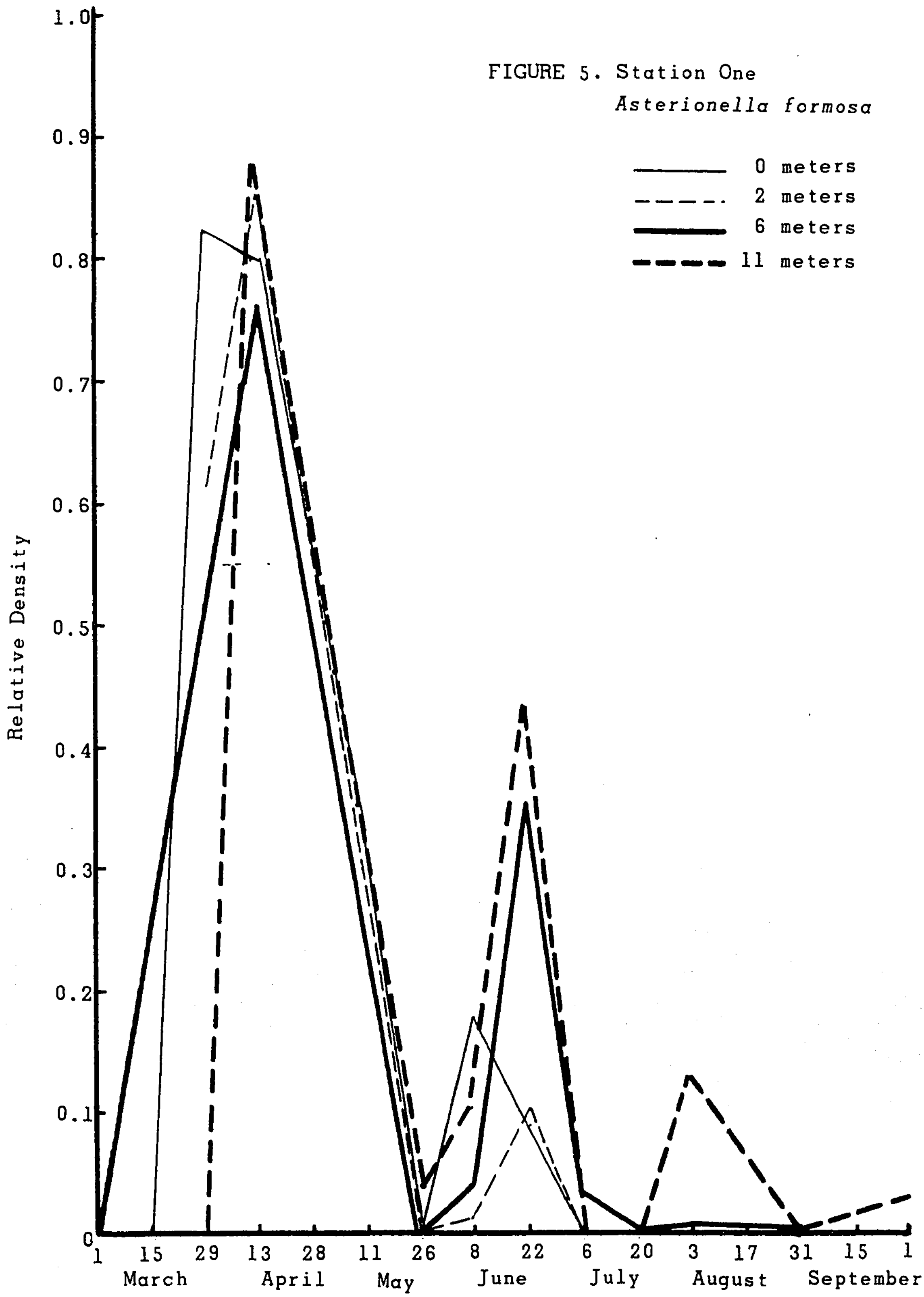


FIGURE 4. Station Three
Dinobryon divergens
0 meters
2 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Relative Density
FIGURE 5. Station One
Asterionella formosa
0 meters
2 meters
6 meters
11 meters
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March
April
May
June
July
August
September

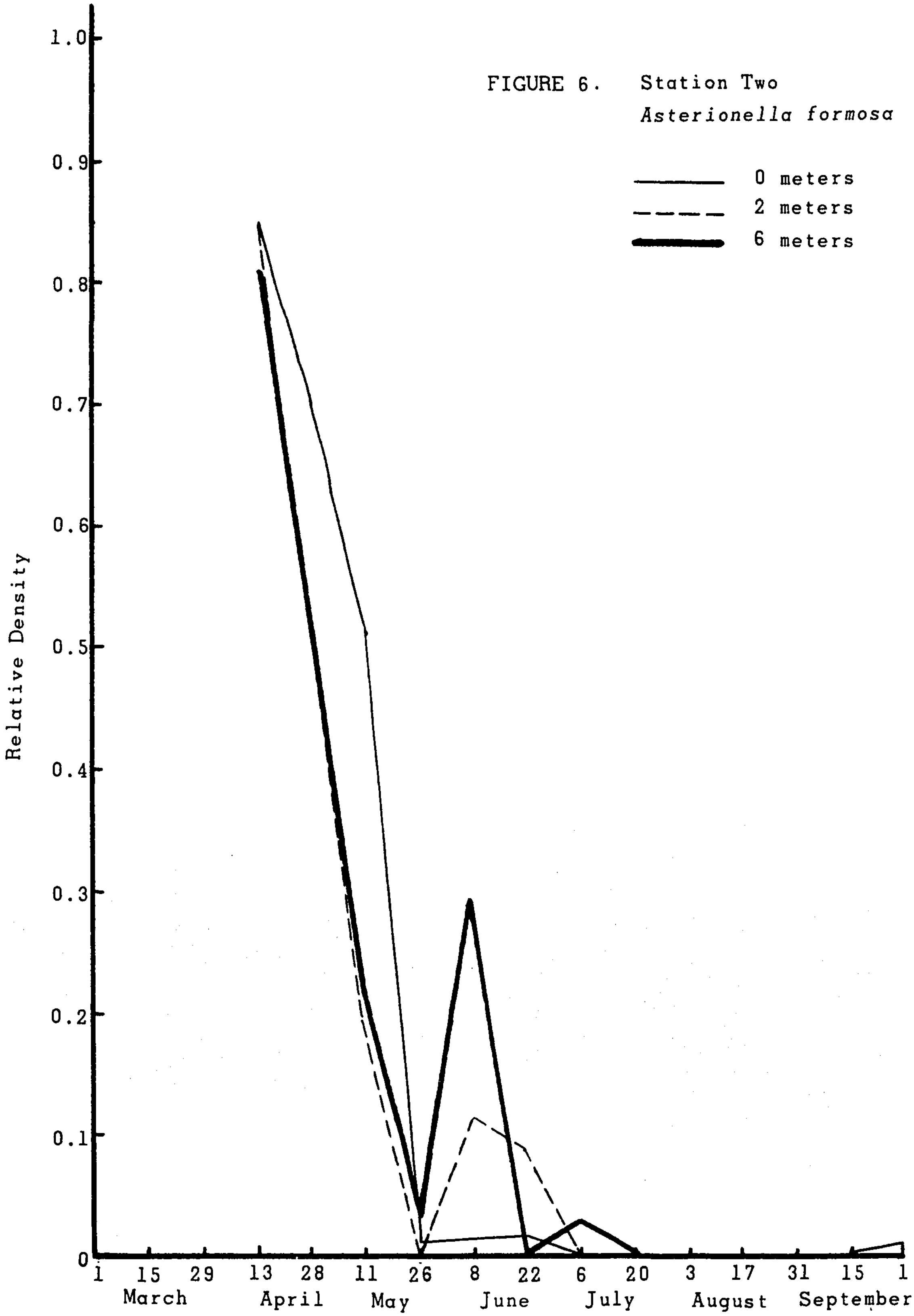


FIGURE 6. Station Two
Asterionella formosa
0 meters
2 meters
6 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

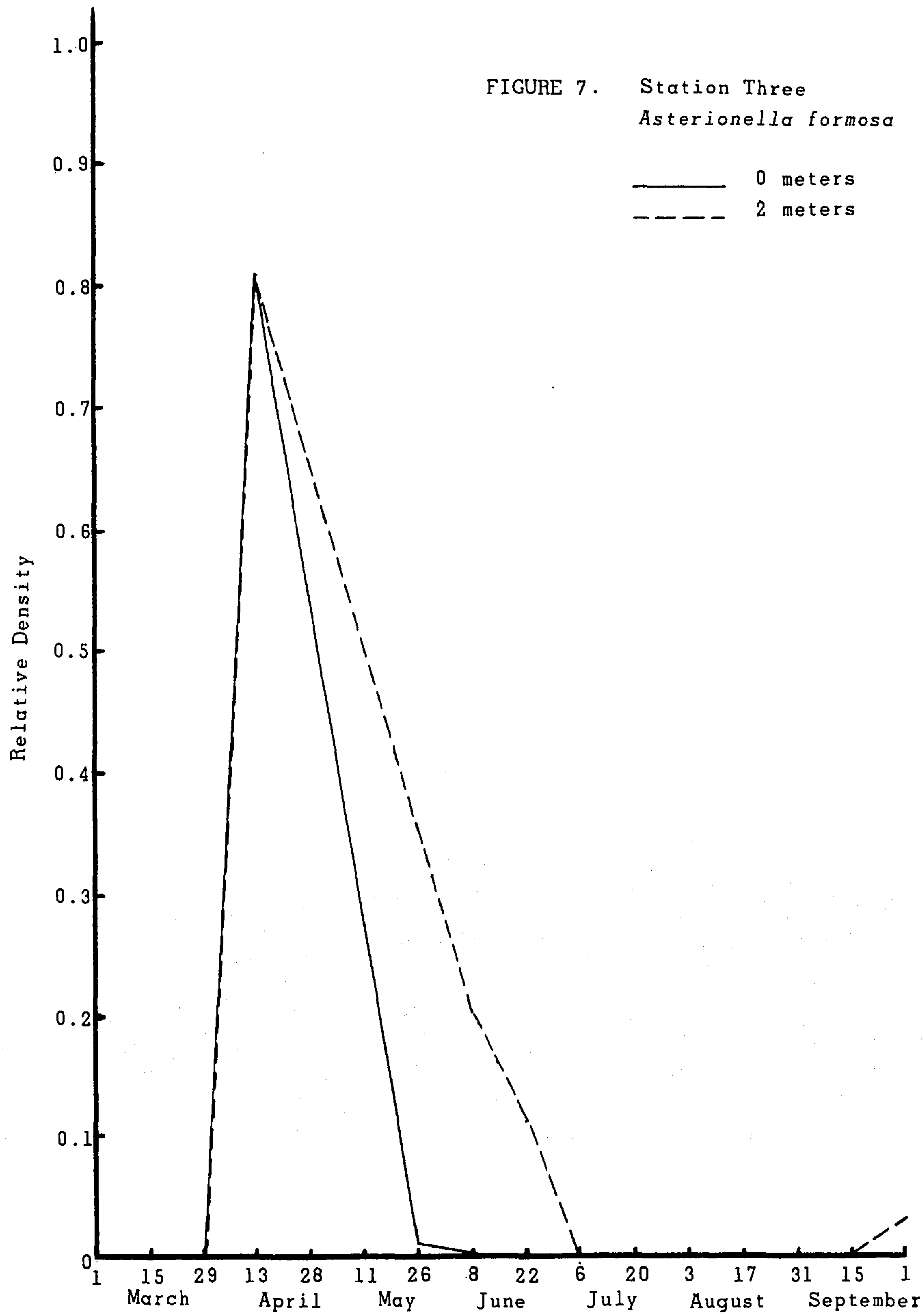


FIGURE 7. Station Three
Asterionella formosa
0 meters
2 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

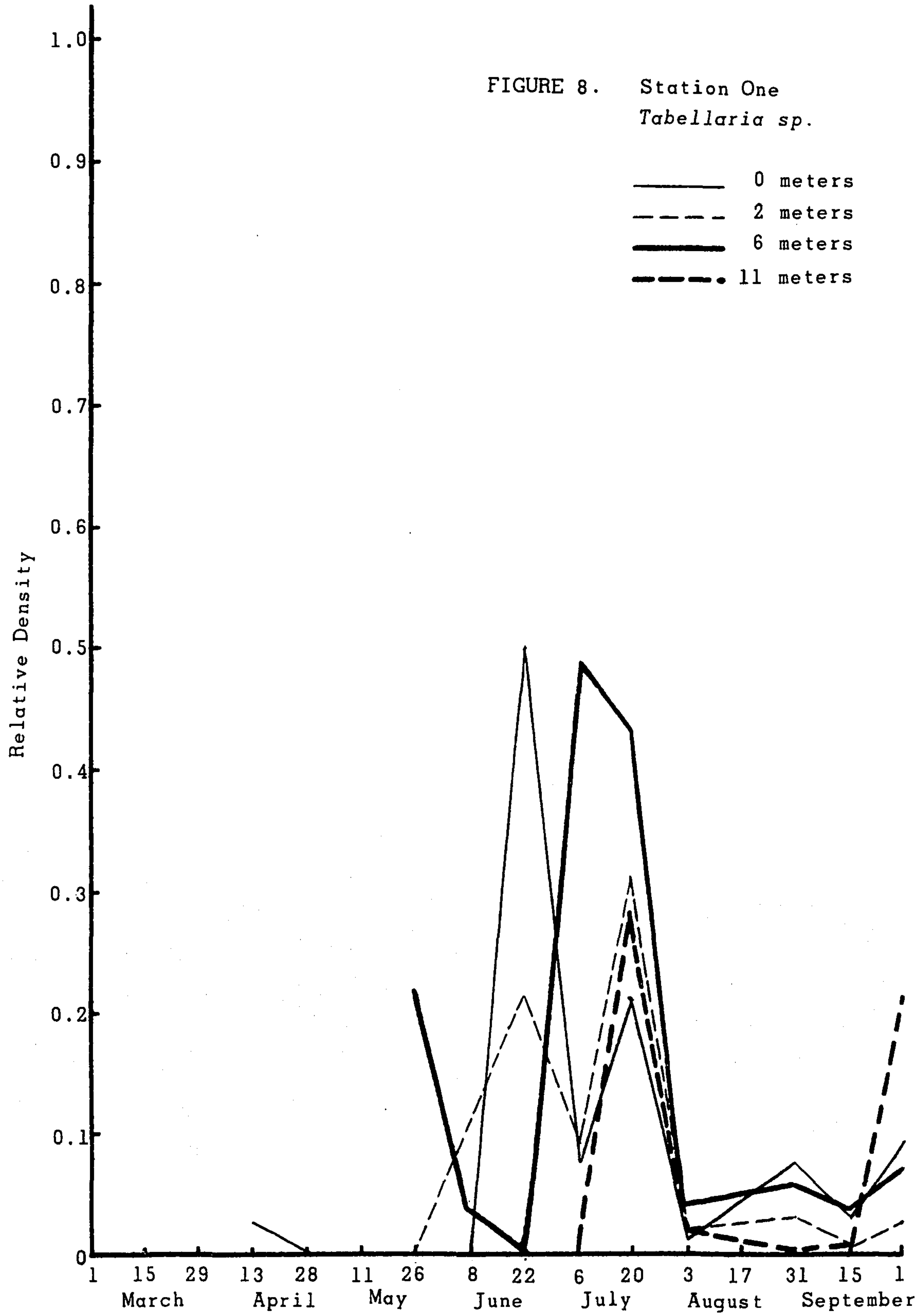


FIGURE 8. Station One
Tabellaria sp.
0 meters
2 meters
6 meters
11 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

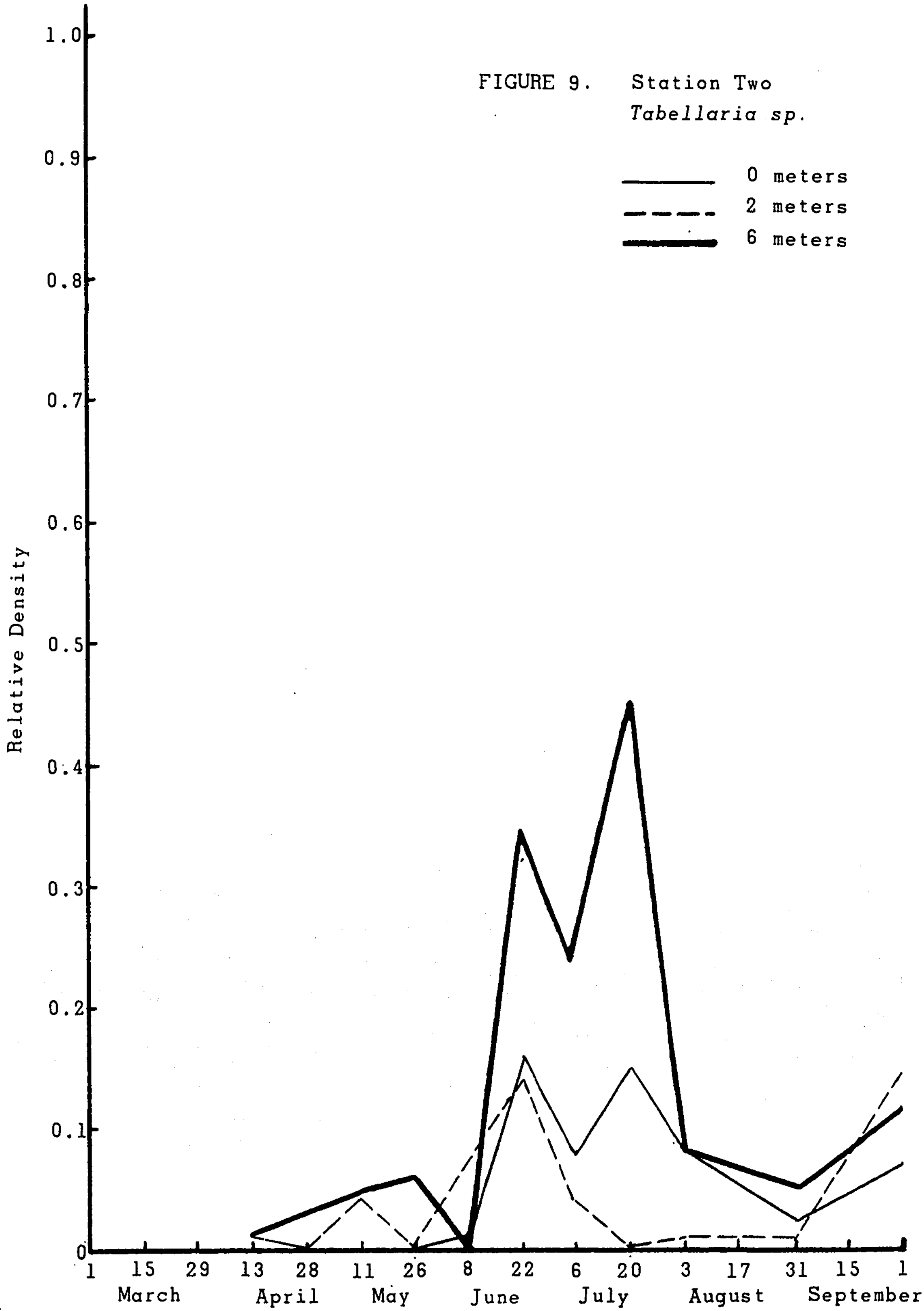


FIGURE 9. Station Two
Tabellaria sp.
0 meters
2 meters
6 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
15
29
13
28
11
26
8
22
6
20
3
17
31
15
1
March
April
May
June
July
August
September

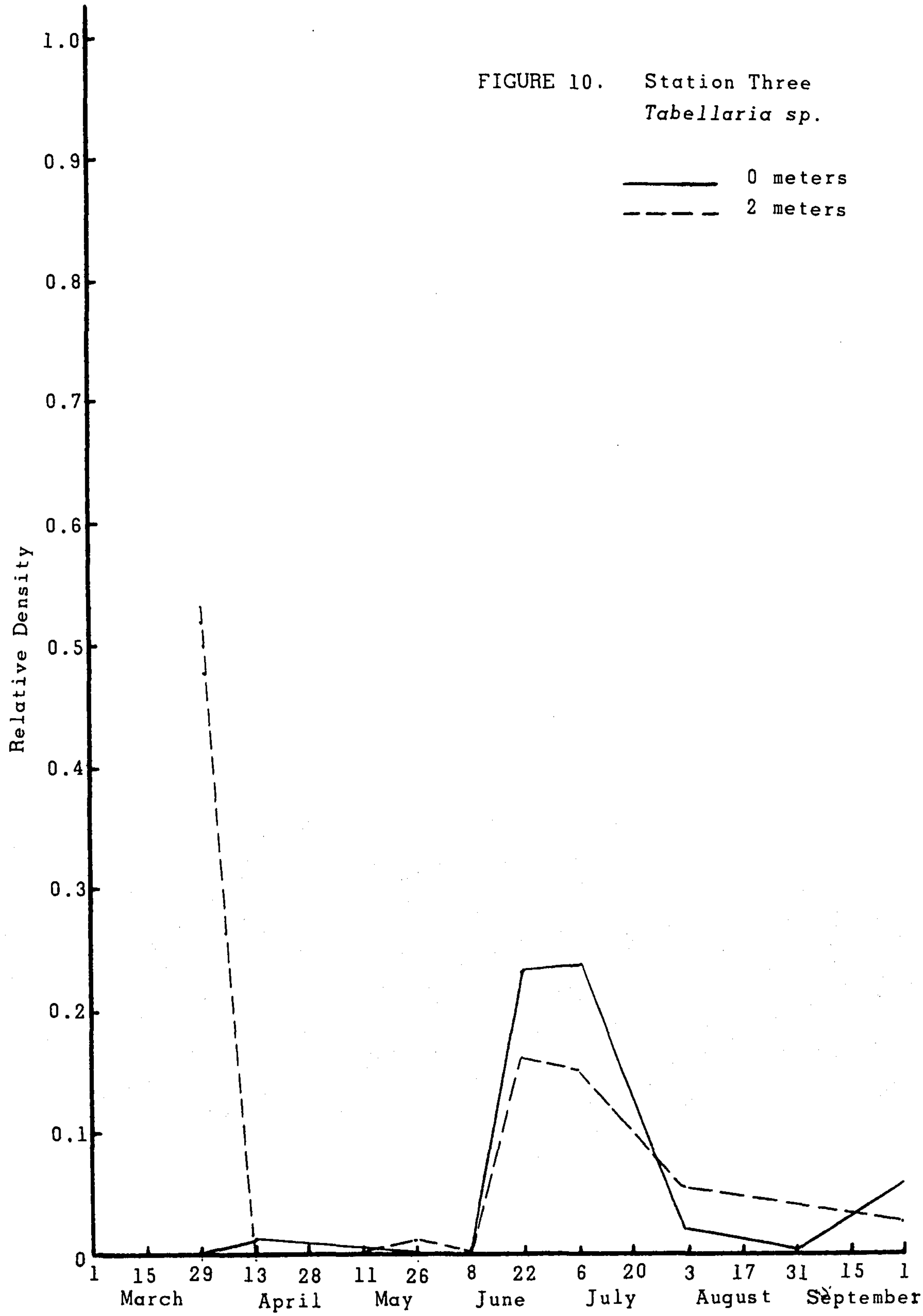


FIGURE 10. Station Three
Tabellaria sp.
0 meters
2 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
15
29
13
28
11
26
8
22
6
20
3
17
31
15
1
March
April
May
June
July
August
September

reached a density of 148.8 cells per milliliter. Stauroneis sp. only appeared once in concentrations of 200 cells per milliliter, but this was probably a high estimate.

The blue-green algae increased in numbers dramatically after the middle of June. More genera of blue-greens were present during the course of the study than golden algae (See Table 1), but only 4 significantly affected the algal population: Microcystis sp., Anabaena flos-aquae, Merismopedia sp., and Gleotrichia echinulata.

Microcystis sp. was the first blue-green to develop large numbers. Figures 11, 12, and 13 show its relative density. On the 20th of July it was found in six meters of water at concentrations of 313.7 colonies per milliliter. However, colonies ranged more generally from 111 to 187 colonies per milliliter in the upper 2 meters. From the 22nd of June to the 20th of July at Stations One and Two, Microcystis sp. comprised up to 50 percent of the algae counted.

Anabaena flos-aquae developed its highest densities on the 20th of July with numbers ranging from 124 to 478 trichomes per milliliter in the upper 6 meters. Although the density declined significantly after than time, the alga maintained a density of about 100 trichomes per milliliter. However, the relative density can be somewhat misleading in this case. For instance, Figure 14 indicated that on July 6th, at 11 meters, A. flos-aquae had high values. However, considering that the total population was significantly lower than that of July 20th, this value must be accepted cautiously.

Merismopedia sp. never developed a density sufficiently large enough to make it a major contributor to the phytoplankton. It did,

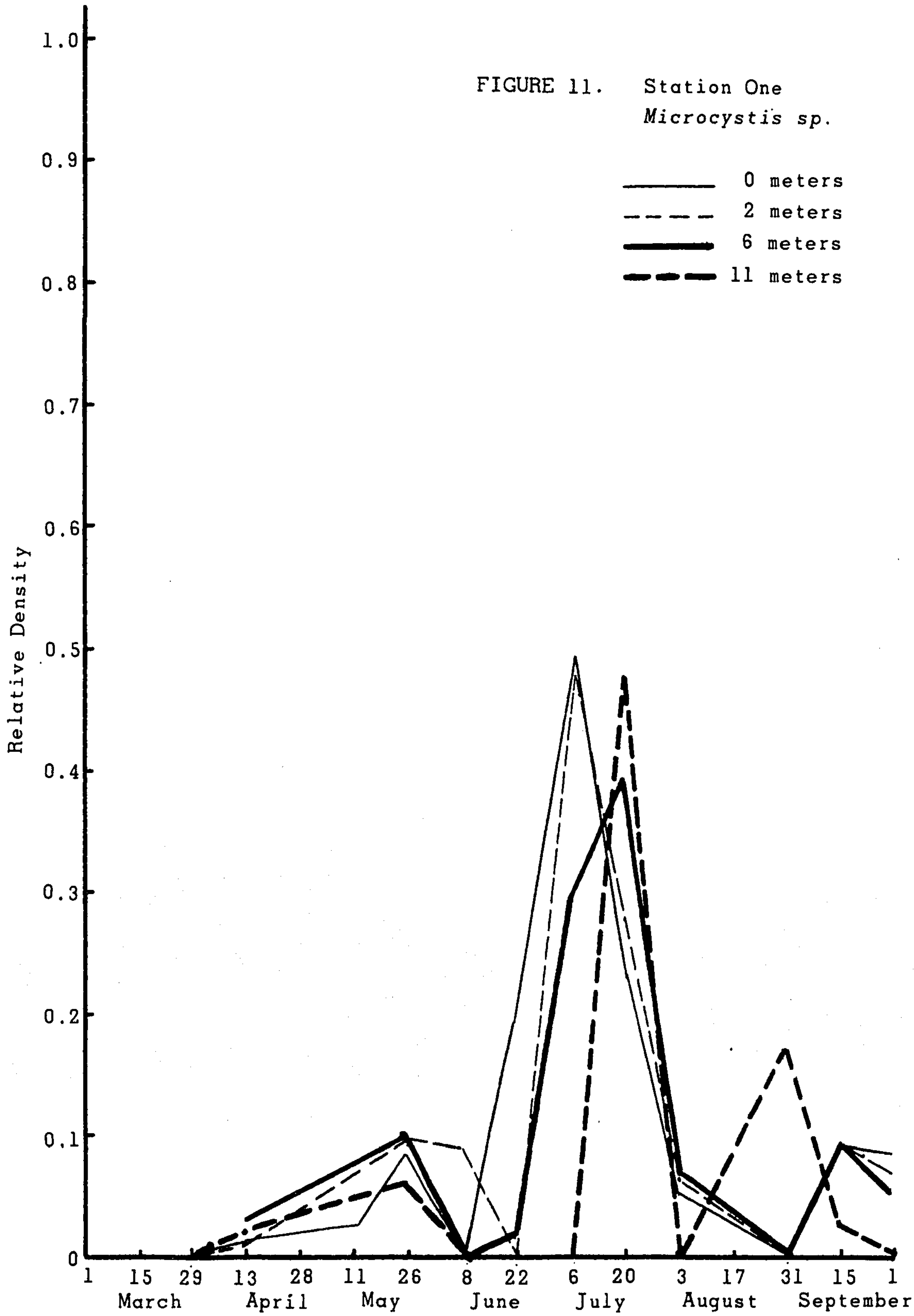
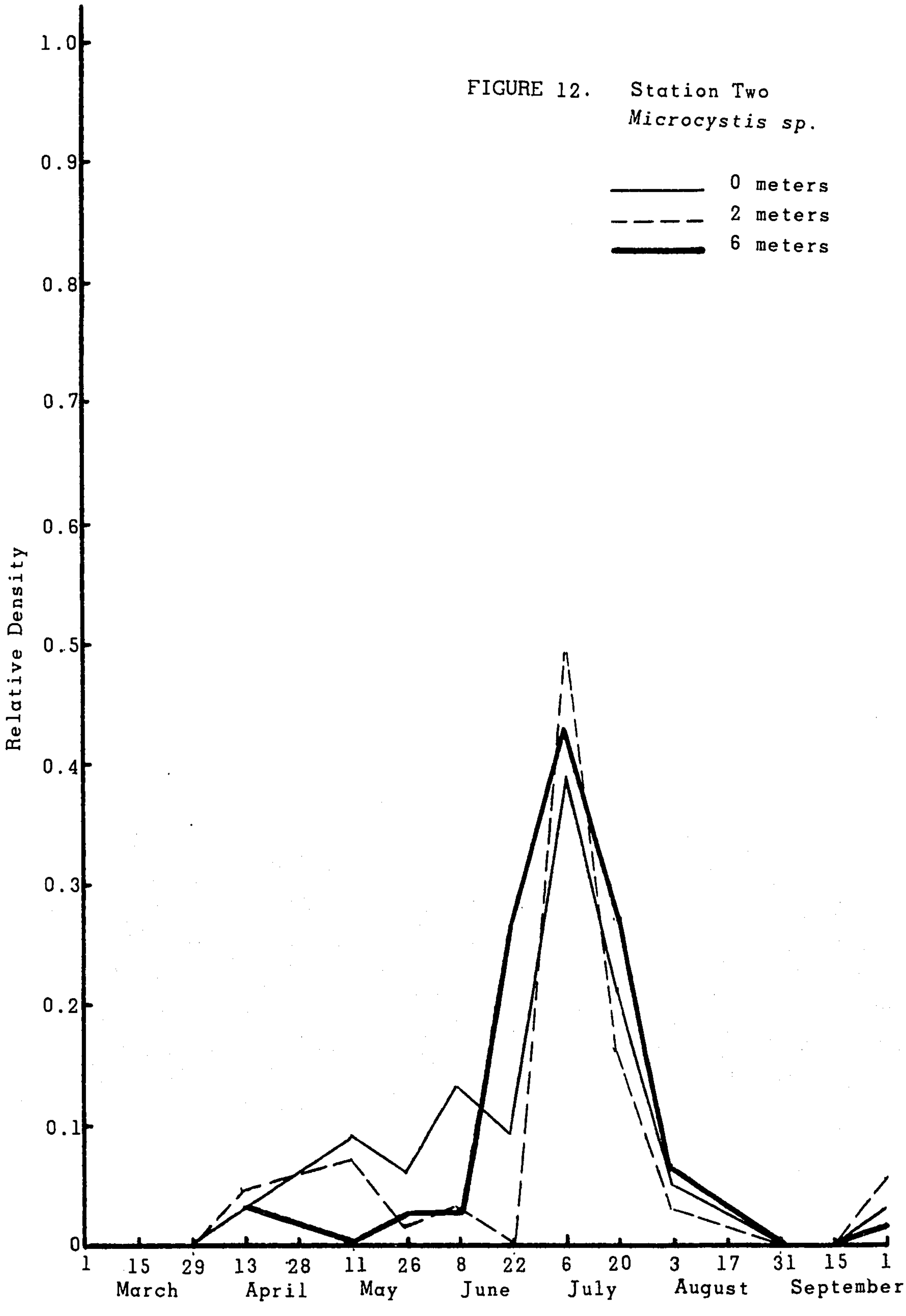


FIGURE 11. Station One
Microcystis sp.
0 meters
2 meters
6 meters
11 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Relative Density
FIGURE 12. Station Two
Microcystis sp.
0 meters
2 meters
6 meters
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

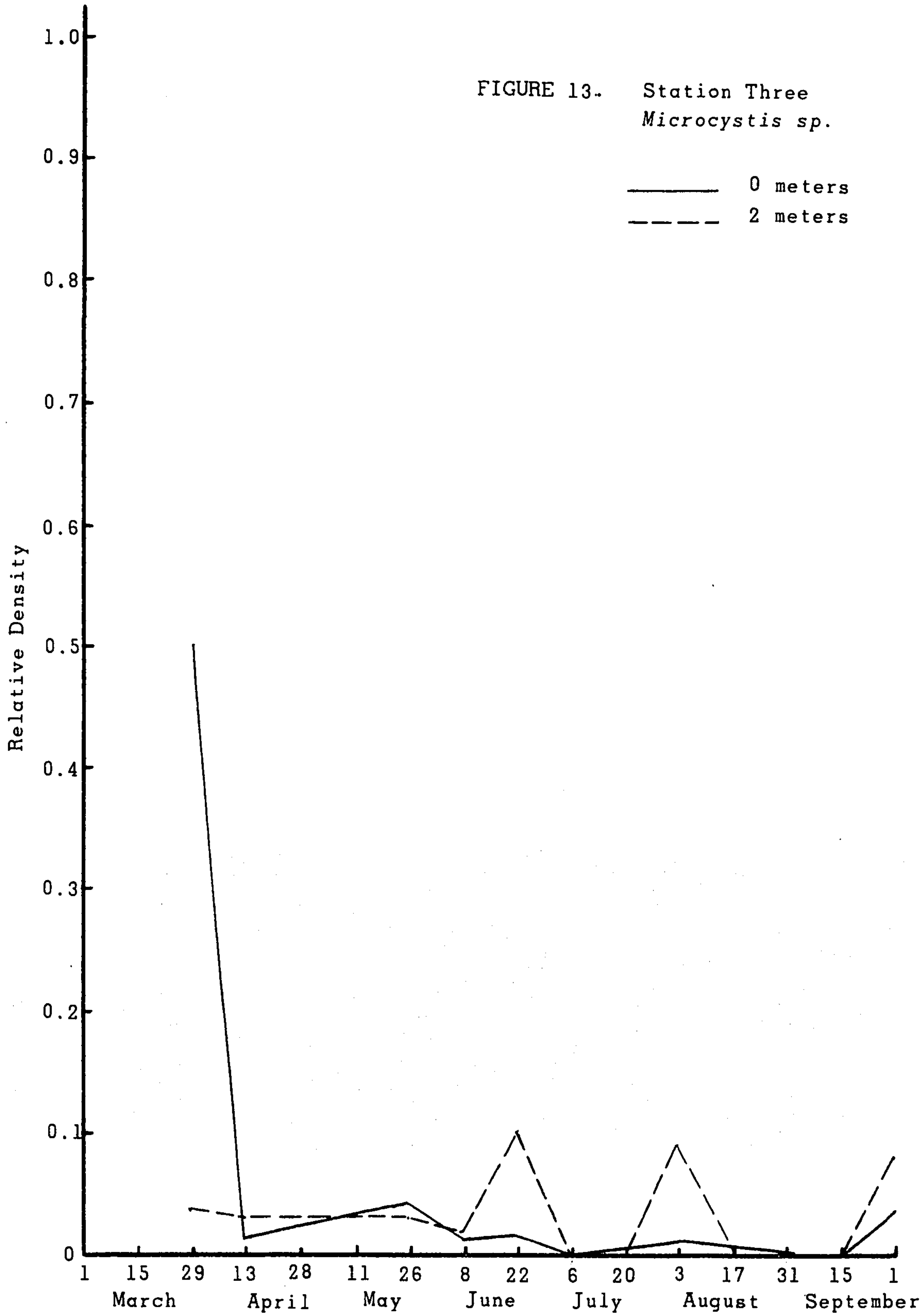


FIGURE 13. Station Three *Microcystis sp.*

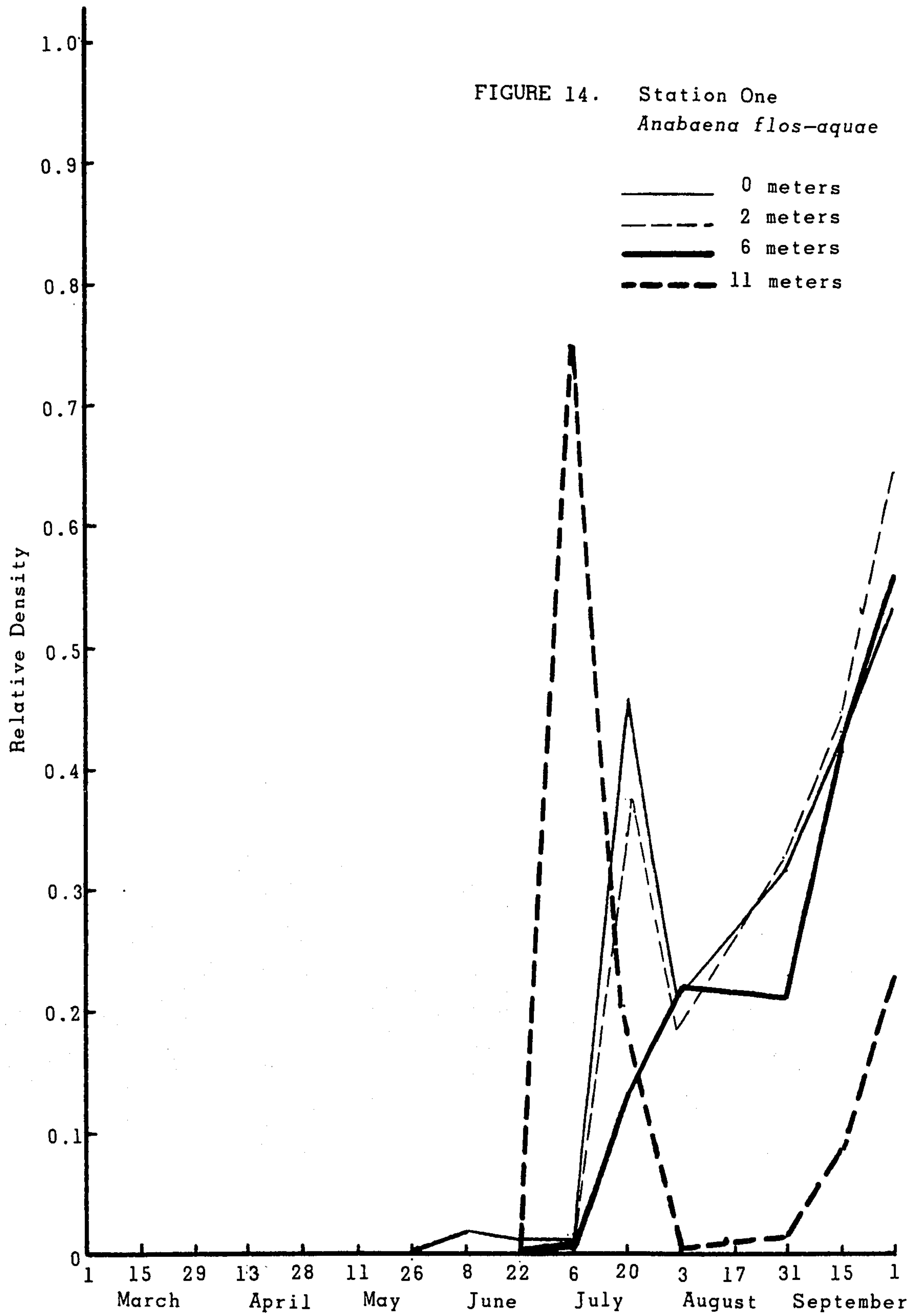


FIGURE 14. Station One
Anabaena flos-aquae
0 meters
2 meters
6 meters
11 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

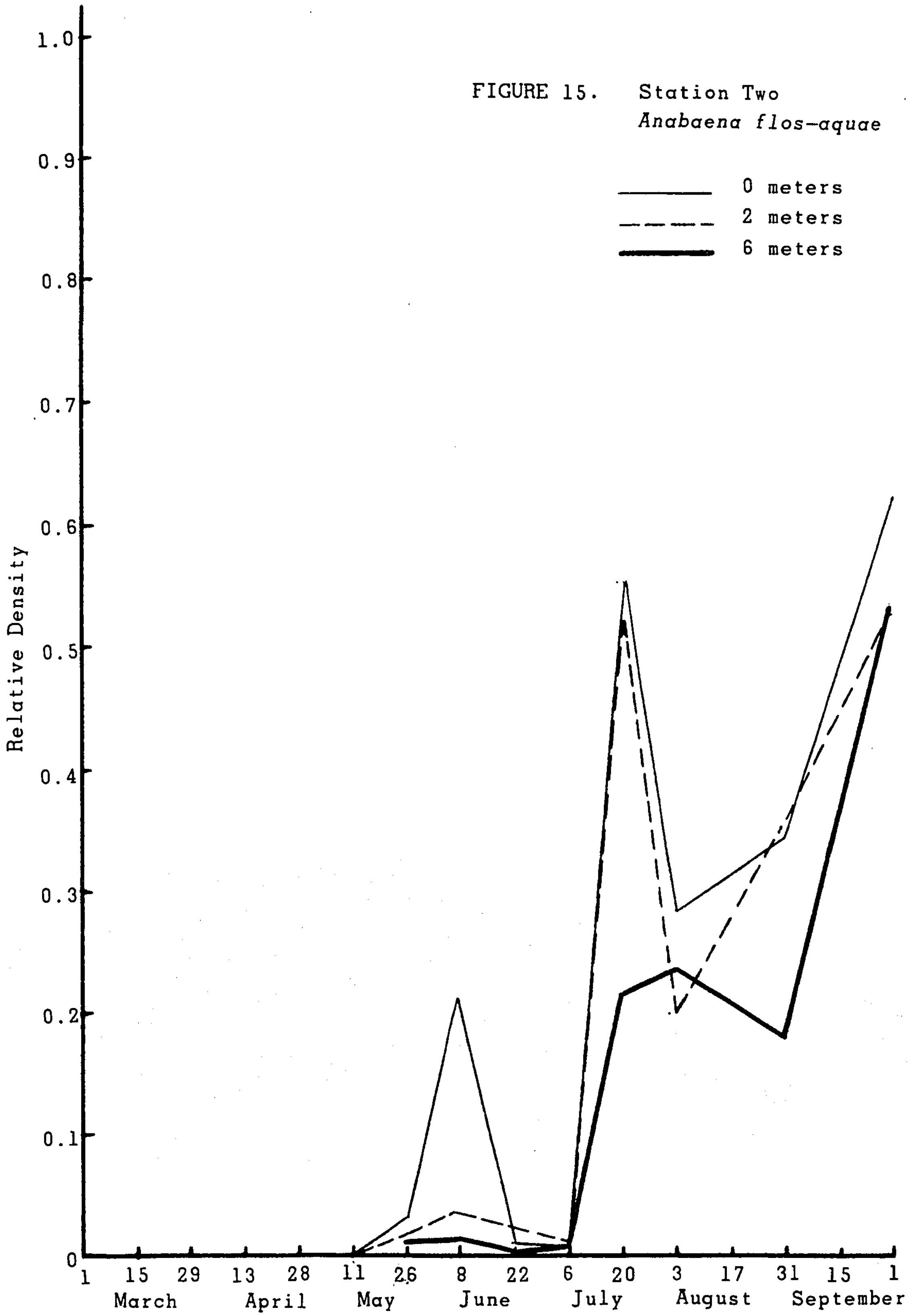


FIGURE 15. Station Two
Anabaena flos-aquae
0 meters
2 meters
6 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March
April
May
June
July
August
September

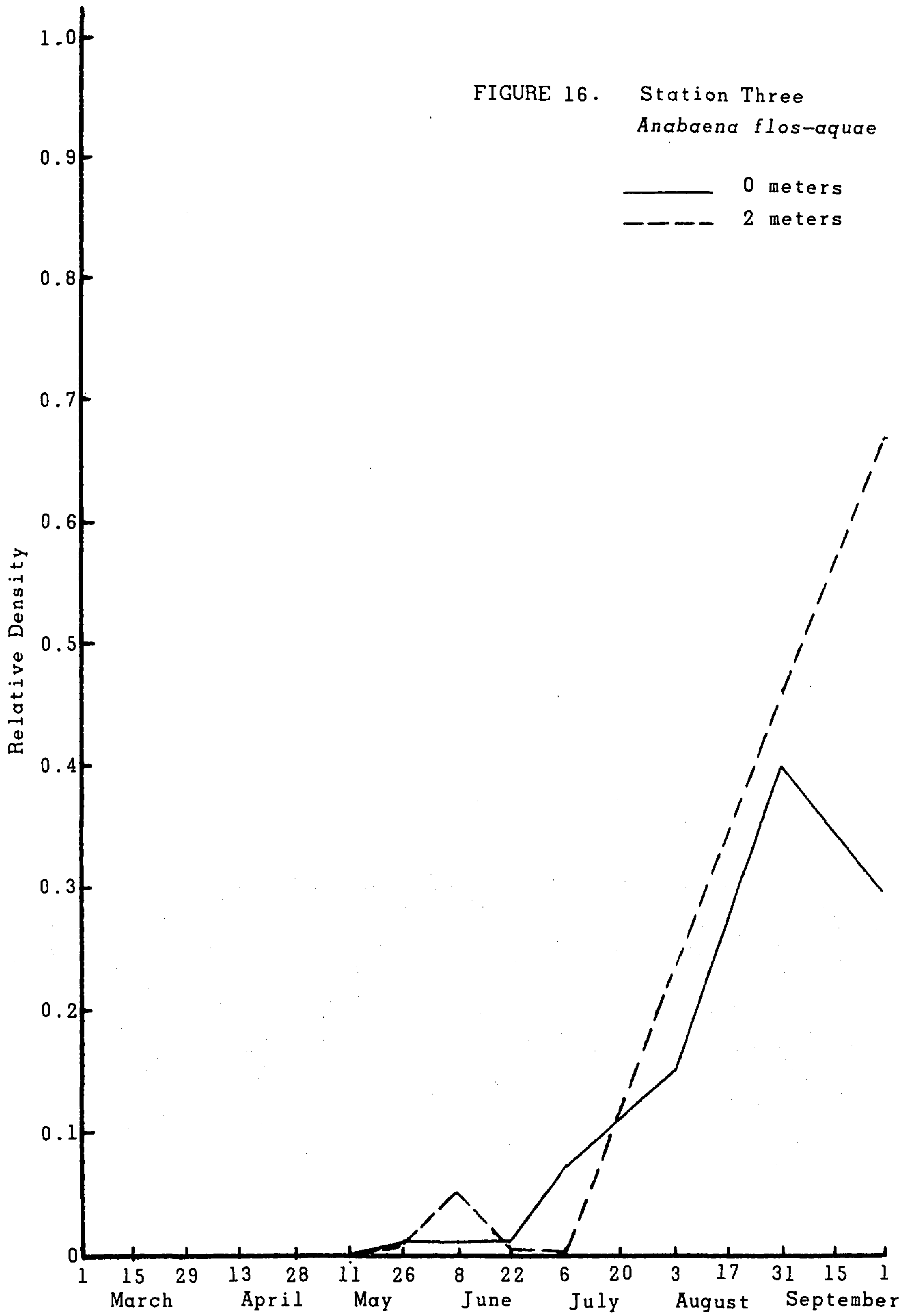


FIGURE 16. Station Three
Anabaena flos-aquae
0 meters
2 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

however, have the highest frequency of occurrence (0.59) of all the blue-green algae. The population never developed a density greater than 48 colonies per milliliter, with one exception. On September 15th 1227 colonies per milliliter were recorded. This was probably an overestimate of the population density since these colonies, at 11 meters, were in a state of decay. Fragmentation accounted for most of the colonies containing no more than 4 or 5 cells in a platelet, hence the abnormally high values mentioned above.

The only other Cyanophyta worthy of note was Gleotrichia echinulata. This blue-green became significant in mid-July. Colonies were macroscopic and occurred in patches in the upper layers of the lake. Though each colony contained thousands of trichomes, the colonies were spread so thin that they rarely appeared in the counting chamber, hence there was no data on their density. A few trichomes did show up in the counting chamber, but these represent a considerable underestimate of the true population density.

The Chlorophyta was represented by 27 different species (See Table 1). None of these ever achieved real significance in the phytoplankton either in numbers or in relative diversity with two exceptions. Quadrigula closterioides reached a density of 109 cells per milliliter at 6 meters at Station One on September 15th. This population boom was extremely short lived, dropping to a density of 10.4 cells per milliliter by the next sampling date. Earlier in the season as shown in Figures 17, 18, and 19, the relative density indicated that Q. closterioides dominated the phytoplankton at the

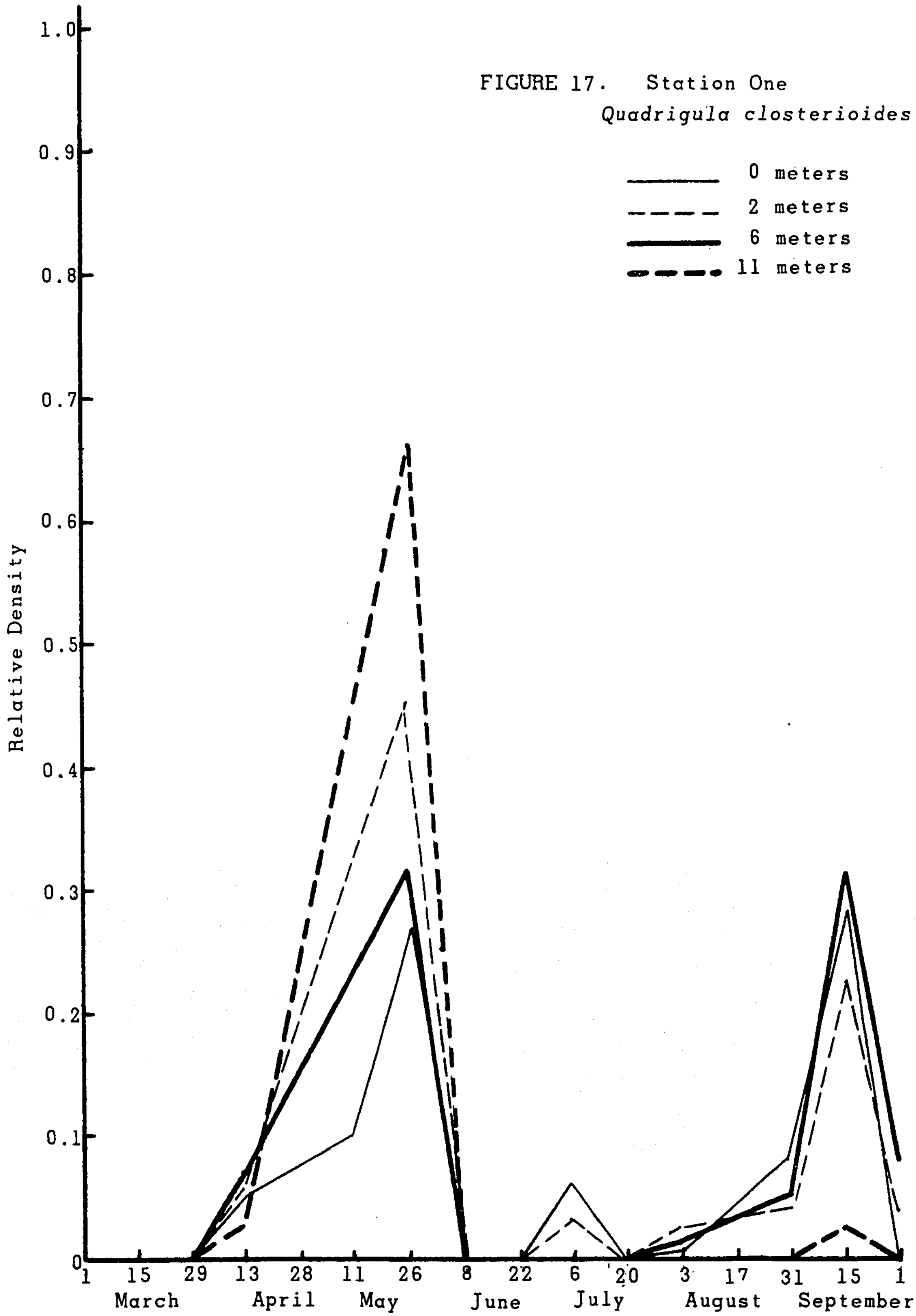


FIGURE 17. Station One
Quadrigula closterioides
0 meters
2 meters
6 meters
11 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

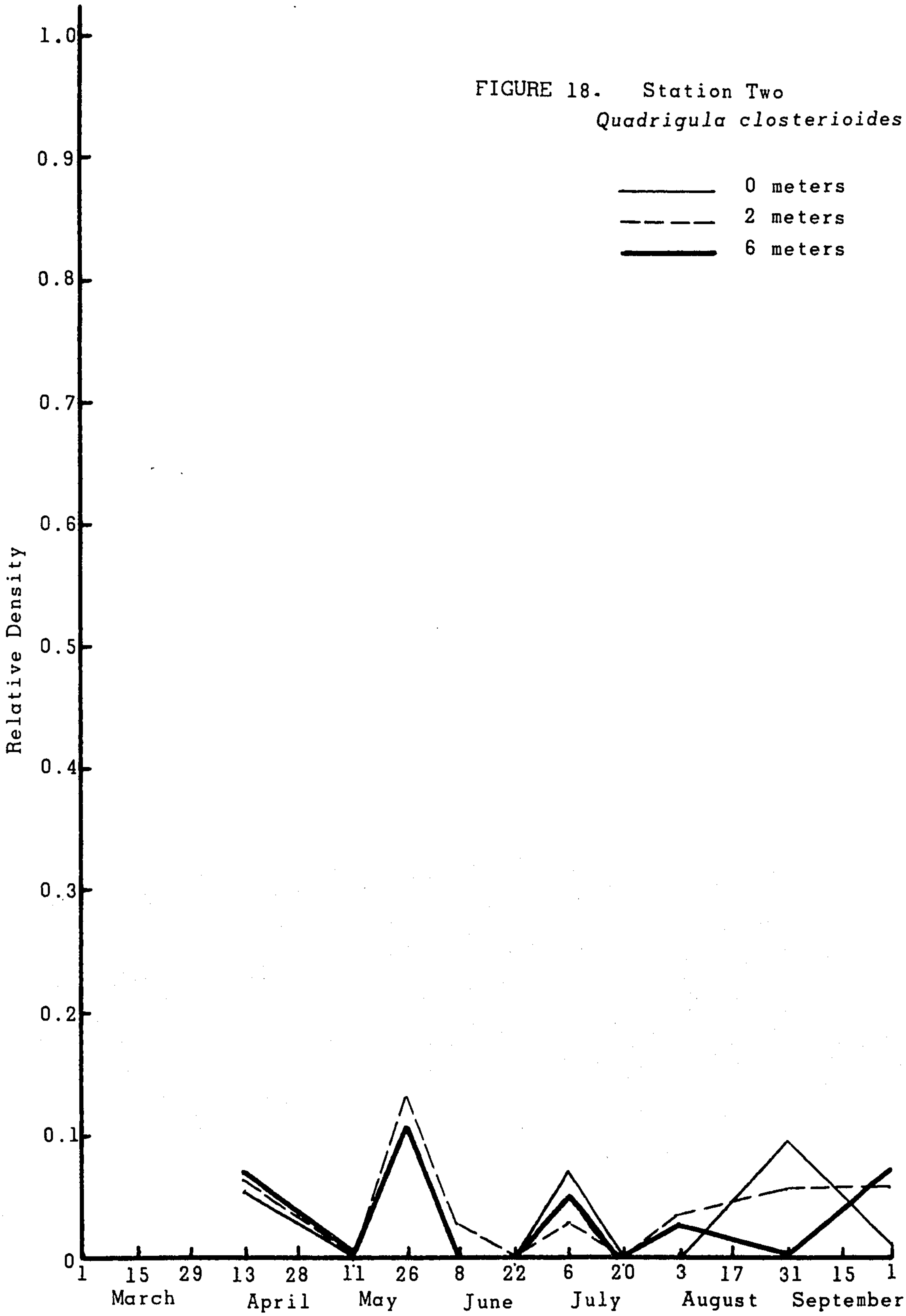


FIGURE 18. Station Two
Quadrigula closterioides
0 meters
2 meters
6 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
15
29
13
28
11
26
8
22
6
20
3
17
31
15
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March
April
May
June
July
August
September

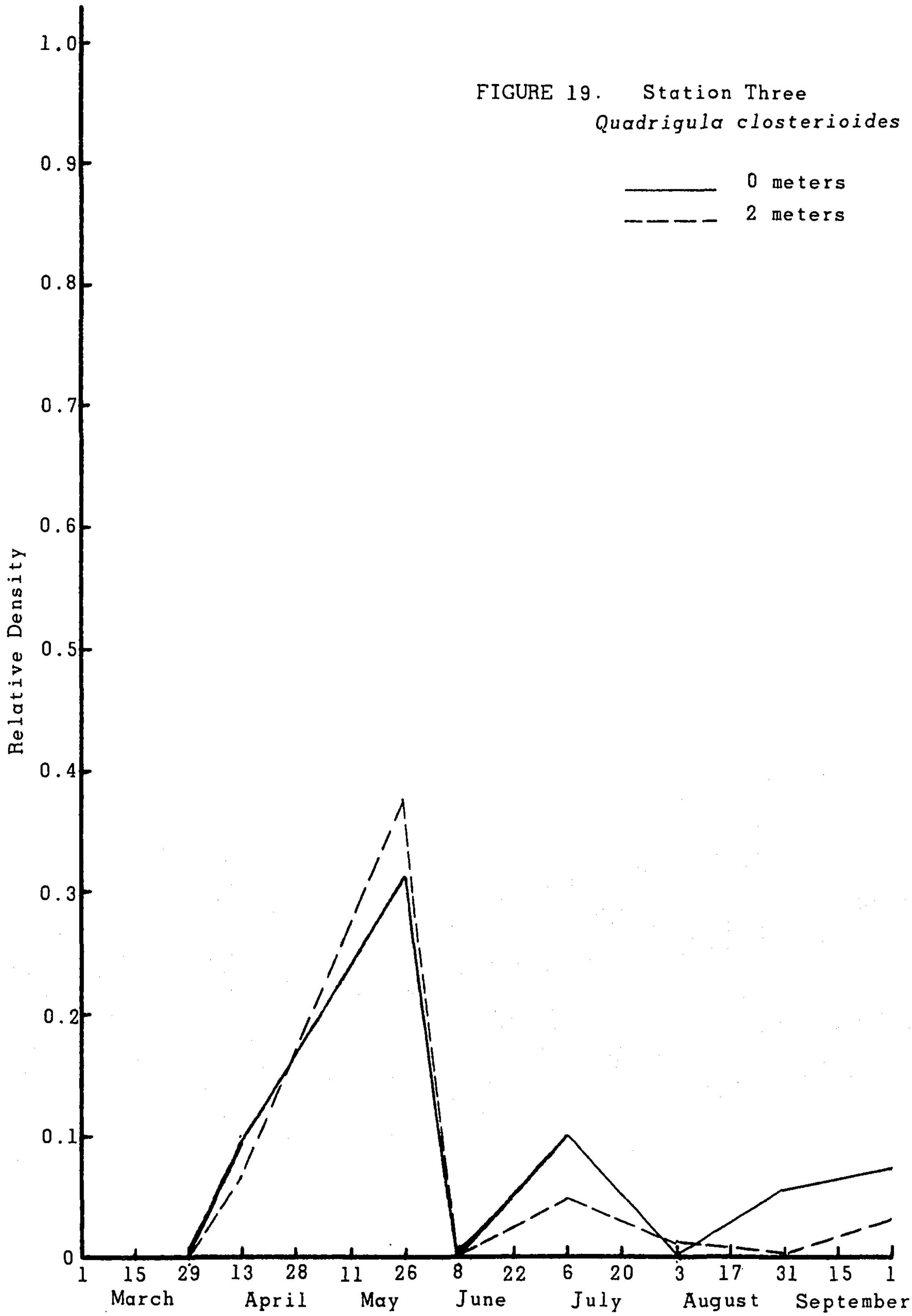


FIGURE 19. Station Three
Quadrigula closterioides
0 meters
2 meters
Relative Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March
April
May
June
July
August
September

lower depths. The total concentration of algae was only 47.29 and Q. closterioides achieved dominance with a maximum of 31 cells per milliliter at 11 meters. Furthermore, Q. closterioides appeared with high frequency over the course of the study period (0.53) and so appeared to be one of the more stable members of the community.

An unidentified alga, probably in the Zygnemataceae, developed significant numbers during August. The plant was found mostly in the upper 6 meters of the water column and ranged in concentration at the different stations from 43 to 197 cells per milliliter. Relative density ranged from 27 to 53 percent.

The Pyrrhophyta and the Euglenophyta contributed only four species to the phytoplankton community of Wall Lake. Ceratium hirundinella occurred periodically throughout the course of the season but never in numbers greater than 7.4 cells per milliliter. The density was so small that no real peak in growth could be observed. Peridinium gatunense likewise occurred quite infrequently and its concentration never exceeded 2.9 cells per milliliter. Phacus longicauda was seen only once at the end of August with a density no larger than 0.62 cells per milliliter at 6 and 11 meters at Station One, and once, on the surface at Station Three. Trachelomonas sp. was seen on the 20th of July in concentrations of 1.49 cells per milliliter.

The diversity index formula described by Wilhm and Dorris (1968) was applied to the data for each elevation and each sample day. The index, as shown in Figures 20, 21, and 22, indicate nearly constant increase in phytoplankton. Surface and two meter data seem to mirror

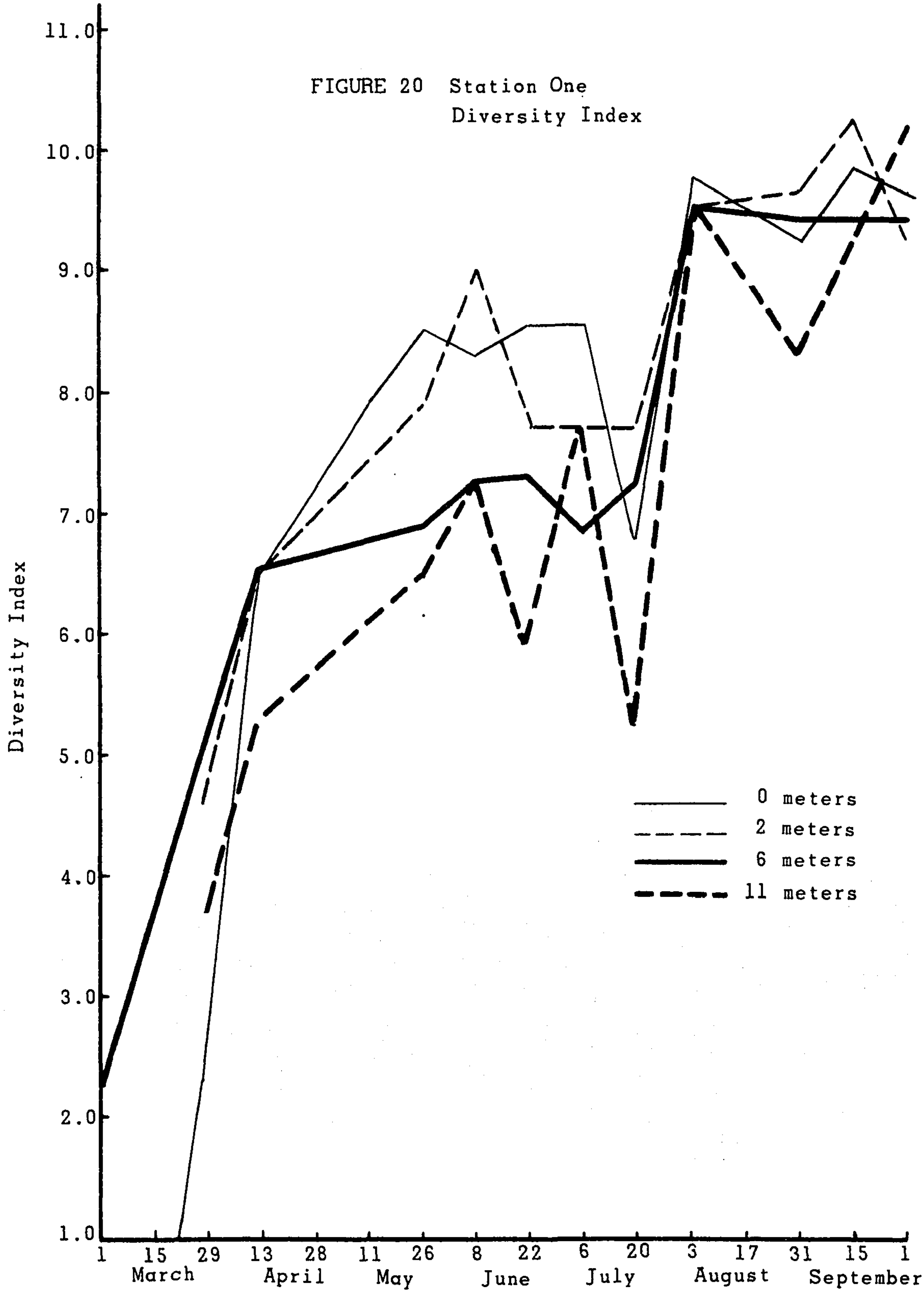


FIGURE 20 Station One
Diversity Index
Diversity Index
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0 meters
2 meters
6 meters
11 meters
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

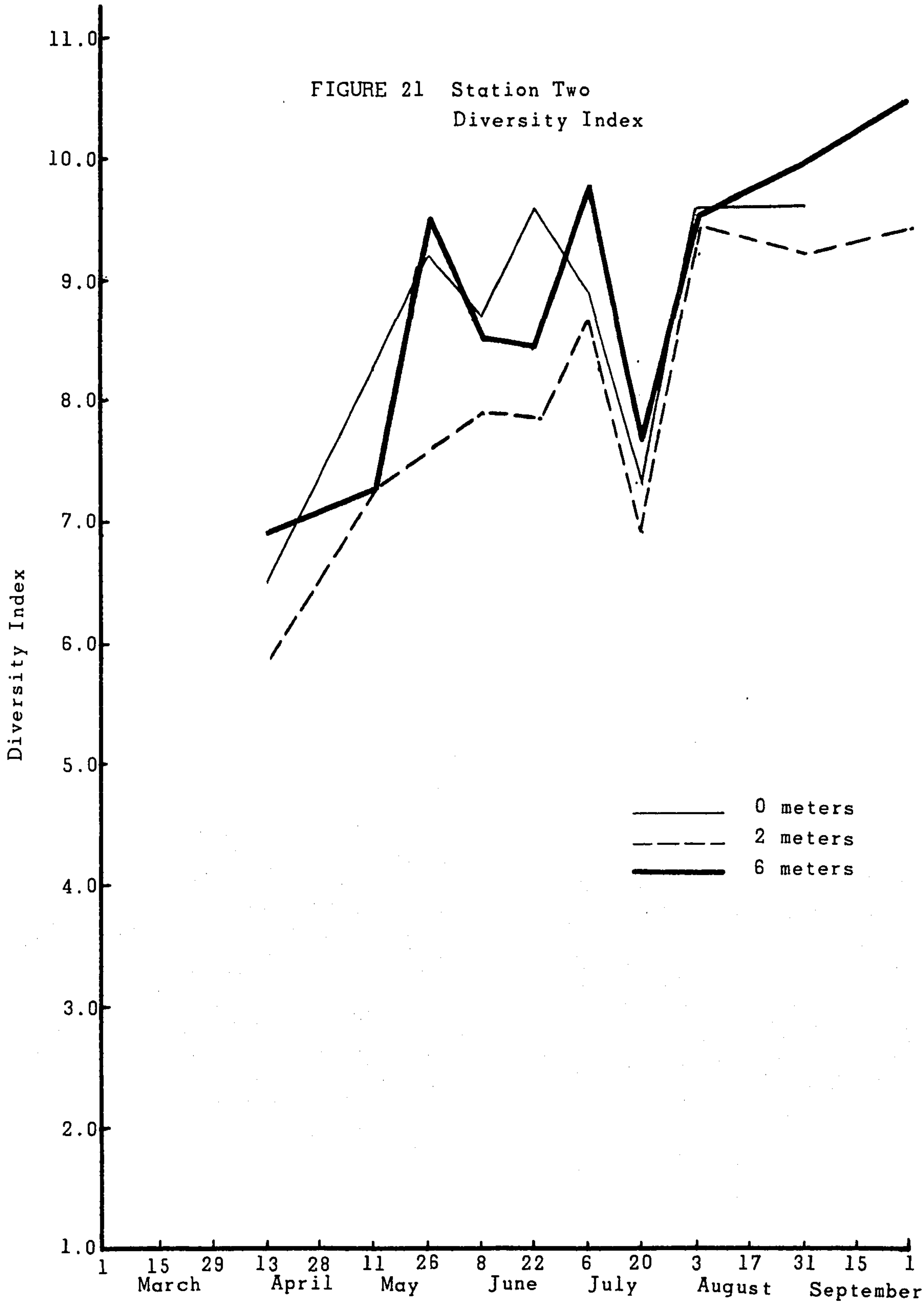


FIGURE 21 Station Two
Diversity Index
Diversity Index
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
1
15
29
13
28
11
26
8
22
6
20
3
17
31
15
1
March
April
May
June
July
August
September
0 meters
2 meters
6 meters

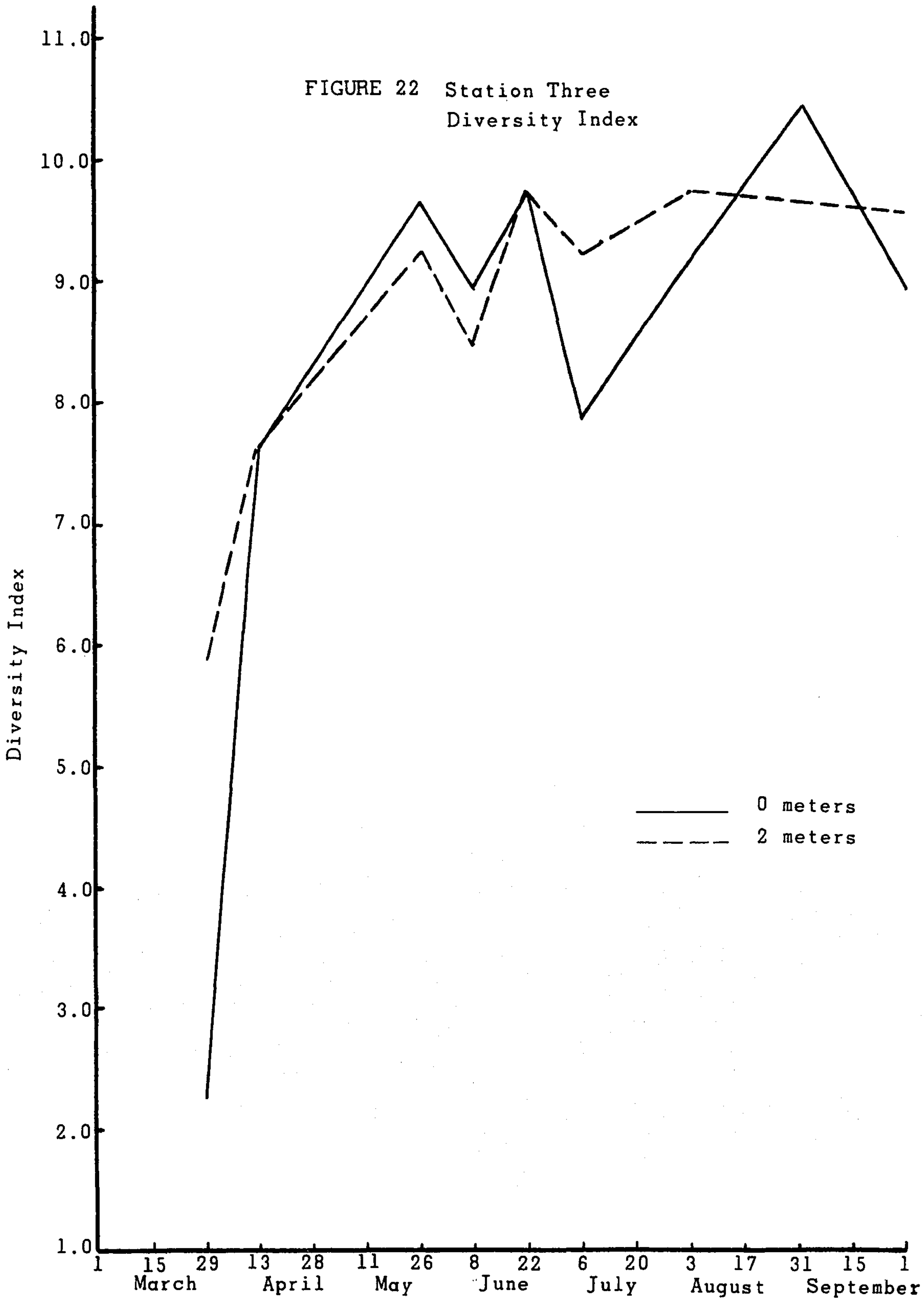


FIGURE 22 Station Three
Diversity Index
Diversity Index
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0 meters
2 meters
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

each other. Greater fluctuations were prevalent in the lower samples particularly at 11 meters. There was a general decline in diversity around the 20th of July. The decline was observed not only at each elevation but also at each station.

Data on fecal coliform density was determined for 10 different stations at the perimeter of the lake from May 26th to August 31st. Figure 23 shows that in most cases fecal coliform density was insignificant. Station 10 averaged 104 colonies per 100 milliliters on August 3rd. Since Michigan Intrastate Water Quality Standards specify that the fecal coliform geometric average for 10 consecutive samples shall not exceed 100, further testing at this site is warranted (Michigan Water Resources Commission, 1969).

Physical and Chemical Parameters

Wall Lake became thermally stratified during June and July. The temperature at 12 meters never became warmer than 16.5°C during the course of the summer, and on the day that temperature was recorded the lake was already showing signs of fall turnover. Probably warmer water from the surface was mixing with the colder water below thus bringing the surface and bottom temperatures closer together. See Figure 24.

The surface temperature was 26°C on both the 20th of July and the 31st of August. Changes in atmospheric conditions seem to have strong effects on water temperature to depths of 5 meters even during the hottest portion of the summer when temperature stratification was the strongest.

FIGURE 23.

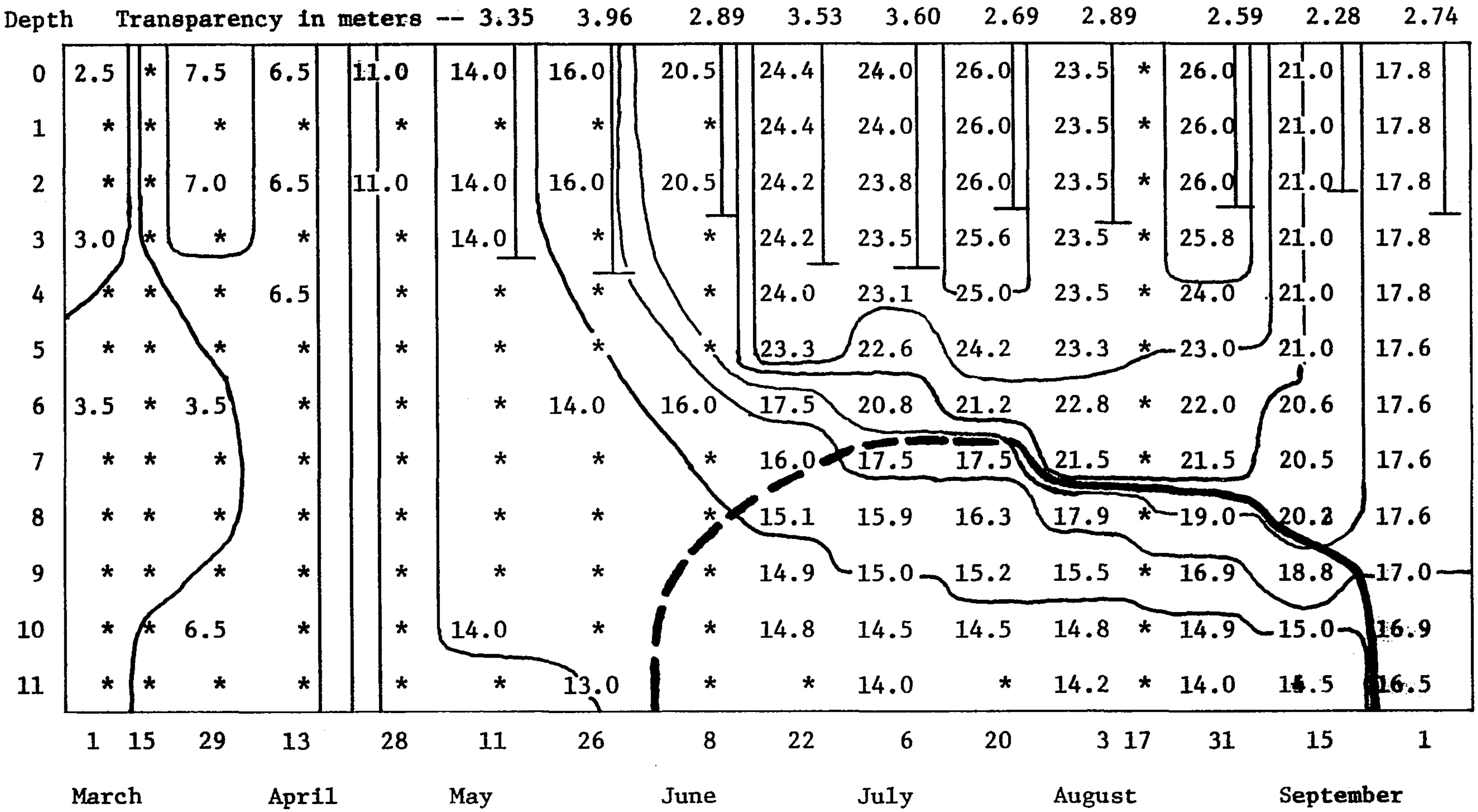
Fecal Coliform Colonies per 100 milliters

STATION	May 26	Jun 8	Jun 22	Jul 6	Jul 20	Aug 3	Aug 17	Sept 15
1	0	0	4	4	17	0	-	4
	0	0	4	0	13	1	-	1
2	0	0	9	0	0	0	-	3
	0	0	6	2	1	1	-	3
3	0	0	2	2	0	2	-	7
	0	0	0	1	2	2	-	9
4	0	0	0	0	1	4	-	3
	0	0	0	1	1	1	-	1
5	0	0	0	0	1	0	-	0
	0	0	0	0	4	1	-	1
6	0	0	0	0	0	0	-	0
	0	0	0	1	1	1	-	3
7	0	0	0	0	8	1	-	91
	0	0	0	0	3	1	-	1
8	0	0	-	0	1	2	-	5
	0	0	-	1	1	4	-	4
9	0	0	0	1	1	0	-	4
	0	0	0	1	4	1	-	3
10	0	0	3	1	-	130	-	30
	0	0	1	3	-	89	-	19

\- indicates no data

FIGURE 24. Temperature, Oxygen and Transparency Diagram.

The temperature is shown in degrees centigrade. The heavy slashed and solid line represents the lower limit of oxygen. Transparency is shown graphically by the inverted "T's". The asterisks indicate no data.



Data on oxygen concentration indicate oxygen depletion below 7 meters by July 20th. Prior to that date significant experimental error was discovered in the sampling technique so as to bias the results upward. However, estimates based on temperature considerations and oxygen trends indicate the basin became anoxic by the beginning of June. This period lasted until the 1st of October when thermal stratification was beginning to dissipate and oxygen concentrations at the 11 meter mark became 0.49 mg O_2 per liter. Figure 24 shows the area devoid of oxygen as either the heavy line or the heavy dashed line at the bottom of the chart from May to October 1st. The dash line represents the area that was estimated.

Figure 24 also shows the depth of light transmission as measured by a Secchi dish. The region of 5 percent transmission was generally around 3.58 meters until July 6th. From then on it averaged 2.63 meters until the end of the study. For the stations where the water was shallower the region of 5 percent transmission extended to the bottom.

The apparent color, that is, the color that usually results from the interplay of light on suspended materials together with factors such as sky and bottom reflection, ranged over the course of the season from 10 to 125 platinum-cobalt units at the surface and from 10 to 450 Pt-Co units at 11 meters.

Turbidity, like color, showed a marked increase both over time and with depth. An abrupt change occurred after July 6 with a four-fold increase at the bottom. Toward the end of the season turbidity was 35 to 40 Formazin Turbidity Units at the surface and between 44 and 140 units at the bottom.

On March 1st, while there was still ice on the lake, the pH was uniform throughout the water column at 6.9. After the ice melted in the second week of March until May 26th the water was slightly alkaline. As stratification became more pronounced, the surface became more alkaline, reaching a maximum of 8.6 on July 20th, and the bottom water became more acidic, reaching the lowest pH of 6.8 at 11 meters. By the first of October the pH had returned to neutral.

During May and the first part of June, nitrate and nitrite nitrogen concentrations increased tremendously. Concentrations as high as 9 milligrams per liter were recorded at Station Two at the surface. Other samples recorded nitrate and nitrite nitrogen concentrations between 6 and 8.5 milligrams per liter. By the 22nd of June these concentrations had all but disappeared and nitrate and nitrite remained near zero throughout the rest of the study period. See Figures 25, 26, and 27.

Ortho plus metaphosphate fluctuate tremendously both over the course of the study and with depth and station. At Station One, for instance, inorganic phosphate ranged from 0 to 1.6 milligrams per liter with concentrations over 1 milligram per liter seven times throughout the study period. In spite of this fluctuation, Figures 28, 29, and 30 indicate that a general trend upward can be noted at all three stations.

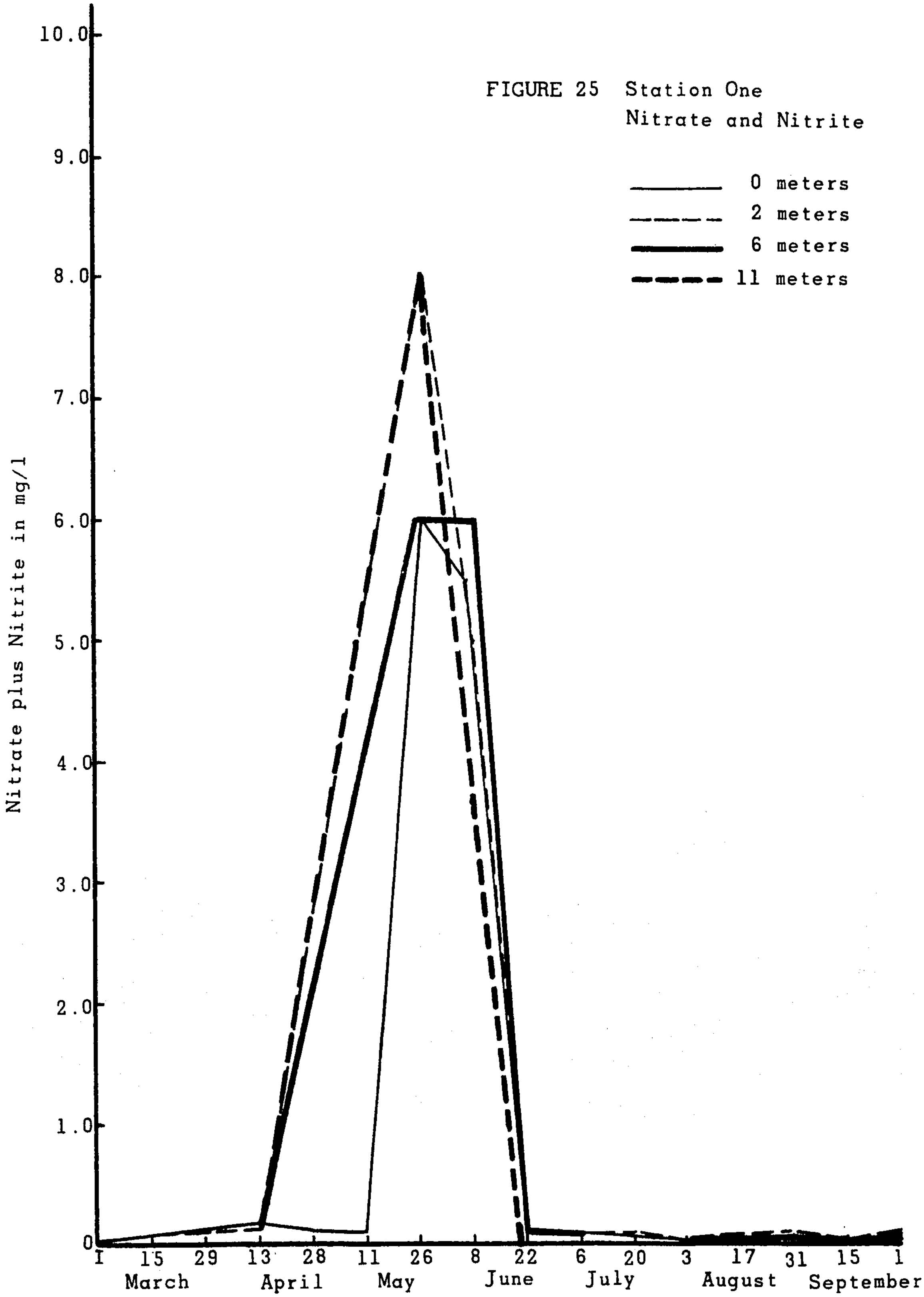
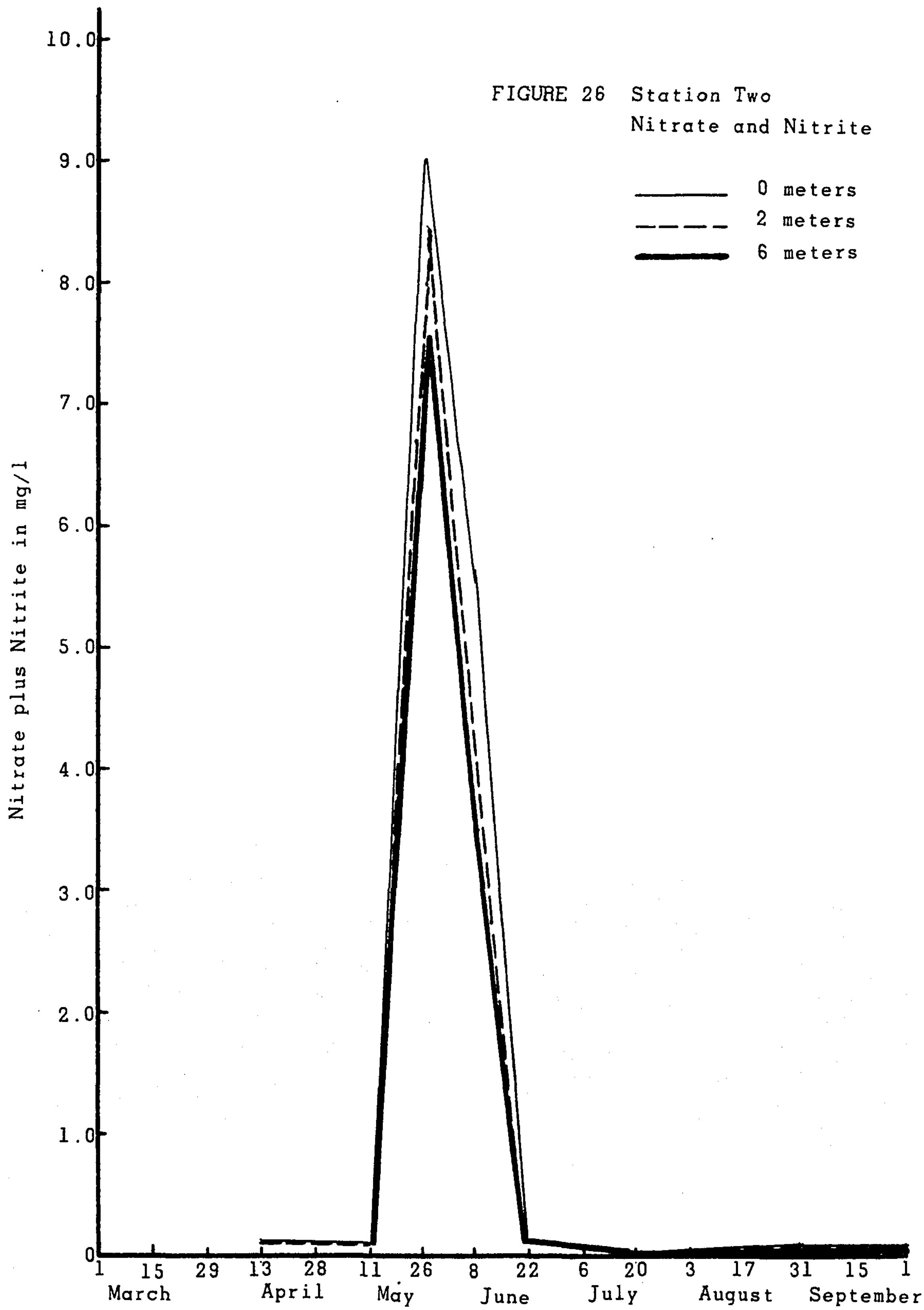


FIGURE 25 Station One
Nitrate and Nitrite
0 meters
2 meters
6 meters
11 meters
Nitrate plus Nitrite in mg/l
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
1
15
29
13
28
11
26
8
22
6
20
3
17
31
15
1
March
April
May
June
July
August
September



10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
Nitrate plus Nitrite in mg/l
FIGURE 26 Station Two
Nitrate and Nitrite
0 meters
2 meters
6 meters
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

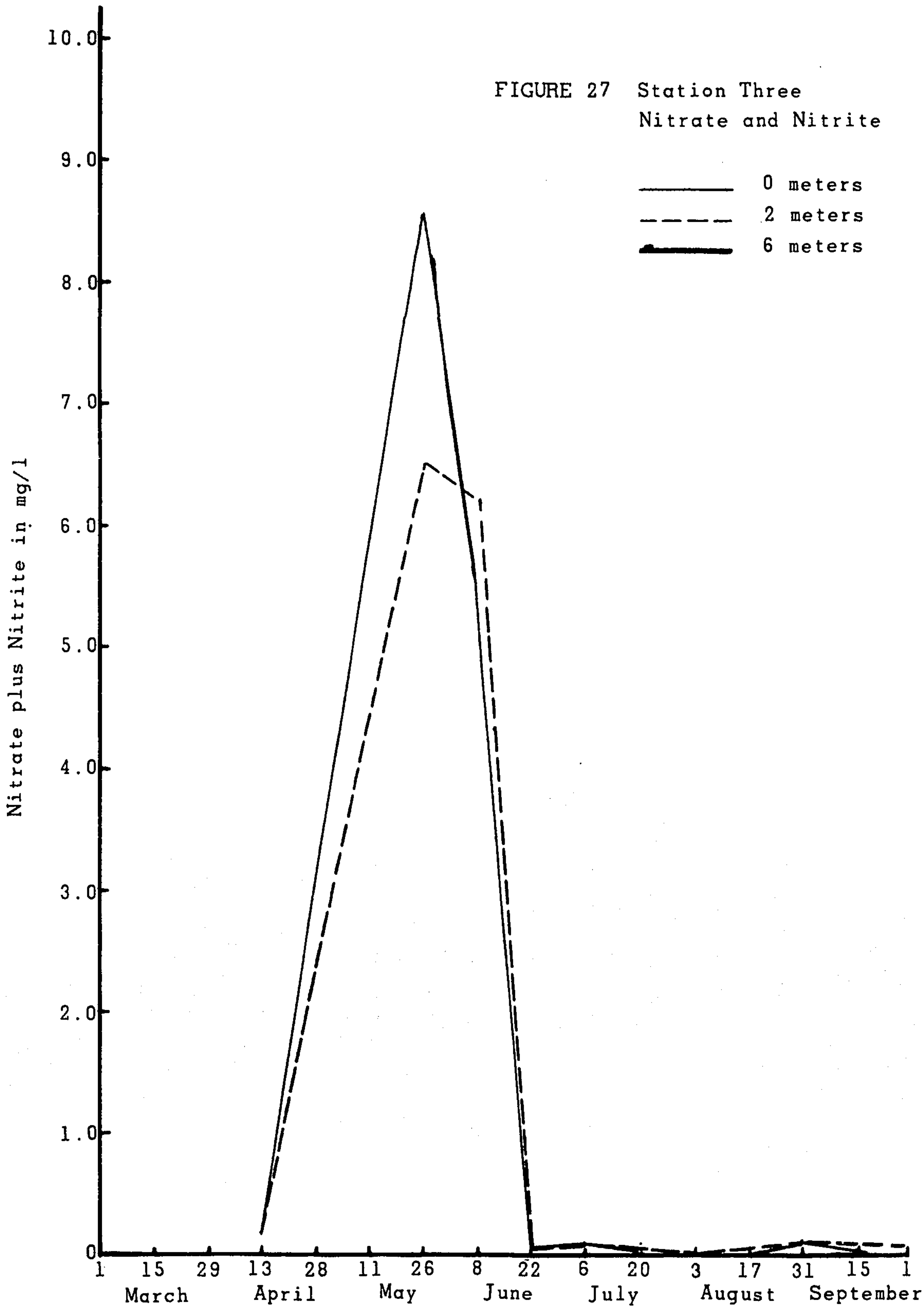
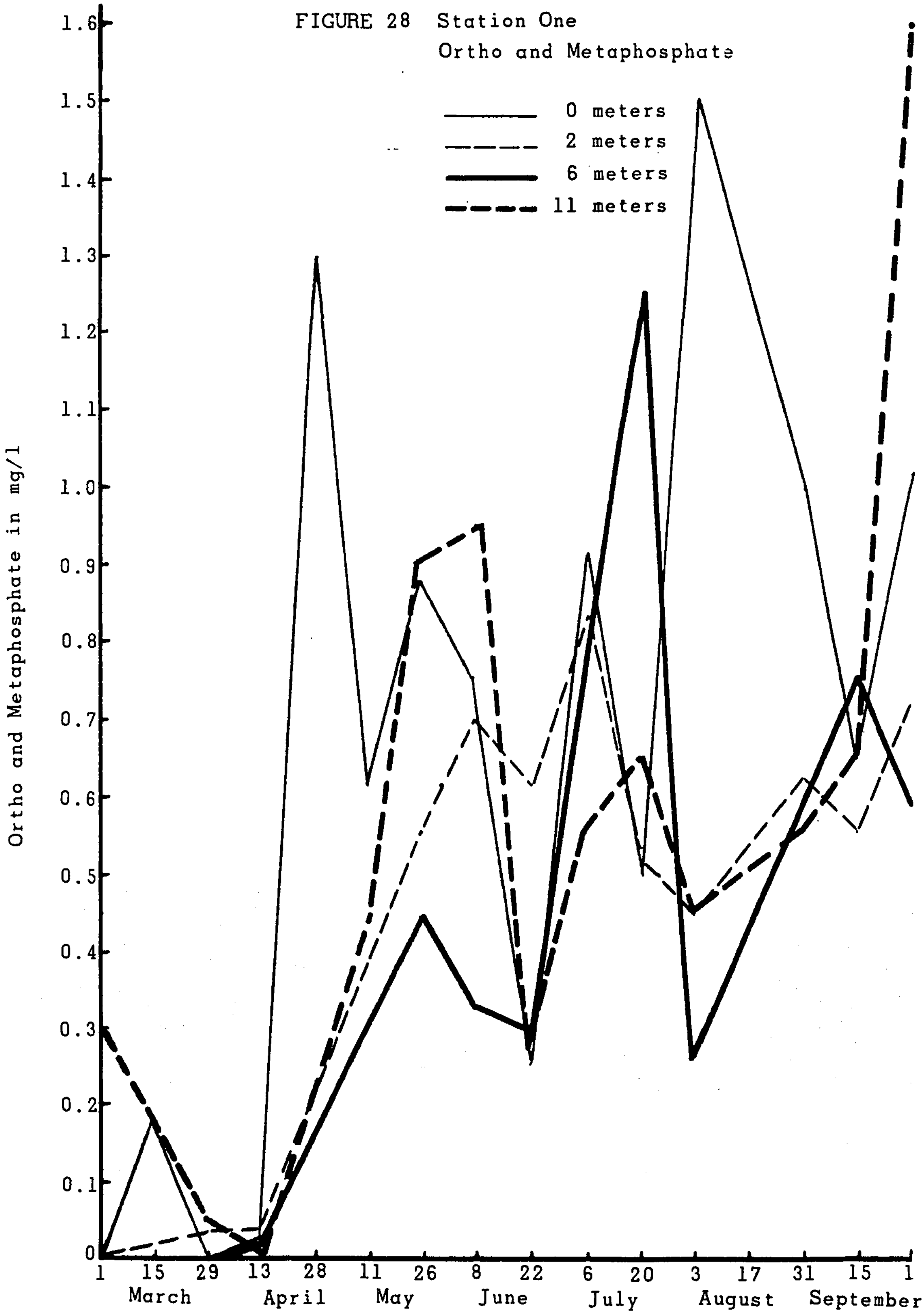


FIGURE 27 Station Three
Nitrate and Nitrite
0 meters
2 meters
6 meters
Nitrate plus Nitrite in mg/l
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

FIGURE 28 Station One
Ortho and Metaphosphate



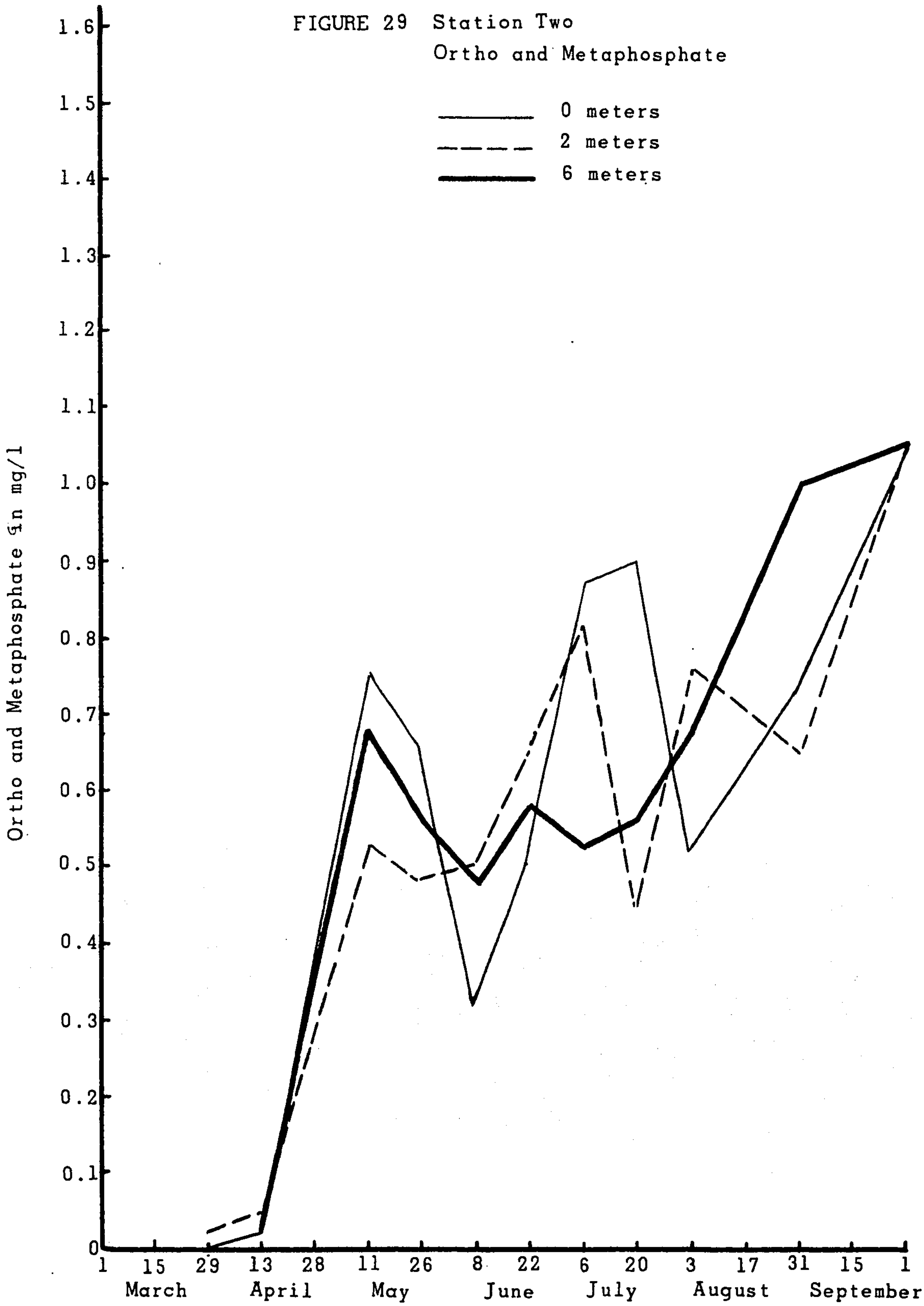


FIGURE 29 Station Two
Ortho and Metaphosphate
0 meters
2 meters
6 meters
Ortho and Metaphosphate in mg/l
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 15 29 13 28 11 26 8 22 6 20 3 17 31 15 1
March April May June July August September

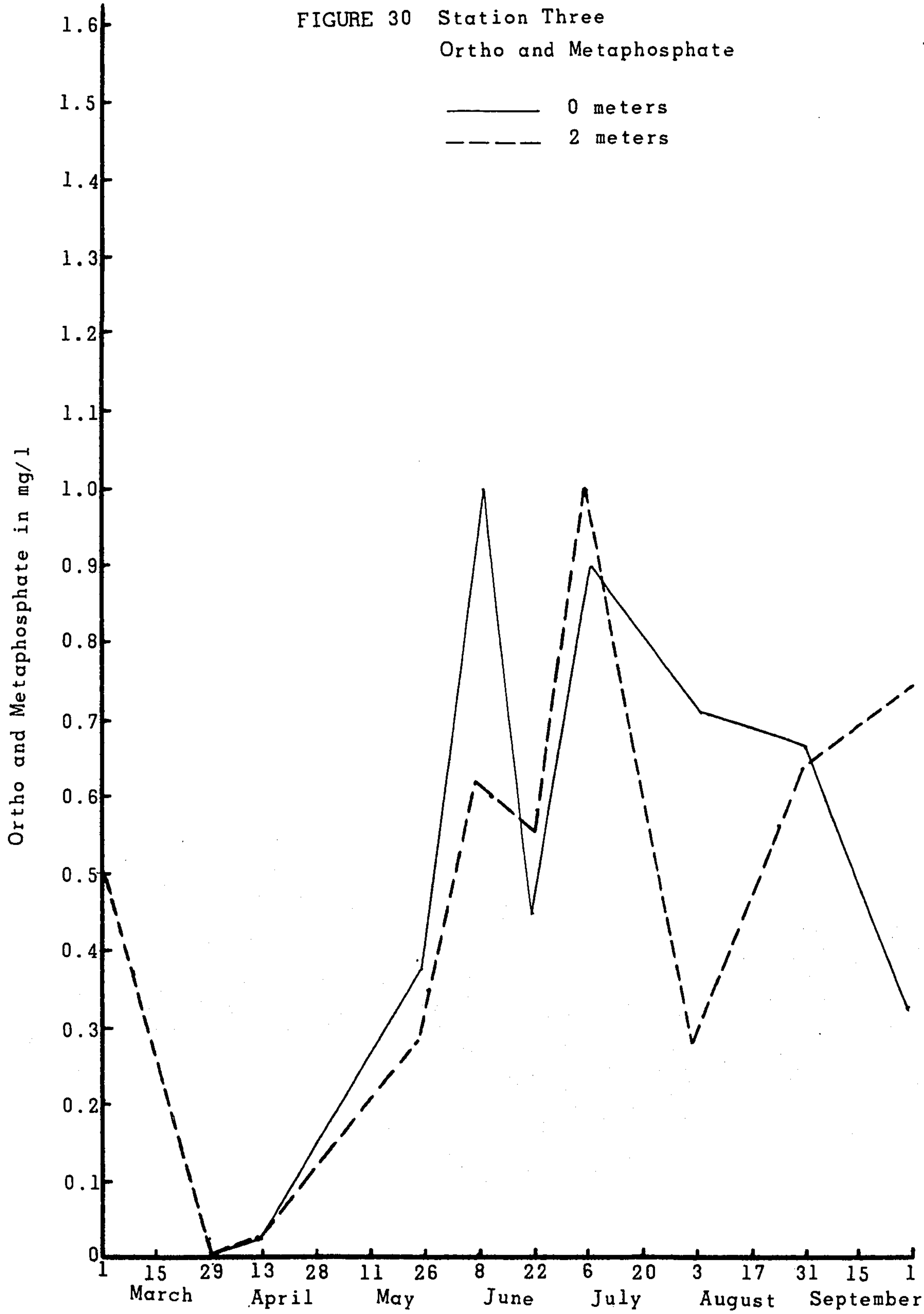


FIGURE 30 Station Three
Ortho and Metaphosphate

DISCUSSION

Lakes are a transitory feature of the landscape when considered on a geological time scale. Most large lakes have existed as such for only some thousands of years. The Great Lakes in North America have ages of less than 8,000 years. Loch Lomond, a large lake in Scotland, has existed for 11,000 years. In spite of their already long existence, life expectancies for the majority of the lakes in the world is still high. Most of the larger lakes will last another 20,000 years (Russell-Hunter, 1970).

As the size of a lake decreases, its life expectancy is rapidly reduced. Many small lakes in the world have already disappeared, being replaced in a series of successional stages first by swamps, then open clearings, and then forests of one kind or another. In lakes, the ageing process brought on by the enrichment of the waters with plant nutrients is called eutrophication.

Lakes low in plant nutrients and consequently having few plants, are geologically young and are called oligotrophic. Lakes high in plant nutrients and therefore high in aquatic plants are called eutrophic. The trend, of course, is toward eutrophy, but the rate is not necessarily constant.

After a lake is formed and undergoes an initial enrichment period, it establishes a trophic equilibrium. If a lake remains undisturbed, this trophic equilibrium can last for a long time. For example, Linsley Pond in Connecticut remained in this steady state for at least seven millenia (Hutchinson, 1973).

With the onset of settlement, however, the catchment area of the lake is disturbed. The cutting of trees, building of roads and overflow from septic tanks, etc., cause richer nutrient runoff into the lake until sooner or later a new steady state is established. Of course, if a new trophic equilibrium is never established then eutrophication continues until a lake as such, no longer exists.

Lake morphology plays an important role in the rate of eutrophication. A very small lake might develop into a bog or even dry land before the arrival of a trophic equilibrium. A large lake, on the other hand, could reach a trophic equilibrium, be disturbed, reestablish a new trophic equilibrium, and repeat this process many times before any noticeable change occurred. Most lakes, and especially those in southwestern Michigan, are somewhere along this continuum. They have been in a trophic equilibrium for many years. Now however, with increased residential use, the equilibrium is shifting and the lakes are becoming more eutrophic.

The extent to which eutrophy has developed in a given body of water can be estimated by studies of biological, chemical, and physical parameters coupled with an understanding of lake morphology.

Physical and chemical parameters are widely used for water quality standards. Data can be easily gathered and analyzed with a high degree of accuracy, and the results are often used as grounds for legal action.

Chemical and physical parameters, however, offer only a simplistic view of the total character of a lacustrine environment.

Chemical data fails to consider variations in concentration between samples or the wide variety of pathways nutrients follow through cycles. Physical parameters are not hard to standardize, but the data is often hard to interpret.

Indicator organisms offer a biological way of assessing the degree of eutrophy. It has long been known that certain organisms present and the size of their populations indicate the degree of eutrophication. Waters high in numbers of a single species are highly eutrophic. Furthermore, among the algae the blue-green algae are indicators of eutrophic waters (Rawson, 1956).

Biological populations are more sensitive to changes in the environment. Chemicals, in quantities not easily measured, will have drastic effects on the plankton community. The degree of eutrophication, however, cannot be quantified with indicator organisms. Organisms live not just when conditions are optimum but through a range of nutrient conditions. It is the total set of conditions, not just one, that causes the success or demise of an organism. Thus, with indicator organisms, trends can be seen but not quantified. Because of the advantages and disadvantages inherent in all approaches to water assessment a consideration of all chemical, physical and biological parameters is the only way to reasonably assess the degree of eutrophy in any lake.

The significant phytoplankton indicators in Wall Lake are the Chrysophyta: *Dinobryon divergens*, *Asterionella formosa*, and *Tabellaria sp.*, and the Cyanophyta: *Gleotrichia echinulata*, Anabaena flos-aquae, and Microcystis sp. The other algae present are important when diversity indices are considered since they reflect the overall stability of the community but their numbers are so much smaller and occurrence much less frequent that it is hard to say if they indicate nutrient rich or poor waters.

Rawson (1956) considered A. formosa, D. divergens and two species of Tabellaria to be indicators of oligotrophic waters. He noted however that presence or absence did not in itself indicate oligotrophic water but only high percentages of the phytoplankton count over much of the summer season. It would seem that as the waters became highly saturated with nutrients these golden algae would have a more restricted growing season, limited probably by silica.

It has long been known that phosphorous is responsible for enhanced utilization of silica in diatoms (Lund, 1969). Mackereth (1953) has shown that 1 microgram per liter of phosphorous can theoretically produce some 1.6×10^7 cells of Asterionella. Furthermore, Dinobryon has been reported blooming in concentrations up to 1 milligram of PO_4 - P per liter (Provasoli, 1969).

Apparently an increase in available phosphorous causes increased silica utilization in the vernal pulse until silica becomes limiting. A rapid die off occurs and, because of low silica, few diatoms are present throughout the summer.

Davis's (1964) work on Lake Erie would tend to support this view. From 1920 to 1963 he noted a change in the spring pulse from Asterionella to Melosira and a shift in the fall pulse, and perhaps this is the most significant shift, from Asterionella, Melosira, Synura to Fragillaria, Melosira, Anabaena, Oscillatoria, Synedra, and Stephanodiscus.

The degree of dominance of the blue-green algae in the Wall Lake ecosystem is hard to assess. Estimates of density reflect trichomes, platelets or colonies per milliliter rather than cells per milliliter. As a result, a strict comparison of blue-green density to golden density, or for that matter any other group of phytoplankton, is impractical. Similar problems would be encountered had biomass measurements been compared. Nevertheless even if viewed in a conservative sense, as colonies per milliliter, there can be no doubt that the blue-green algae, primarily Anabaena and Microcystis are significant plankters in the summer waters. The same is true of Gleotrichia. Even though no estimate of population size is available, its apparent density, as viewed from the surface, and its persistence for several weeks leaves little doubt as to its significance as a plankter.

For all the blue-green algae, concentrations are generally the same in the upper two meters of the water column. Greater fluctuations are noted in cell groups seen at lower levels (See Figures 11, 14, and 15). This was probably due to gradual disintegration of the cell groups as they slipped below the thermocline and the compensation level. Disintegration accounted for cell groups with fewer cells per group and hence an artificially higher population, in some cases, at the deeper regions.

It is interesting to note that coincidentally with the decrease in nitrate and nitrite, the blue-green algae began showing their summer upsurge. It is well known that many of the Cyanophyta can fix atmospheric nitrogen (Stewart, 1970) and this appears to be the case here.

Certain of these N_2 fixing blue-green algae, including Anabaena flos-aquae can produce toxic substances which can have deleterious effects on animals that drink water. Toxic strains of Anabaena flos-aquae can produce a toxin which can kill mice in one to two minutes after a lethal dose is administered (Prescott, 1968).

Gleotrichia echinulata is another blue-green alga that can fix atmospheric nitrogen. It too is noted as a noxious plankter when in significant numbers. Certain strains are known to cause symptoms in bathers similar to the "swimmers' itch" cercariae (Prescott, 1968).

Another type of indicator organism in aquatic environments is fecal coliform bacteria. Though fecal coliform does not indicate eutrophication per se, they are good indicators of water pollution by untreated sewage. Fecal coliform bacteria can enter a lacustrine environment either through overflow of septic tanks or directly through the feces of mammals. Because of these two avenues of input many samples must be taken before water quality can be characterized. Although the samples taken at Wall Lake at ten different sites throughout the summer were probably not enough to draw any firm conclusions, several of the samples had high fecal coliform densities and this would seem to indicate septic tank leakage and suggest further more extensive studies are needed to verify this observation.

The degree of eutrophication in Wall Lake indicated by the phytoplankton is also supported by the chemical data. Nitrogen and phosphorous have long been considered essential to organismic growth. In the aquatic ecosystem these two nutrients affect the day to day development through the season to the exclusion of almost all others. Since a lake acts as a sink for the surrounding land, phosphorous and nitrogenous compounds run off into waters and become trapped there.

Like most essential elements the nutrient cycle for both nitrogen and phosphorous is very complex. Turnover time in some parts of the cycle is very short.

Describing the concentration of any one compound must be done with some care. The phosphorous level is one parameter that has to be viewed cautiously. The large variations in concentration from elevation and from day to day as indicated in Figures 28, 29, and 30 probably are not that meaningful since turnover time for phosphorous is around 5 minutes between cells and inorganic phosphorous, and upwards of 3 days between higher plants, bacteria in the mud, and inorganic phosphate (Hayes and Phillips, 1958). If we accept the difficulties inherent in phosphate measurement and disregard the large variation, there still remains a definite upward trend to approximately 0.9 milligrams per liter.

Lund (1969) cited 3 milligrams per liter PO_4- P in the River Lee, 1.33 milligrams per liter in the Queen Elizabeth II Reservoir and 1.40 in King George VI Reservoir as examples of phosphorous concentration in eutrophic waters. At those sites he noted 40, 10 and 7 thousand diatoms per milliliter. Wetzel (1966) reported 1.5 to

3.0 milligrams per liter PO_4 in Sylvan Lake, a hypereutrophic lake in southern Indiana.

Quantities that large do not have to be present, however, to cause large growths of noxious algae. Schindler (1971) reported that in a lake that had been artificially fertilized with nitrogen and phosphorous Oscillatoria, Lyngbya, and Pseudoanabaena developed in water having only 3 to 16 micrograms per liter phosphorous.

It would seem unlikely that any single input into an ecosystem would bring about the same ecological response or at least to the same degree, in all bodies of water. Variations in phosphate level and quantities of algae will probably vary significantly from lake to lake. Nevertheless, the amount of phosphate present in Wall Lake and the kind of plankton present indicate a degree of eutrophication that is undesirable.

Nitrate and nitrite concentrations as shown in Figures 25, 26, and 27 indicate a rapid rise of inorganic nitrogen in the spring. This early increase to 7, 8, and 9 milligrams per liter was lake wide and could reflect fertilizer usage by lake residents in the spring. However, other possible sources of nitrogen are increased septic tank usage before sufficient sewage flora could develop to remove waste products, spring rains and runoff, and nitrogen fixing bacteria. After the initial rise, inorganic nitrogen diminished to near zero. This drop might indicate nitrogen is a limiting factor to some phytoplankton toward the end of the summer. Information on lacustrine nitrogen budgets and the significance of individual sources is very sparse (Brezonik, 1972).

In most cases the proximal cause of the nitrogen upsurge, and for that matter for the phosphorous upsurge, is largely speculation. A gross insult to the ecosystem from obvious sources such as a sewage treatment plant would be an exception. The distal cause however is almost certainly related to man and his population density around the lake.

The physical and morphometric data further point out the eutrophic nature of Wall Lake. The lake is a dimictic type that undergoes thermal stratification from the middle of May until the first of October. Much of the lake is above the thermocline and subject to circulation throughout the entire summer. In this portion of the lake, detritus is rapidly digested aerobically and the products circulated. The compensation point is nearly at the bottom for most of the lake so photosynthesis exceeds respiration throughout much of the water column. Many rooted aquatic plants can easily grow in such a situation and weed encroachment is likely to be an ever increasing problem for home owner.

The oxygen concentration is essentially zero below 7 meters, as shown in Figure 24, for most of the summer months. Only 14 percent of the total volume is below 7 meters of water and one thing this would indicate is that the lake can only support the more tolerant warm water fishes.

Apparent color, as measured in Platinum-cobalt units can vary from zero in very clear lakes to as high as 300 units in very dark waters of bog communities (Reid, 1961). Color of water is derived from substances in solution or from materials in collodial state as well as interplay of light on suspended particulate materials together with factors such as reflection from lake bottom or lake surface.

Turbidity on the other hand is a measure of the opaqueness of the water. It is not a uniform parameter even within a lake. (Reid, 1961). Taken together with color and percent transmittance, it can however indicate the amount of suspended substances as well and planktonic and triptonic matter in the water.

True color in Midge and Mary lakes, two bog lakes in Wisconsin, are 29 and 123 Pt-Co units respectively (Birge, in Reid, 1961). Apparent color at Wall Lake as expected is somewhat higher because of extra substances present in the water. In spite of the color and the concentration of plankton, Secchi disk transparencies seem quite high. Figure 24 indicates values were never less than 2.28 m. even during the height of the summer. Lake Washington by comparison had measurements as little as 1.5 meters during the highest point in sewage diversion (Edmondson, 1973). Reid (1961) reported that Lake Texoma on the Texas-Oklahoma border had values of only a few centimeters. Schindler (1971) observed an artificially fertilized lake that had a visibility of 0.7 to 0.95 meters after nutrients were applied.

The phytoplankton, chemistry, and physical data and lake morphology all point toward eutrophy of Wall Lake. The rate of eutrophy cannot be discerned until data from coming years is obtained. However, it is obvious that as long as the population density increases in the Wall Lake drainage basin, and no attempt is made to curb nutrient input, the lake will respond with increases in phytoplankton and increases in weeds.

If the inflow of nutrients is cut off a certain degree of recovery can be expected. The rate of recovery is dependent upon the depth of the lake and the rate of water replacement. Stone Lake in Indiana, a relatively shallow lake with a retention time of 11 years, failed to show an immediate improvement for the first 5 years after sewage diversion (Edmondson, 1973). Because of the shallowness of Wall Lake and the slow rate of flow at its outlet it would seem unlikely that recovery here would be any quicker.

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