Spring 1977

Effect of Deforestation by the Douglas-Fir Tussock Moth on the Quality of Streamflow and Stream Productivity Parameters

Martin Ed Hicks
Central Washington University

EFFECT OF DEFORESTATION BY THE DOUGLAS-FIR TUSSOCK MOTH ON THE QUALITY OF STREAMFLOW AND STREAM PRODUCTIVITY PARAMETERS

A Thesis

Presented to

the Graduate Faculty

Central Washington State College

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

Martin Ed Hicks

May, 1977

APPROVED FOR THE GRADUATE FACULTY

_____

Robert E. Pacha, COMMITTEE CHAIRMAN

_____

Thomas H. Thelen

_____

Robert L. Brown

EFFECT OF DEFORESTATION BY THE DOUGLAS-FIR TUSSOCK MOTH ON THE QUALITY OF STREAMFLOW AND STREAM PRODUCTIVITY PARAMETERS

by

Martin E. Hicks

May, 1977

The purpose of this study was to determine if deforestation by a recent outbreak of Douglas-fir tussock moth and logging of such deforested timber has had any effect on stream water quality. To determine this, seven different watersheds of three types were examined. The three types were: undamaged watersheds as controls, watersheds with deforestation and watersheds with deforestation where the timber was subsequently logged. Twenty-four variables were used to determine water quality. Included were seven biological and seventeen chemical variables.

In general, the results indicate only seasonal fluctuations and differences between watersheds due to inherent properties of individual watersheds. Increased turbidity levels were detected on logged watersheds which could be correlated with the logging activities.

ACKNOWLEDGEMENT

This study was funded by the U. S. Department of Agriculture Douglas-fir tussock moth program, under a research contract (#19-239) and in a cooperative aid study between the U. S. Forest Service Forest Hydrology Laboratory, Wenatchee, Washington, and Central Washington State College, Ellensburg, Washington.

I wish to express special thanks to Dr. D. B. Swanger, Dr. R. E. Pacha, Dr. R. H. Brown, Dr. T. H. Thelen, and Dr. A. R. Tiedemann for their time, judgment and advice during this study. In addition, I would like to thank Dr. S. D. Smith, who advised me as an undergraduate as well as during my graduate study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The recent infestation of Douglas-fir tussock moth in eastern Oregon resulted in major deforestation in areas of the Umatilla National Forest. Research has demonstrated that deforestation of more than 25 percent results in increased runoff from the deforested watersheds (8). A study by Bethlahmy (2) on a watershed in Colorado with 30 percent deforestation, due to a bark beetle epidemic, showed that runoff had not returned to normal yield after 25 years. This demonstrates a long term effect on runoff. No attempts were made in these studies to determine if the increased runoff effected water quality.

Helvey (5,6,7) reported a 50 percent increase for 1971 and a 400 percent increase for 1972 in water yield after all vegetation on three watersheds in North-Central Washington was destroyed by wildfire. In addition, Tiedemann and Helvey (15,16) observed that the concentration of nitrate nitrogen in the water increased during the first and second year following the fire. However, no attempts were made to determine effects on water quality using other parameters.

With the Douglas-fir tussock moth deforestation, damaged timber is often removed by salvage logging operations. These operations may cause additional alterations in water quality by disruption of soil structure (9).

Disruption of soil structure may hasten erosion, leading to increased turbidity (9), as well as allowing for increased removal of nutrients from the soil (3,12,13), therefore increasing nutrient concentration in surface and ground waters.

Because of the effects of deforestation on water yield and on water quality it is possible that deforestation by Douglas-fir tussock moth and subsequent salvage logging may cause changes in water yield and quality. This study was designed to investigate this possibility. For this purpose three different types of watersheds were used for analysis. These included unaffected watersheds as controls, watersheds defoliated by the tussock moth, and watersheds defoliated by the tussock moth with subsequent salvage logging operations. Both chemical and microbiological parameters were studied for determination of water quality.

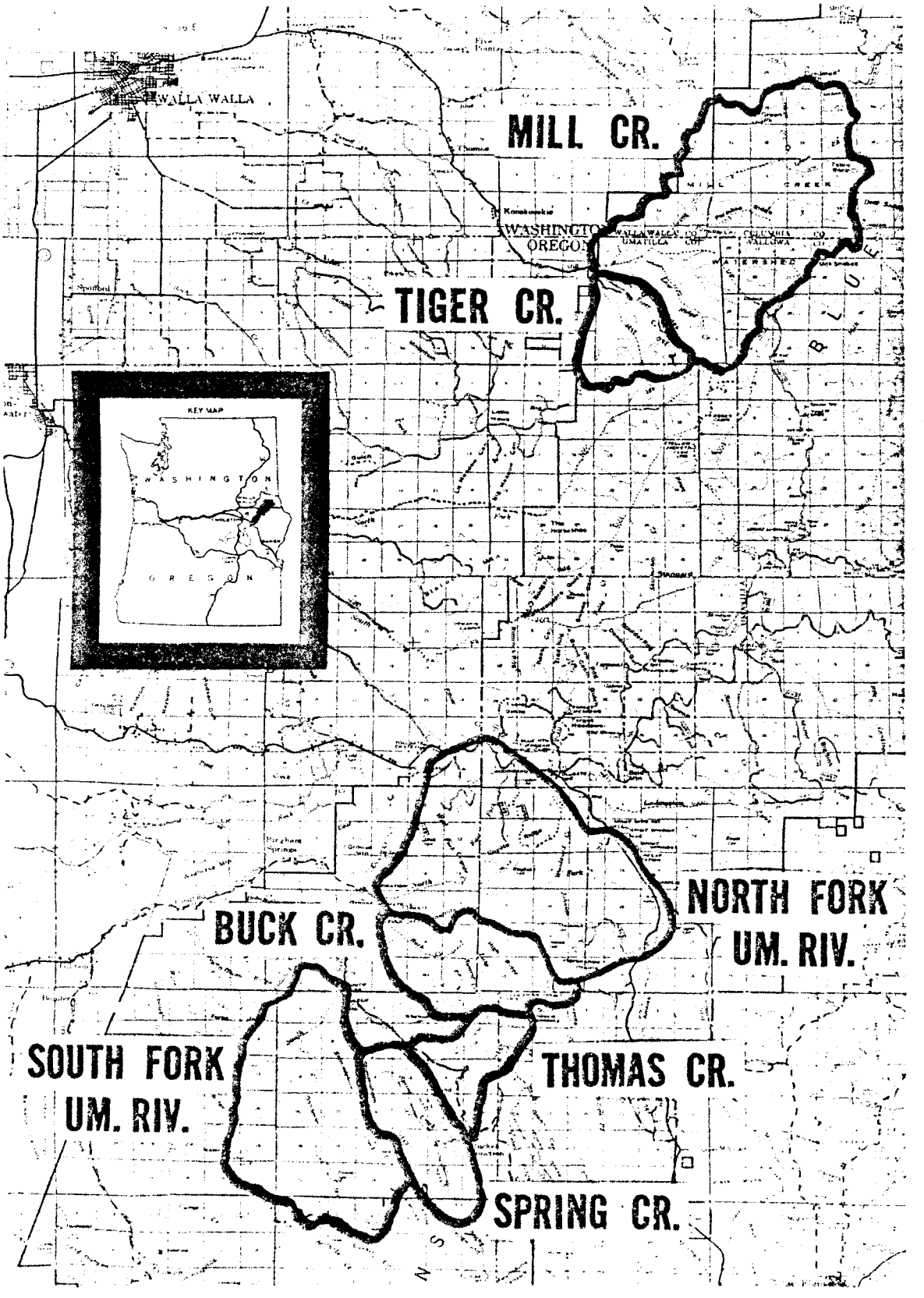
SITE DESCRIPTION

The experimental watersheds used in this study were selected using three criteria. First, the watersheds had to possess a year around stream. Second, the sampling point on each stream had to be accessible for sampling throughout the winter. Third, each stream had to be close enough to the laboratory (Ellensburg, Washington) to allow for a maximum transit time at four degrees centigrade of 6 hours. Seven experimental watersheds were selected which satisfy each of these conditions.

The seven streams selected lie in two different areas on the western slope of the Blue Mountains, east of Pendleton, Oregon in Umatilla County (Figure 1, Willamette Principal Meridian). Five of these watersheds, Buck Creek, Spring Creek, Thomas Creek, South Fork Umatilla River and North Fork Umatilla River, are part of the Umatilla River drainage system. The remaining two watersheds are Mill Creek and one of its tributaries, Tiger Creek. The Mill Creek drainage area is approximately 17 miles north of the Umatilla River system (Figure 1).

The North Fork of the Umatilla River and Mill Creek were selected as control watersheds. The North Fork is a large drainage of approximately 18,000 acres, with a few summer cabins and a small skiing resort high in the drainage. There are a few isolated areas of tussock moth defoliation within the watershed centered along Coyote Creek, which accounts for less than 1 percent of the watershed. Samples were collected approximately one quarter mile upstream from the North Fork campground (R.37E., T.3N., Section 22, NW corner). The second control, Mill Creek, is also a large drainage of approximately 22,000 acres. There is no apparent tussock moth defoliation within the watershed. The Mill Creek drainage is fenced off from public access since it serves as the City of Walla Walla's domestic water supply and therefore is relatively undisturbed. Samples were taken approximately fifty feet upstream from where FS Road N 62 crosses the creek (R.38E., T.6N., Section 21, NE corner).

FIG. 1 Map showing location and relative size of watersheds studied


WALLA WALLA
MILL CR.
TIGER CR.
KEY MAP
WASHINGTON
OREGON
BUCK CR.
NORTH FORK
UM. RIV.
SOUTH FORK
UM. RIV.
THOMAS CR.
SPRING CR.

Spring Creek, Buck Creek and the South Fork of the Umatilla River were selected as tussock moth deforested watersheds. Spring Creek is a watershed encompassing approximately 5600 acres. Spring Creek has scattered defoliation throughout the watershed with more concentrated defoliation along the ridges, which accounts for about ten percent of the watershed being affected. Samples were collected approximately fifty feet upstream from its confluence with Thomas Creek (R.37E., T.2N., Section 10, SW corner). The second affected watershed, Buck Creek, is a slightly larger watershed of approximately 7200 acres. There is no deforestation on the main stream of Buck Creek but scattered deforestation exists on several tributaries. Samples were collected approximately 300 yards upstream from its confluence with the South Fork of the Umatilla River (R.37E., T.3N., Section 22, SW corner). The third affected watershed, the South Fork of the Umatilla River, is a much larger watershed of approximately 18,000 acres. No major defoliation exists along the main branch of the South Fork but there is scattered deforestation along one of its primary tributaries, Shimmiehorn Creek. This defoliation accounts for approximately five percent of the watershed being affected. Samples were collected approximately one quarter mile upstream from its confluence with Thomas Creek (R.37E., T.2N., Section 5, N center). A concession had to be made to use watersheds with low percentage defoliation as affected streams, rather than a

minimum thirty percent as originally intended since those streams with more defoliation and year around access were being logged.

Thomas and Tiger Creeks were selected as defoliated watersheds which were subsequently logged. Thomas Creek encompasses approximately 3500 acres and 30-40 percent of the watershed has been deforested by the tussock moth. Extensive salvage logging has been carried out in the upper drainage. Samples were collected approximately fifty feet upstream from its confluence with Spring Creek (R.37E., T.2N., Section 10, SW corner). The second defoliated watershed which has subsequently logged, Tiger Creek, is a slightly larger watershed of approximately 4600 acres. Extensive defoliation occurred throughout the watershed accounting for approximately forty percent of the watershed being deforested and subsequently logged. Samples were collected approximately 100 yards upstream from its confluence with Mill Creek (R.38E., T.6N., Section 21, NE corner).

METHODS

Studies have established that bacterial numbers in streams follow a diurnal cycle (11). Therefore the sampling times were kept constant to minimize variation due to the cycle. Collections were made between 0700 and 1200 using 1000 ml sterilized, polypropylene bottles. The water samples were packed in ice immediately and transported to Ellensburg, Washington for laboratory analysis. Aliquots

of water for those chemical analysis which did not have to be conducted within 24 hours were preserved and stored in accordance with procedures outlined in Standard Methods for the Examination of Water and Wastewater (13th Edition)(1) and Manual of Methods for Chemical Analysis of Water and Wastes (17).

Chemical and microbiological analysis were conducted in accordance with procedures outlined in Standard Methods for the Examination of Water and Wastewater (13th Edition) (1) and Manual of Methods for Chemical Analysis of Water and Wastes (17). Briefly the analyses were carried out as follows:

Temperature - Water temperatures were measured at each sample site in degrees centigrade at the time of sampling. The measurements were made using a mercury thermometer enclosed in a metal field case.

pH - The pH of each water sample was determined immediately after the samples were returned to the laboratory. No attempt was made to determine pH in the field due to a time limit on several of the microbiological tests and the long transport time to the laboratory. All measurements were made with a Beckman Century SS-1 dual electrode pH meter.

Alkalinity - A 100 ml unaltered aliquot from each stream was titrated with approximately 0.02 N H_2SO_4 to an electrometrically determined end point of pH 4.5. Alkalinity determinations were made a few hours after sampling. Sample

bottles were not opened until just prior to titration. Total alkalinity is expressed as mg/l $CaCO_3$.

Specific Conductance - The conductance of each water sample was determined using a Yellow Springs Instrument Co. (YSI) Model 31 Conductivity Bridge. The conductance was measured in micromho/cm at 25°C.

Turbidity - The turbidity of each sample was determined in Jackson Turbidity Units (JTU) by using a Hach 2100 turbidometer. This instrument compares the intensity of the light scattered by a water sample under defined conditions with the intensity of light scattered by a reference standard.

Filterable Sediment - One liter of water from each stream was filtered through oven dried (105°C), pre-weighed, Whatman #1 filters (5.5 cm. diameter). The filters and residue were then oven-dried again at 105°C. The sediment was determined by the weight difference and reported as mg/l.

Ammonia Nitrogen - A 50 ml portion of water was mixed with 5 ml of phenol reagent (0.106 M phenol and 0.0017 M sodium nitroprusside) and 5 ml hypochlorite reagent (0.125 M NaOH and 0.04% sodium hydrochlorite) and then placed in a 37°C water bath for 1.5 hours. The intensity of the resultant blue color was determined spectrophotometrically at 660 nm and the ammonia concentrations determined by comparison to a standard curve. The results are reported as mg NH_4-Nitrogen/l.

Kjeldahl Nitrogen (Organic) - A 250 ml aliquot from each sample was boiled for approximately ten minutes to remove ammonia. After cooling, 10 ml. concentrated sulfuric acid, 10 ml 10% sodium chloride and 1.0 ml 1% copper sulfate were added and the samples heated for approximately 40 minutes. The resulting solution was cooled and then diluted with 250 ml distilled water. This solution was then made alkaline with the addition of 50 ml 10 N sodium hydroxide. The ammonia was distilled off, trapped in CO_2-free distilled water and quantified as described for ammonia nitrogen. Results are reported as mg Kjeldahl-Nitrogen/l.

Nitrite Nitrogen - A 30 ml portion of water was mixed with 1 ml of 0.058 M sulfanilimide and 1 ml 0.0038 M N-(1-napthyl)-ethylenediamine-di-hydrochloride. The resultant red color was quantified spectrophotometrically at 540 nm and the nitrite concentration was determined by comparison with a standard curve. The results are reported as mg NO_2-Nitrogen/l.

Nitrate Nitrogen - A 50 ml sample was passed through a cadmium-copper column in order to reduce any nitrate present to nitrite. The nitrite determination as previously described was then conducted on a 30 ml portion of column effluent. The nitrate is then determined by the difference between the reduced and unreduced samples and reported as mg NO_3-Nitrogen/l.

Orthophosphate - Fifty ml of water from each sampled site was thoroughly mixed with 8 ml of a solution containing

50 ml 5N H_2SO_4, 5 ml 0.0082 M potassium antimonyl tartrate, 15 ml 0.032 M ammonium molybdate and 30 ml ascorbic acid. The resulting color which develops after 15 minutes was quantified using a Klett photometer with a red filter at 660 nm. Concentrations were determined from a standard curve and reported as mg Orthophosphate/l.

Total Phosphate - Fifty ml of water was heated for 30 minutes with 0.4 g ammonium persulfate and 1 ml of 11 N H_2SO_4. An orthophosphate determination as described above was run on the sample after bringing the volume back to 50 ml. The results are reported as mg Total phosphate/l.

Sulfate - Sulfate was determined turbidimetrically. A small quantity of barium chloride was added to 100 ml of water and mixed for 1 minute. The turbidity of the resulting barium sulfate precipitate was measured with a spectrophotometer at 420 nm. The results are reported as mg SO_4/l.

Cations - Sodium, Potassium, Calcium and Magnesium - The levels of sodium and potassium in all water samples were determined by atomic emission spectrophotometry while the levels of calcium and magnesium were measured by atomic absorbance spectrophotometry. These tests were conducted using an Instrumentation Laboratory Model IL 251 AA/AE Spectrophotometer.

Total and Psychrotrophic Bacteria - The levels of total and psychrotrophic bacteria in all streams were measured by pour plating an appropriate dilution of each sample onto nutrient agar. Total bacteria plates were incubated

at 25°C and counts were made after 96 hours of incubation. Plates for determination of psychrotrophs were incubated for 2 weeks at 5°C.

Total Coliforms, Fecal Coliforms and Fecal (Group-D) Streptococci - The numbers of these organisms present in each stream were quantified by filtering appropriate volumes of water through sterile Gelman GN-6 membrane filters and incubating the filters on m-Endo broth, m-FC broth and m-Enterococcus agar respectively. The total coliform and fecal streptococci plates were incubated at 35°C and the fecal coliform plates were incubated at 44.5°C $\pm$ 0.2°C. Plate counts for total and fecal coliforms were done after 24 hours and counts for fecal streptococci after 48 hours.

Actinomycetes and Fungi - Determinations of the numbers of these two groups of organisms were made by pour plating several ml of water from each sample onto chitin agar (10) and rose bengal agar (0.3 g KH_2PO_4, 0.15 g $MgSO_4 \cdot 7H_2O$, 1.50 g peptone, 3.0 g glucose, 6.0 g agar, 0.3 ml of 3.3% rose bengal solution, 300 ml distilled H_2O) respectively. The plates were incubated at 25°C and colonies were counted after 5 days incubation.

Statistical Analysis - A one-way analysis of variance was performed on the data using a CDC 6400 computer at the University of Washington, Seattle. The program used was one of the Statistical Package for the Social Sciences (SPSS) programs available within the CDC 6400. This program enables the user to run multiple comparisons using one or

several different procedures. Tukey's method of multiple comparisons was used in this study.

RESULTS AND DISCUSSION

The seven watersheds studied were very high quality, oligotrophic waters. Table 1 compares the mean values for all watersheds to the North American average (4). This table shows that for all variables, except sulfate, the watersheds studied had a lower mean than the North American average. This emphasizes the point that the watersheds studied were oligotrophic waters. The fact that the values for the watersheds studied are lower than the North American average is even more important considering that the values for the North American average were first published in 1924 (4). These values have undoubtedly risen in the last 50 years with increased domestic and industrial useage of water. In addition, all seven watersheds are classified AA Extraordinary (highest classification) using Washington State health standards for interstate drinking water. To receive this classification the watershed must meet the following criteria: total coliform organisms shall not exceed median values of 50 with less than 10% of samples exceeding 230 when associated with any fecal source, water temperature shall be less than 15.5^{o}C, pH shall be within the range of 6.5-8.5 with an induced variation of less than 0.1 units, and turbidity shall not exceed 5 JTU. Apparently tussock moth deforestation and subsequent salvage logging

Table 1

Comparison of Mean Concentration With North American Average

	Controls		Affected			Affected and Logged		North American Average
	No. Fk. Umatilla River	Mill Creek	Spring Creek	So. Fk. Umatilla River	Buck Creek	Thomas Creek	Tiger Creek	
Total Coliforms #/100 ml	42	44	42	66	41	48	70	--
Fecal Coliforms #/100 ml	5	3	2	2	1	1	3	--
Fecal Streptococci #/100 ml	9	22	10	12	11	7	30	--
Water Temperature ^{o}C	7.6	7.3	6.3	6.9	7.1	6.7	7.6	--
Filterable Sediment mg/l	1.8	1.6	1.0	2.4	1.9	2.1	2.3	--
Total Bacteria #/ml	322	566	294	204	368	351	621	--
Psychrotrophic Bacteria #/ml	89	198	82	69	132	100	240	--
Actinomycetes #/ml	4	3	4	2	3	3	5	--
Fungi #/ml	4	4	3	3	3	3	4	--
pH	7.68	7.75	7.46	7.49	7.62	7.23	7.56	--

Table 1 Continued

	Controls		Affected			Affected and Logged		North American Average
	So. Fk. Umatilla River	Mill Creek	Spring Creek	So. Fk. Umatilla River	Buck Creek	Thomas Creek	Tiger Creek	
Specific Conductance micromho/cm	64.8	60.8	46.1	48.7	63.4	48.2	52.2	--
Alkalinity mg $CaCO_3$/l	69.3	66.3	51.9	53.6	66.9	54.3	55.1	--
Kjeldahl Nitrogen mg/l	0.17	0.18	0.20	0.20	0.21	0.18	0.20	--
Nitrate Nitrogen mg/l	0.02	0.05	0.002	0.003	0.01	0.004	0.05	1.2
Ammonia Nitrogen mg/l	0.0004	0.0005	0.0005	0.0004	0.0005	0.0006	0.0005	--
Turbidity JTU	1.7	1.6	2.8	1.9	2.2	4.8	3.9	--
Total Phosphate mg/l	0.04	0.04	0.02	0.02	0.03	0.03	0.03	0.07
Ortho Phosphate mg/l	0.04	0.04	0.02	0.02	0.03	0.02	0.02	
Sulfate mg/l	28.9	21.6	25.9	23.1	39.5	30.5	28.1	15.0
Calcium mg/l	8.2	7.1	6.9	5.8	7.5	5.7	6.0	19.0
Magnesium mg/l	2.2	2.5	1.9	1.8	2.5	2.0	2.2	4.9
Potassium mg/l	1.3	1.8	1.3	1.5	1.6	1.6	1.3	1.8
Sodium mg/l	4.3	2.8	2.3	3.1	4.0	2.5	2.4	7.5

operations have not seriously degraded water quality since all watersheds can still receive this high classification.

Due to the large volume of data collected by this study one of the simplest and most informative methods of displaying the data was by plotting value ranges for each month. The mean was calculated using the values from all seven watersheds for that month. In this way the graphs display the monthly range of values, and the seasonal fluctuation which occurred for most variables during the study period. Seasonal fluctuations demonstrated different patterns depending on the variable in question. One of the simplest patterns is demonstrated by water temperature which displays highs in the summer and lows in the winters, reflecting general climatic changes. Most of the variables display such seasonal fluctuations, especially microbiological variables, in response to general climatic changes. Intuitively a narrow range would indicate no difference between the watersheds for that month. A consistently narrow range over the entire study period would indicate no difference for that variable. A consistently wide range would indicate that at least some of the watersheds may be different. In addition, this would mask the seasonal fluctuation exhibited for most variables.

Of the twenty-three variables investigated, eleven: total coliforms, fecal coliforms, fecal streptococci, water temperature, filterable sediments, psychrotrophic bacteria, actinomycetes, fungi, kjeldahl nitrogen, ammonia nitrogen

and calcium (Figures 2-12) showed consistently narrow ranges throughout the study period. The remaining twelve variables exhibited relatively large ranges over most of the study period. To determine if these wide ranges did indeed indicate a difference between at least some of the watersheds, the data for each variable were analyzed statistically using a one-way analysis of variance. This analysis indicated whether any significant difference existed between any of the watersheds for each parameter studied. If the analysis of variance indicated a difference the data were then analyzed using Tukey's multiple comparisons. This permits the determination of which watersheds are significantly different for that variable.

All twenty-three variables were analyzed using the one-way analysis of variance. Since nitrite nitrogen, although tested for, was never detected in any of the watersheds, it was not analyzed statistically. Of the twenty-three variables analyzed, eleven: total coliforms, fecal coliforms, fecal streptococci, water temperature, filterable sediments, psychrotrophic bacteria, actinomycetes, fungi, kjeldahl nitrogen, ammonia nitrogen and calcium (Figures 2-12) showed no significant difference. These eleven variables also exhibited consistently narrow ranges throughout the study period. The statistical analyses thus support the intuitive observations discussed above. The other twelve variables will be discussed in detail below.

FIG. 2 Monthly ranges and means of total coliforms, July 1975 to December 1976

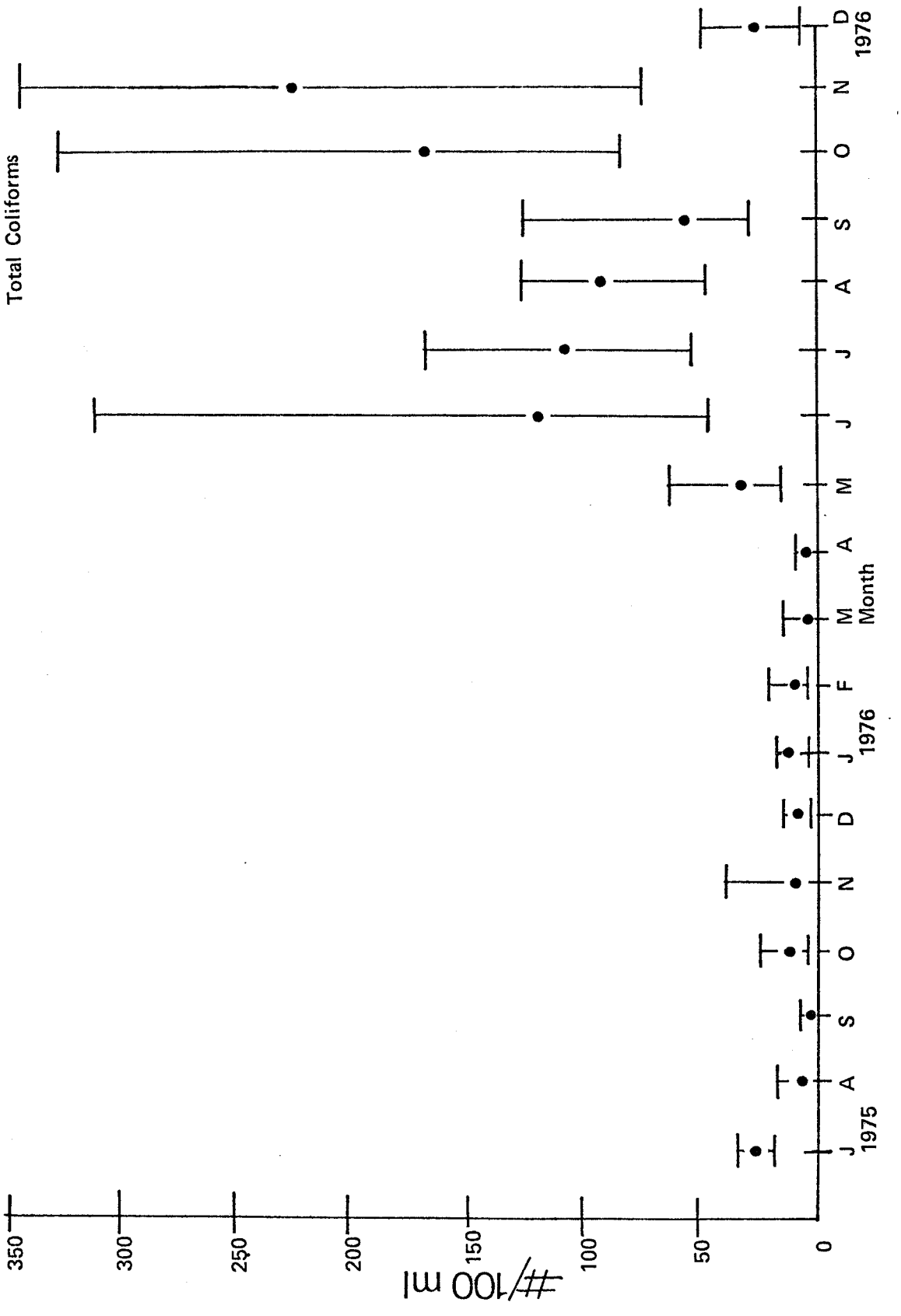

Total Coliforms
#/100 ml
350
300
250
200
150
100
50
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
1975
1976
Month

FIG. 3 Monthly ranges and means of fecal coliforms, July 1975 to December 1976

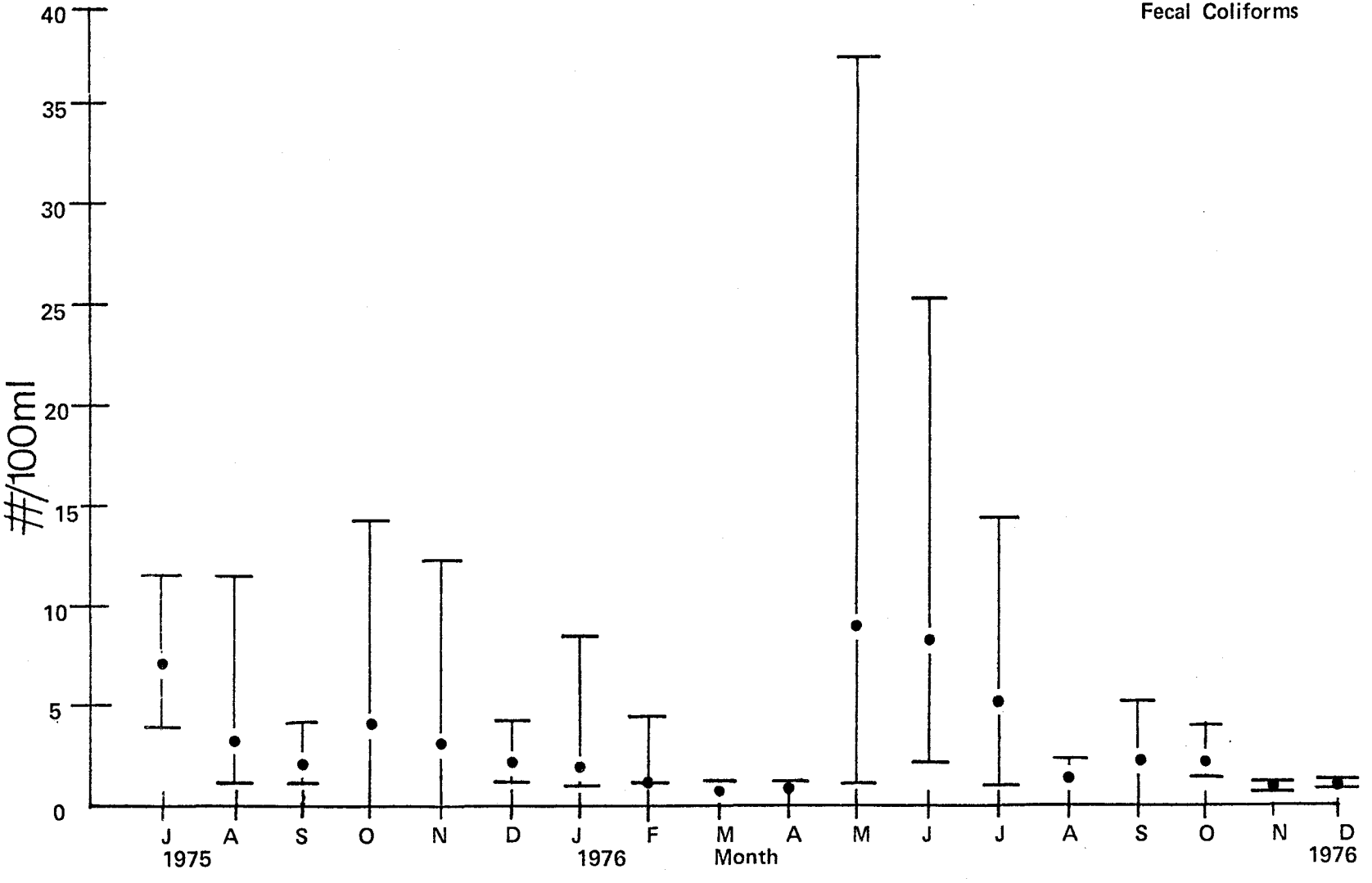

Fecal Coliforms
#/100ml
40
35
30
25
20
15
10
5
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month
1976

FIG. 4 Monthly ranges and means of fecal (Group-D) streptococci, July 1975 to December 1976

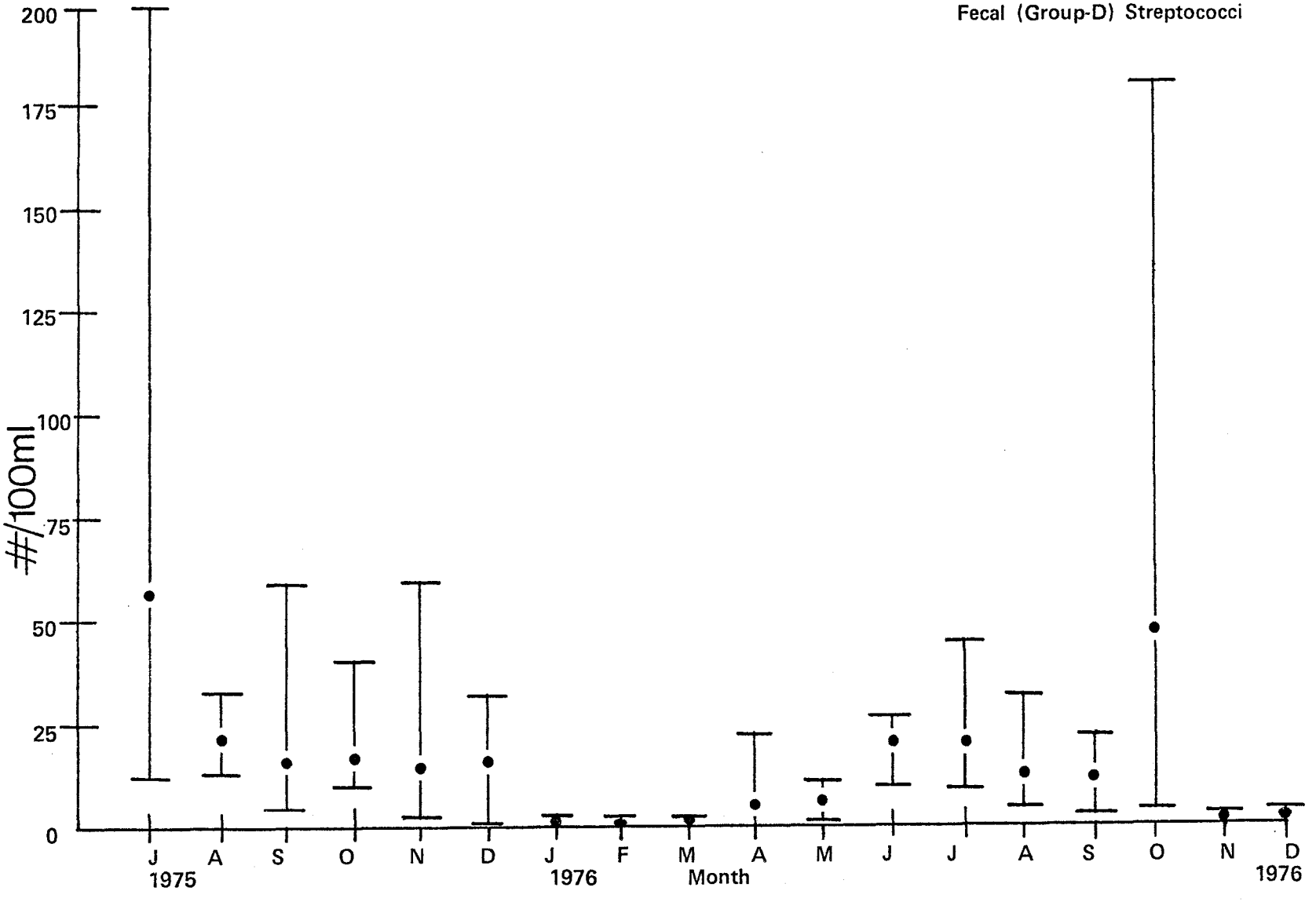

Fecal (Group-D) Streptococci
200
175
150
125
100
75
50
25
0
#/100ml
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month
1976

FIG. 5 Monthly ranges and means for water temperature, July 1975 to December 1976

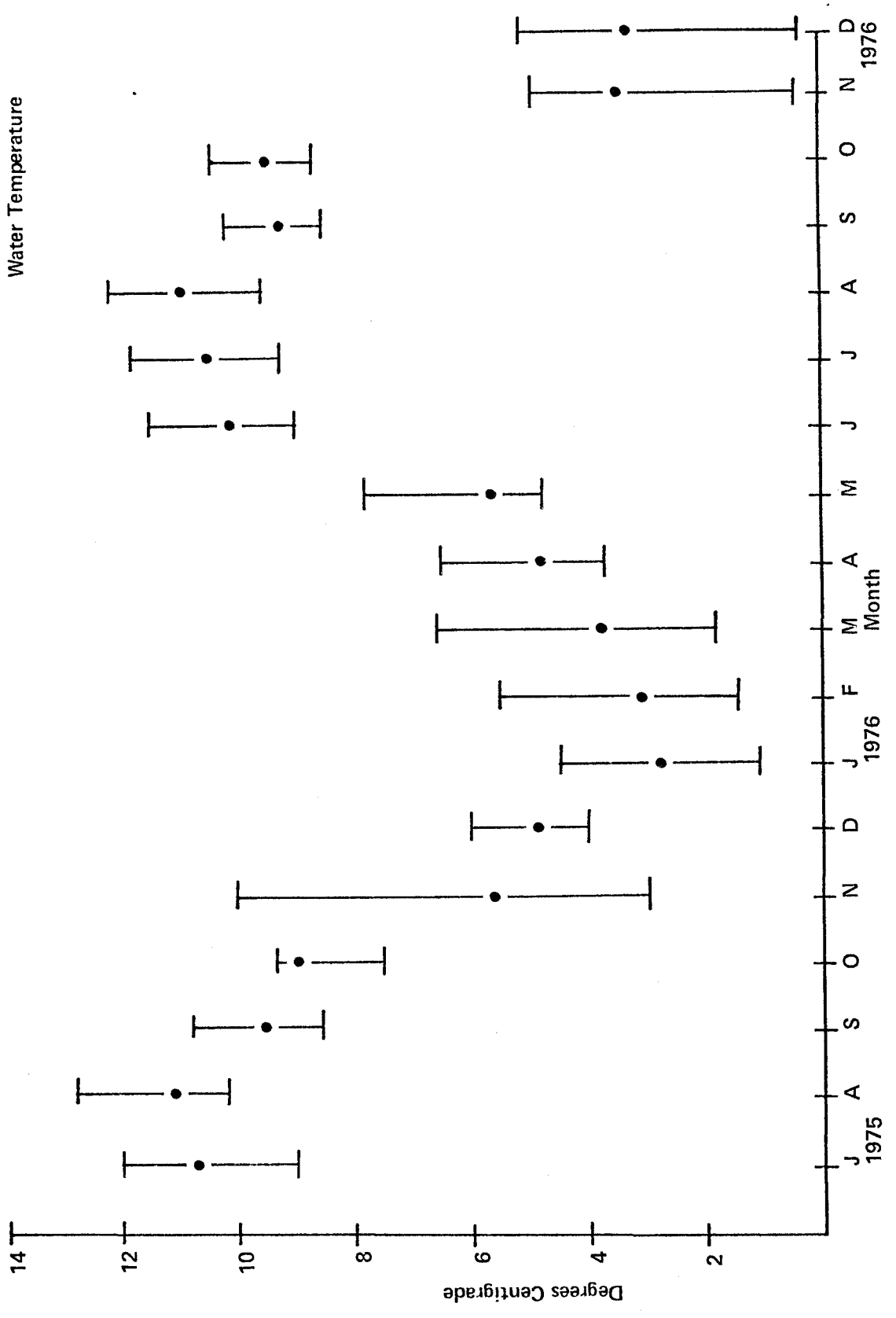

Water Temperature
Degrees Centigrade
14
12
10
8
6
4
2
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month

FIG. 6 Monthly ranges and means of filterable sediment, September 1975 to December 1976

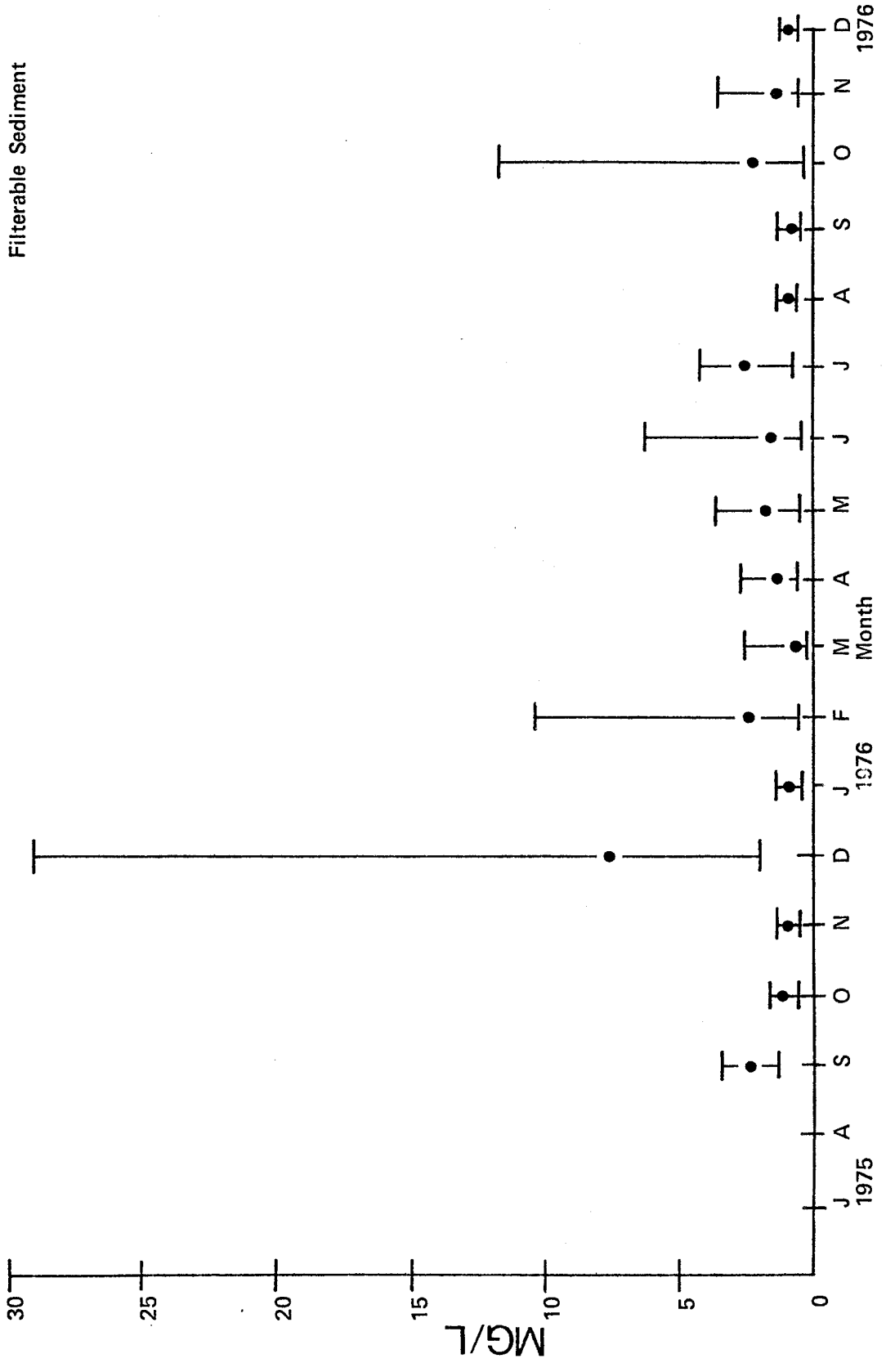

Filterable Sediment
MG/L
30
25
20
15
10
5
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month

FIG. 7 Monthly ranges and means of psychrotrophic bacteria, September 1975 to December 1976

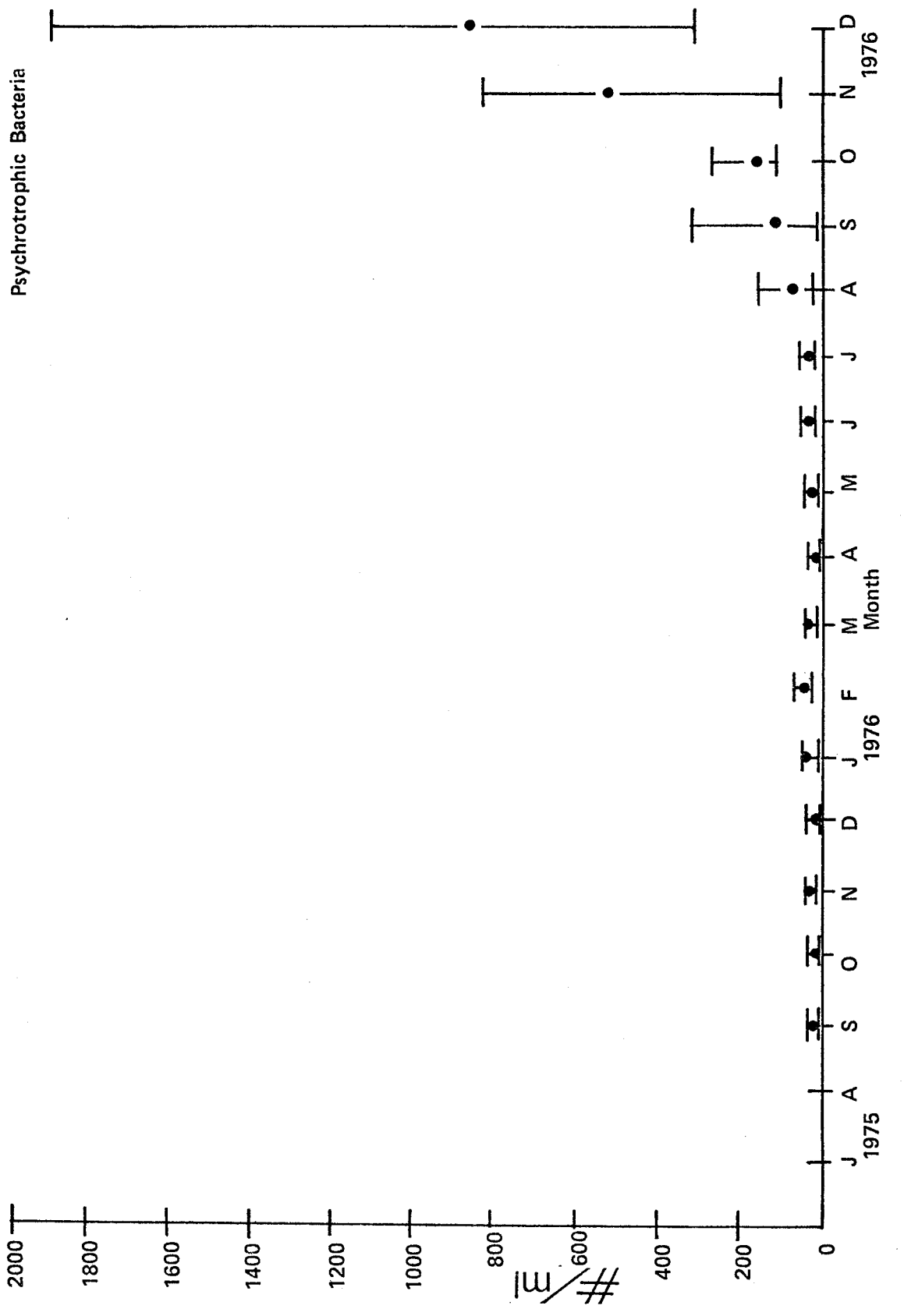

Psychrotrophic Bacteria
#/ml
2000
1800
1600
1400
1200
1000
800
600
400
200
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
1976
Month

FIG. 8 Monthly ranges and means of actinomycetes, July 1975 to December 1976

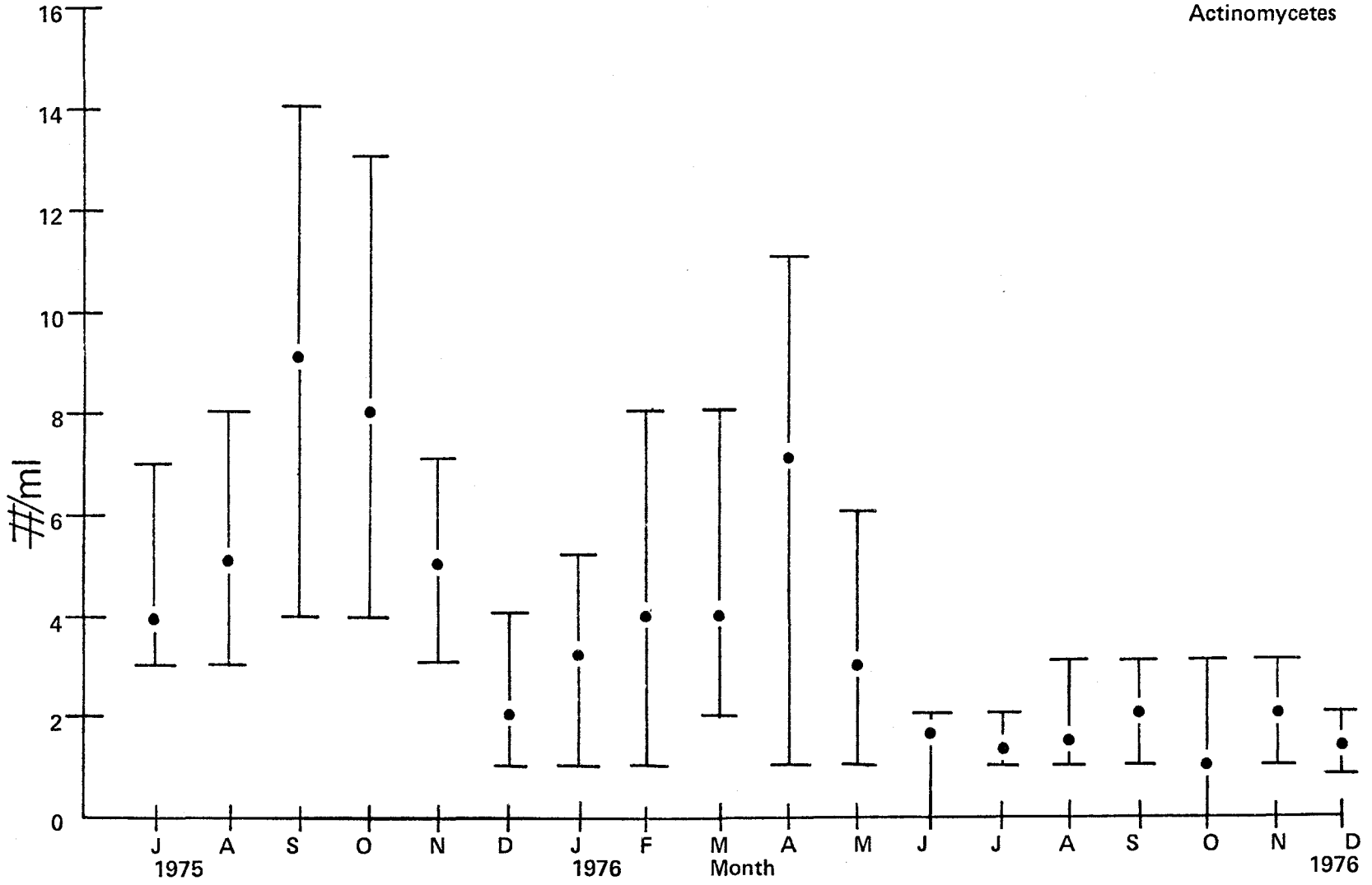

Actinomycetes
16
14
12
10
8
6
4
2
0
#/ml
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month
1976

FIG. 9 Monthly ranges and means of fungi, July 1975 to December 1976

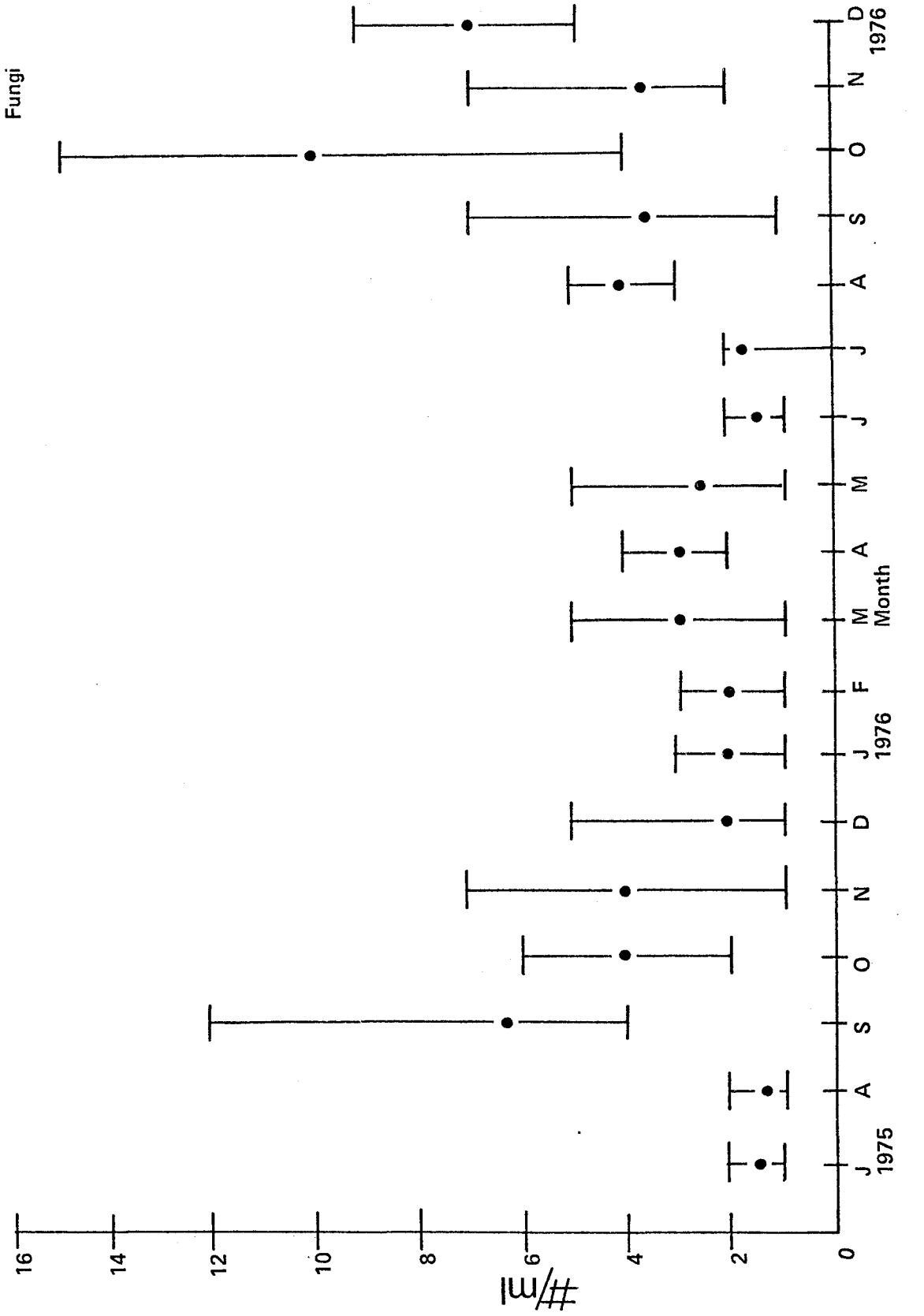

Fungi
#/ml
16
14
12
10
8
6
4
2
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month

FIG. 10 Monthly ranges and means for kjeldahl nitrogen, July 1975 to December 1976

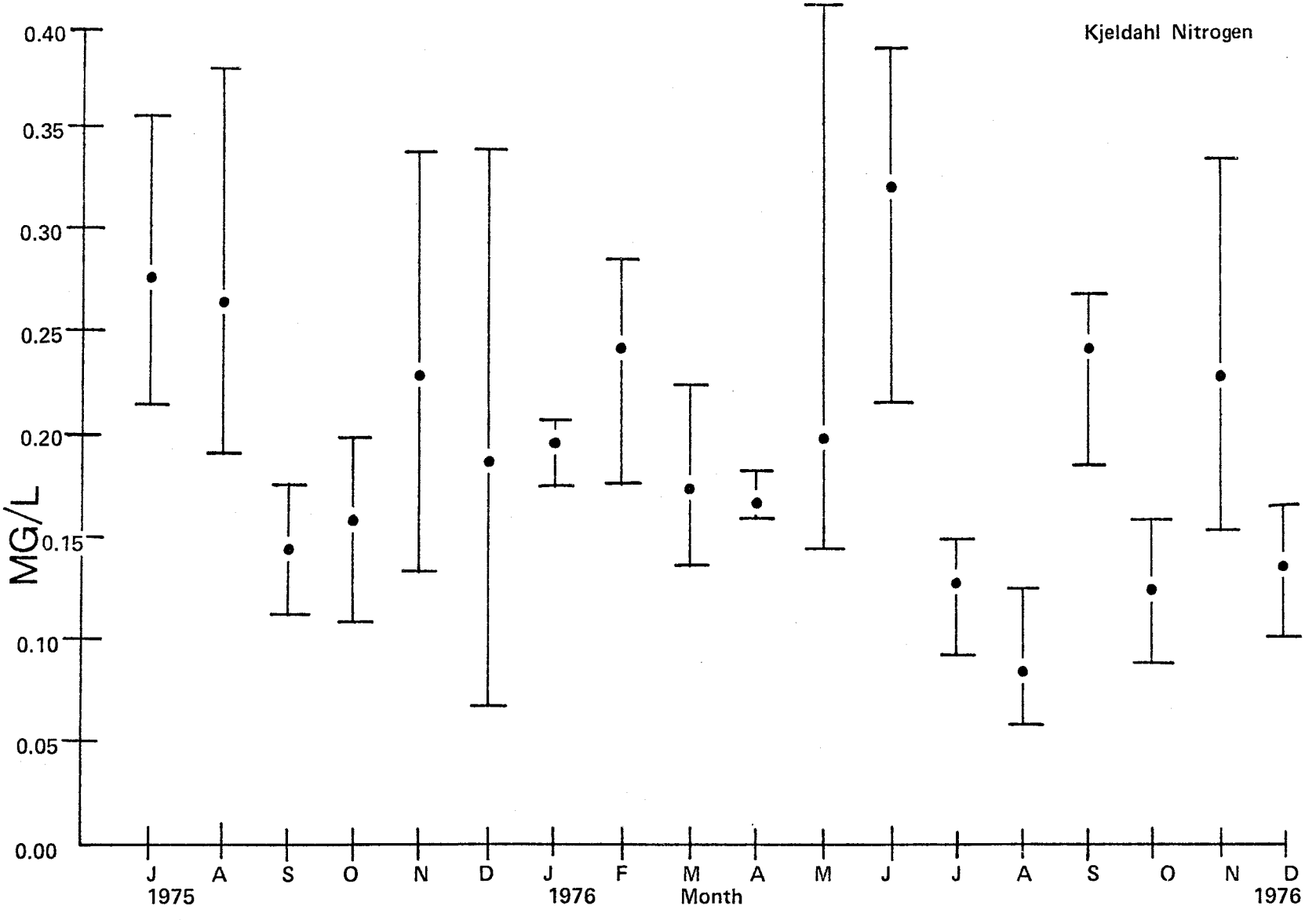

Kjeldahl Nitrogen
MG/L
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month
1976

FIG. 11 Monthly ranges and means for ammonia nitrogen, July 1975 to December 1976

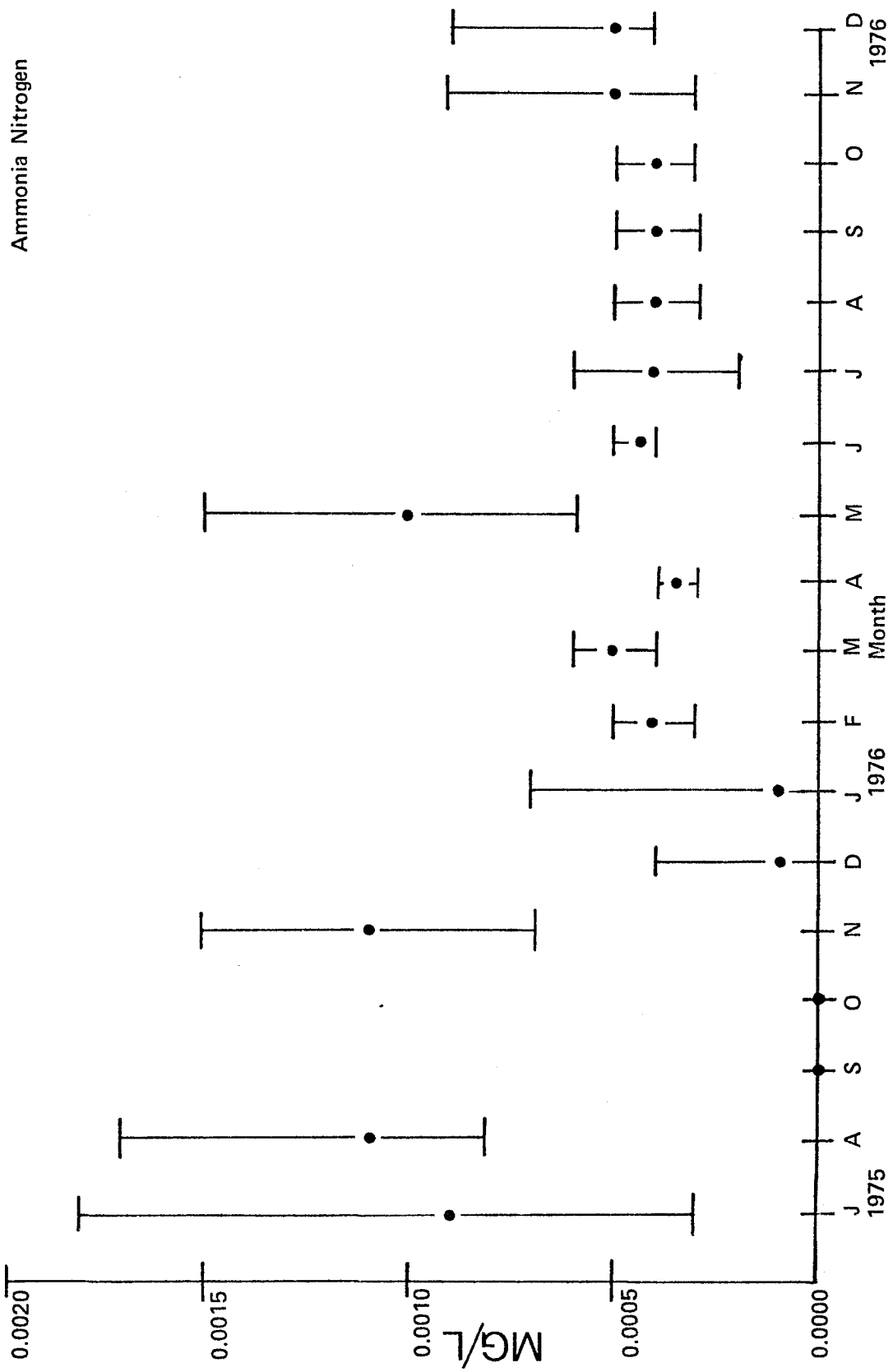
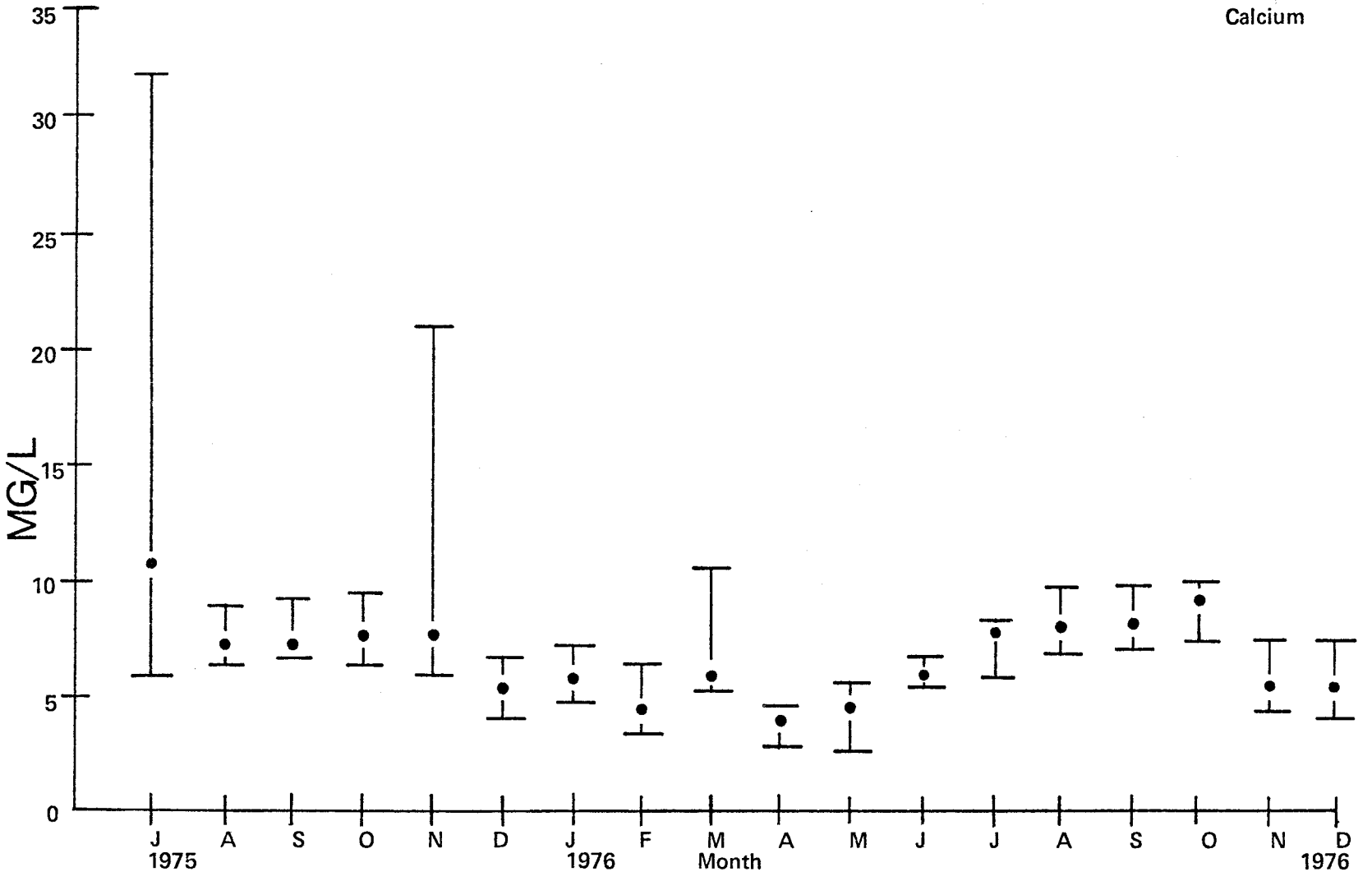

Ammonia Nitrogen
MG/L
0.0020
0.0015
0.0010
0.0005
0.0000
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month

FIG. 12 Monthly ranges and means for calcium, July 1975 to December 1976


Calcium
MG/L
35
30
25
20
15
10
5
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month
1976

Total bacteria (Figure 13) is the only biological variable which showed a significant difference between any of the watersheds. The fact that South Fork, (defoliated watershed), had consistently lower total bacteria counts than Mill Creek (control) and Tiger Creek (logged stream) over the entire sampling period is responsible for this significance. In addition, during November and December of 1976 Mill and Tiger Creeks exhibited a drastic rise in total bacteria of approximately 5 times the normal counts. During this same period South Fork exhibited only a three fold increase which also contributed to the significant difference. The fact that Mill and Tiger Creeks are the two watersheds located approximately 17 miles north of South Fork minimizes the significance of this difference. There is similarity in the seasonal fluctuation pattern for all watersheds with South Fork exhibiting lower and more consistent values. The other two affected streams also have generally higher values than South Fork. The consistently low values on South Fork appear to be a characteristic property of the watershed, and therefore the difference is not believed to be due to the effects of deforestation.

Stream pH values (Figure 14) show a definite similarity in season patterns and vary only within a narrow range. Each watershed appears to have its own characteristic and consistent pH range which accounts for the difference. This resulted in two deforested watersheds being significantly different from both controls but also different from the

FIG. 13 Monthly ranges and means of total bacteria, July 1975 to December 1976

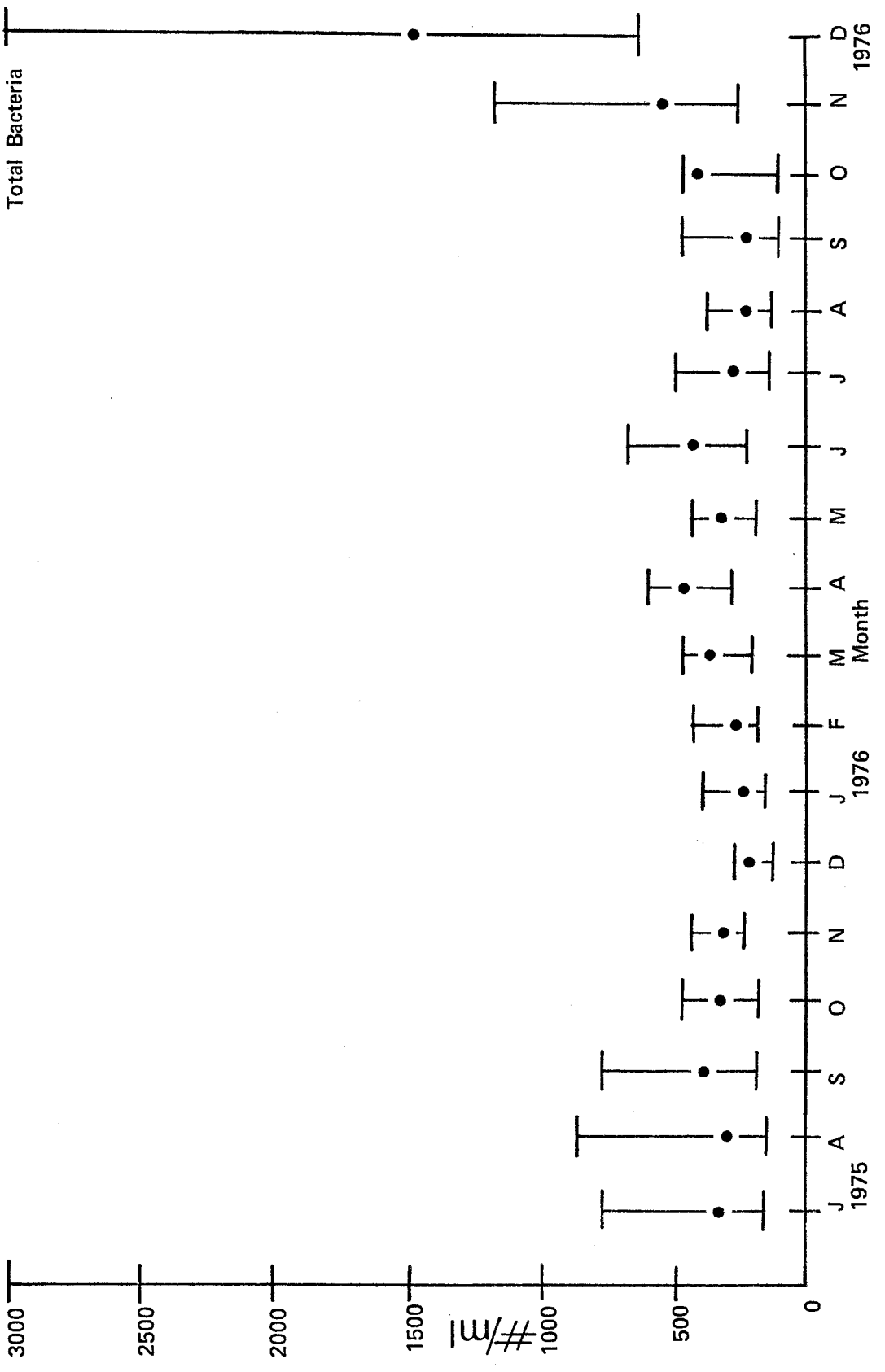
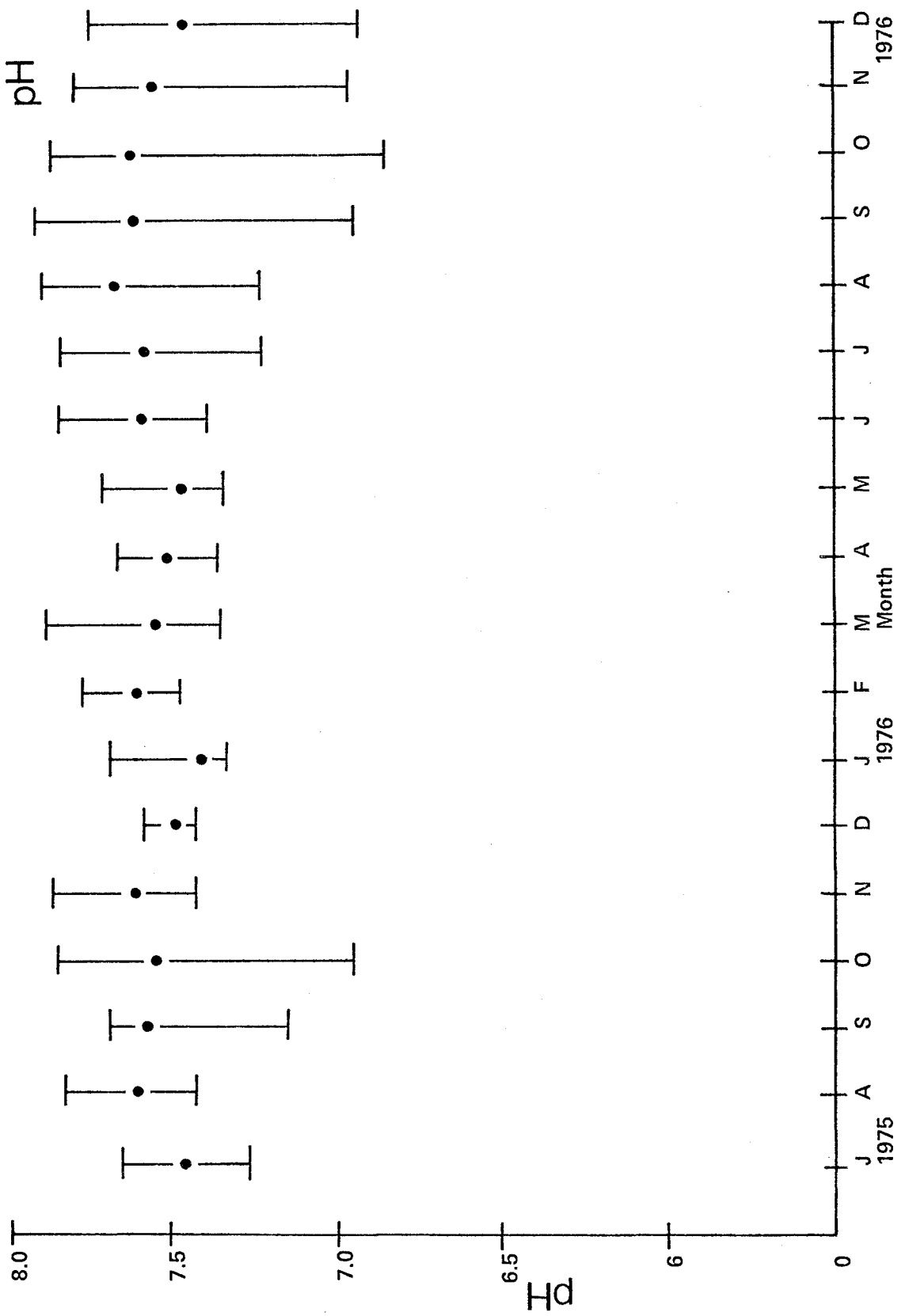

Total Bacteria
3000
2500
2000
1500
1000
500
0
#/ml
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month

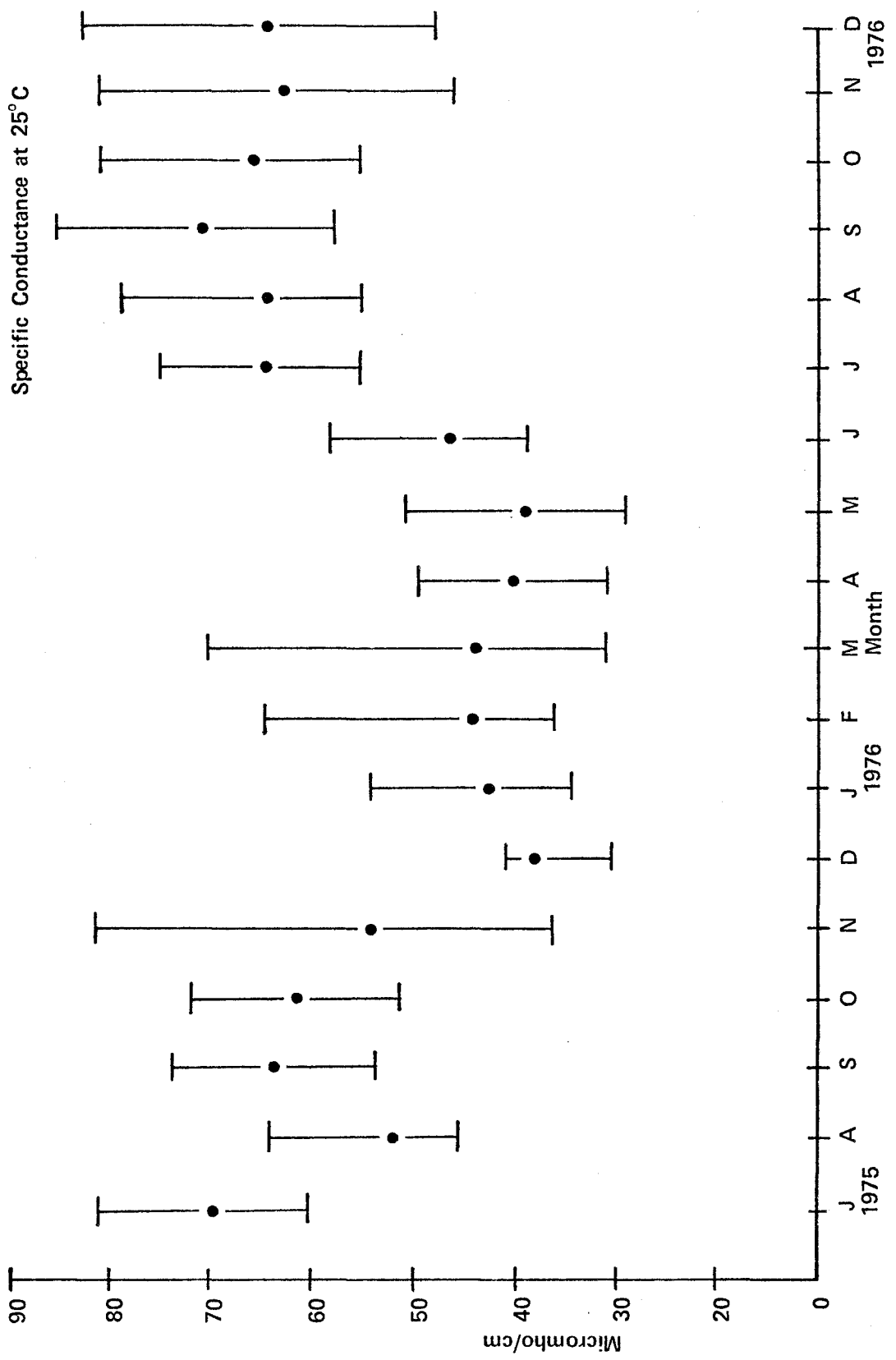
FIG. 14 Monthly ranges and means for pH, July 1975 to December 1976


pH
8.0
7.5
7.0
6.5
6
0
J
1975
A
S
O
N
D
J
1976
F
M
A
M
J
J
A
S
O
N
D
1976
Month

other deforested watershed which were similar to the controls. In general, the significant difference is believed to be due to the inherent pH of each watershed and not an effect of deforestation or subsequent logging.

Specific conductance (Figure 15) shows similar fluctuations in pattern for each of the watersheds. North Fork and Mill Creek (controls) and Buck Creek (defoliated watershed) exhibited consistently higher conductance values than Spring Creek and South Fork (defoliated watersheds) and Thomas Creek (defoliated and subsequently logged watershed). If the difference were due to tussock moth deforestation or logging the reverse would be expected. That is, the controls would have lower values than the affected and logged watersheds. Buck Creek (deforested watershed) is not significantly different from the controls but exhibits significantly higher conductance values than the other defoliated watersheds and Thomas Creek (logged watershed). North Fork exhibited a large increase in conductance during the winter, January-March, of 1976. There were only slight increases noted during this same period on the other watersheds. The large increase for North Fork is confirmed by alkalinity values which exhibit the same increase. There is no explanation offered for this increase except that it is apparently due to some occurrence within the watershed which was more extreme in or peculiar to North Fork. In general, the significant difference noted for specific conductance is believed to be due to individual properties

FIG. 15 Monthly ranges and means for specific conductance, July 1975 to December 1976


Specific Conductance at 25°C
Micromho/cm
90
80
70
60
50
40
30
20
0
J
1975
A
S
O
N
D
J
1976
F
M
A
M
J
J
A
S
O
N
D
1976
Month

of the watershed and not to tussock moth defoliation or defoliation with subsequent logging.

Alkalinity patterns (Figure 16) are very similar to conductance patterns as should be expected. The significant difference is again due to the consistently higher values of the controls (North Fork and Mill Creek) and the defoliated watershed (Buck Creek) with no significant difference between these three watersheds. Buck Creek is statistically different from the other two deforested watersheds but is not different from the logged watershed (Thomas Creek). This differs from the conductance results where Buck Creek is statistically different from Thomas Creek. As previously noted North Fork demonstrates a rather large increase in alkalinity during the winter, January-March, of 1976 as compared to the other watersheds, which corresponds to a similar increase in specific conductance. In general, the differences are believed to be due to inherent qualities of the watershed, not to the altering effects of tussock moth deforestation or subsequent logging operations.

The controls (North Fork and Mill Creek) as well as Tiger Creek (logged watershed) all exhibited consistently higher values of nitrate nitrogen (Figure 17) than the other watersheds. All of the deforested watersheds and Thomas Creek (logged watersheds) show low and consistent values for nitrate nitrogen instead of high and erratic values as would be expected if the deforestation and logging were having an effect. Upon initial evaluation of the extensively

FIG. 16 Monthly ranges and means for alkalinity, July 1975 to December 1976

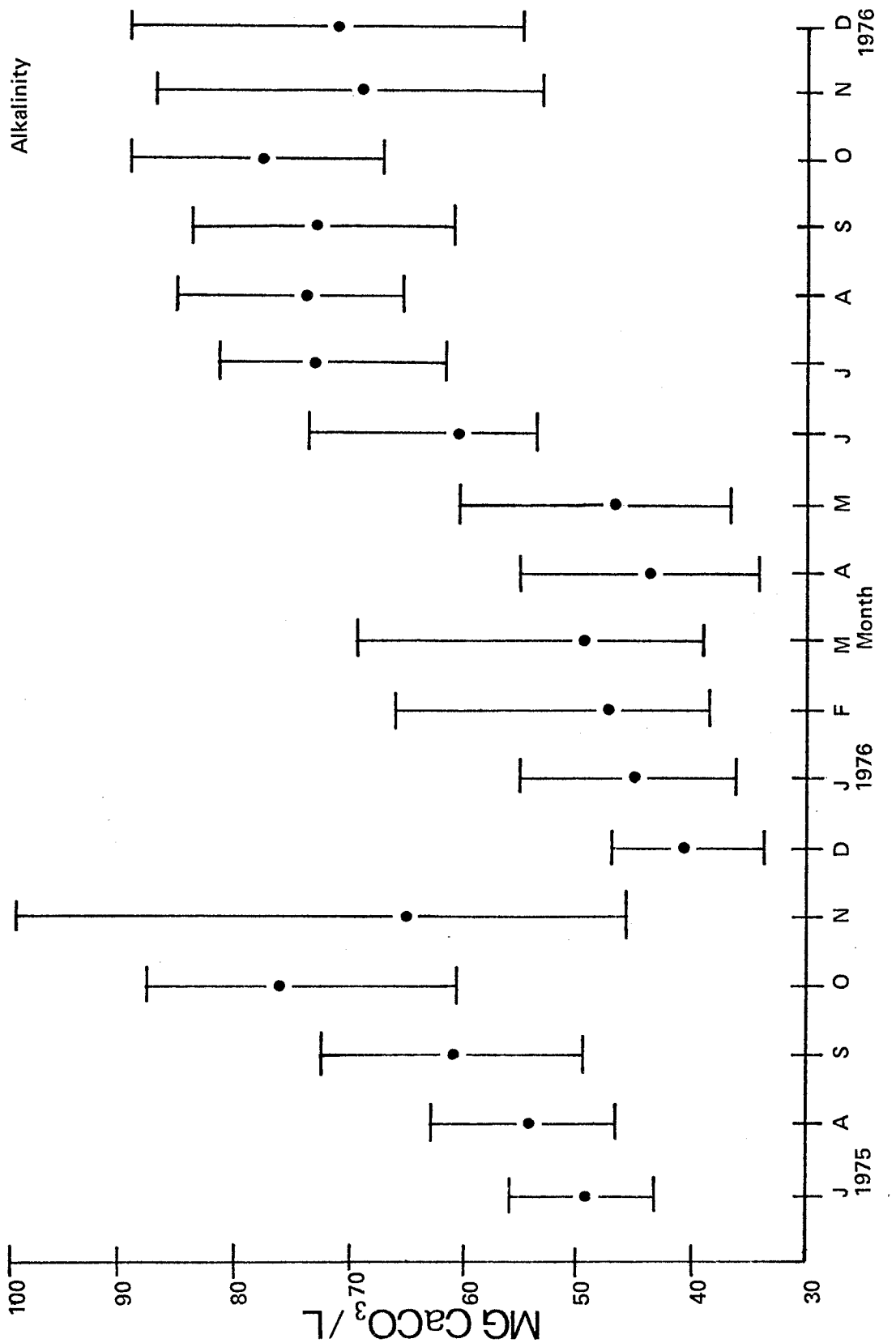
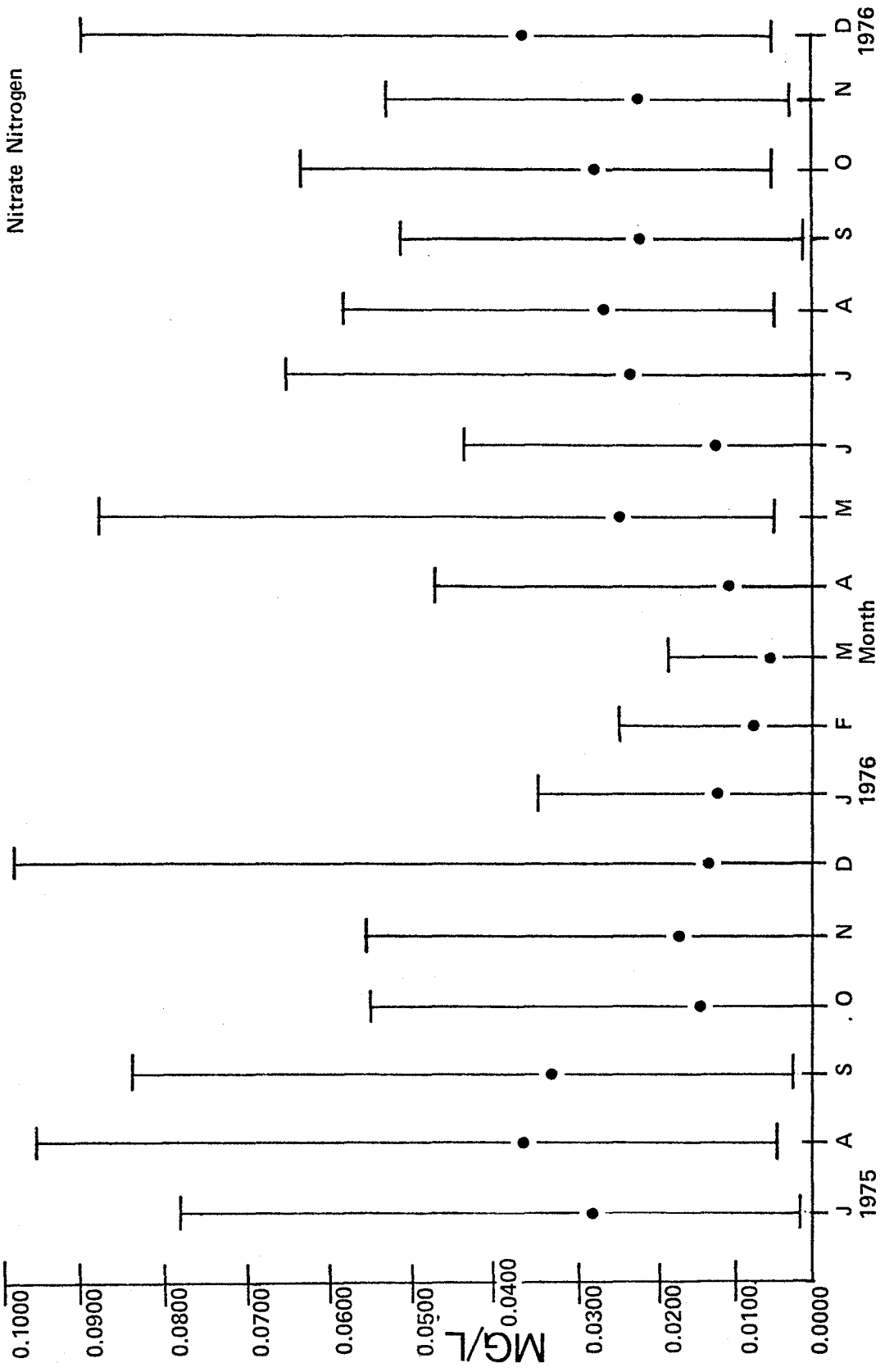

Alkalinity
MG CaCO3 /L
100
90
80
70
60
50
40
30
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month

FIG. 17 Monthly ranges and means for nitrate nitrogen, July 1975 to December 1976


Nitrate Nitrogen
MG/L
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
J
1975
A
S
O
N
D
J
1976
F
M
A
M
J
J
A
S
O
N
D
1976
Month

logged Tiger Creek it appears to exhibit high and erratic nitrate levels as would be expected after logging. However, upon further examination we find there is no statistical difference between Tiger and Mill Creek (geographically adjacent control watershed) and that there exists some consistency in their seasonal fluctuations. The significant difference in nitrate levels appears to be due to characteristic properties of the individual watersheds and not to effects of tussock moth defoliation or subsequent logging activities.

Turbidity values (Figure 18) show consistency in pattern fluctuations which can be correlated with seasonal changes in streamflow and runoff. The two logged watersheds (Thomas and Tiger Creeks) have significantly higher values than either of the controls and Thomas Creek has higher levels than any of the defoliated watersheds (Figure 19). This difference can be contributed to disruption of soil structure by logging activities which then allows runoff to wash more particulate matter into the stream (9). The fact that the test for filterable sediment did not show a difference between the watersheds would indicate that the increased turbidity was due to the presence of fine particles which passed through the filters. This is consistent with the fact that fine loams are the primary soil type in the study area. Such fine particles take a considerably longer time to settle than larger particles. This fact might cause removal problems in a domestic water supply,

FIG. 18 Monthly ranges and means for turbidity, July 1975 to December 1976

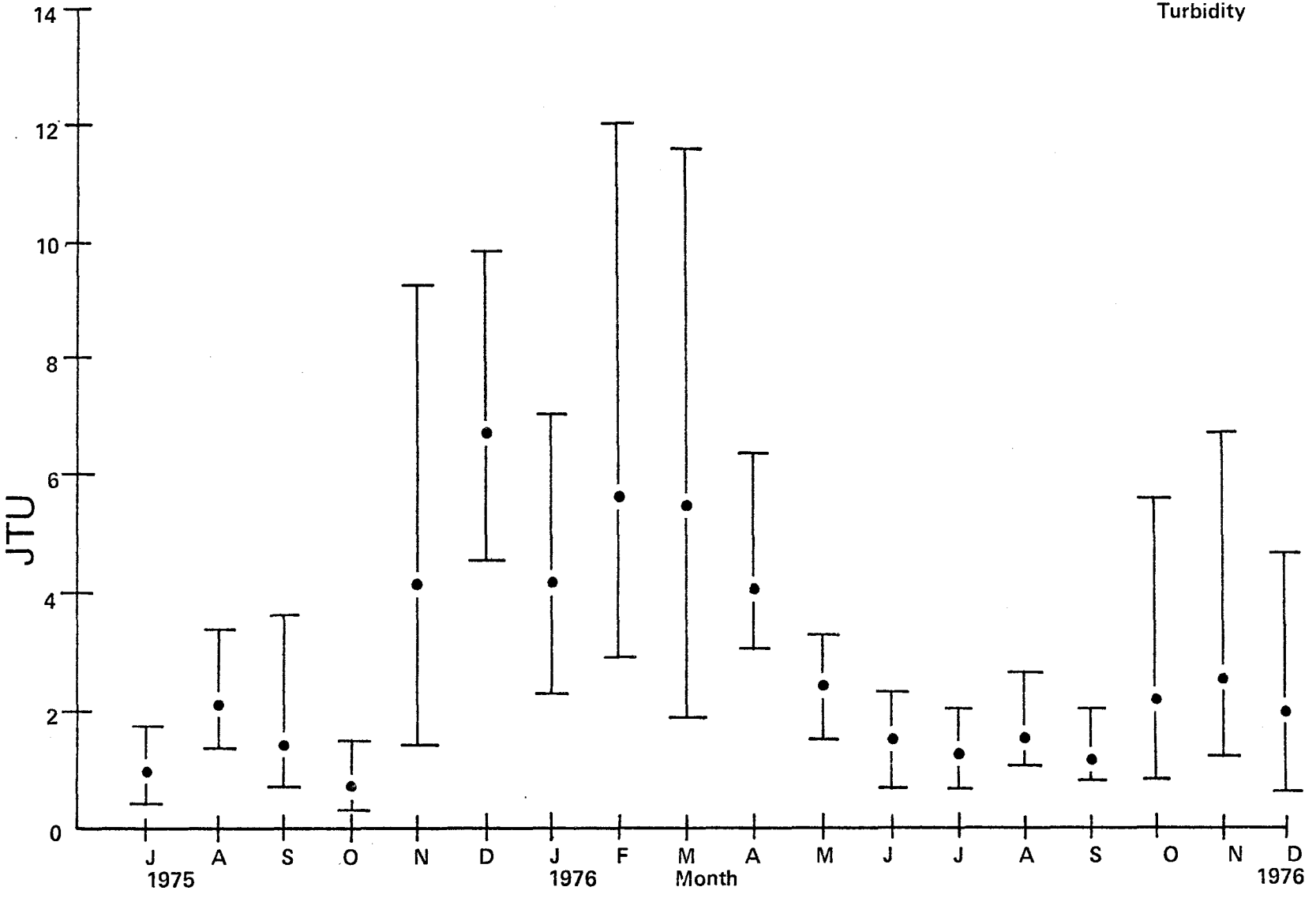
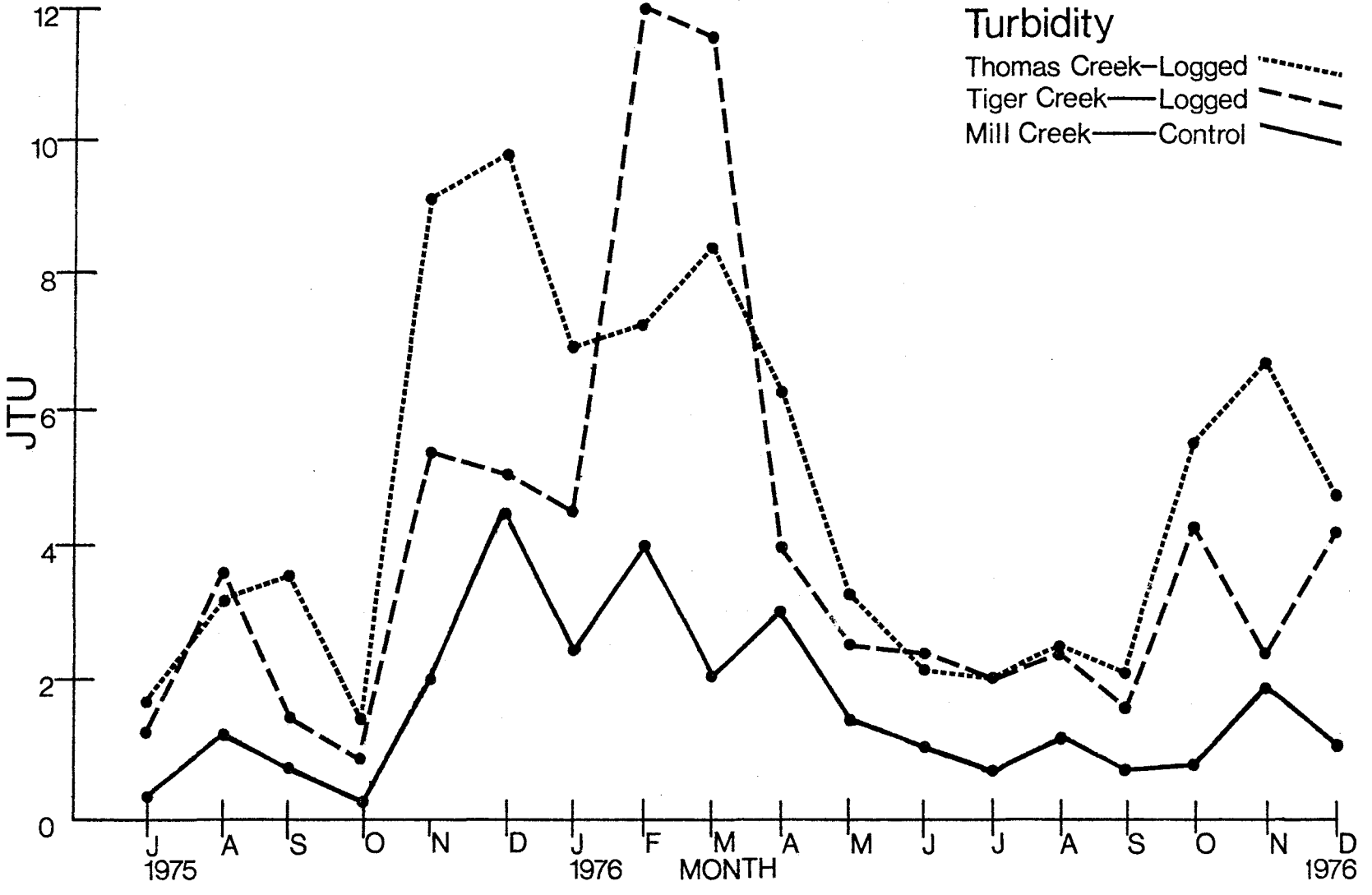

Turbidity
JTU
14
12
10
8
6
4
2
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month
1976

FIG. 19 Comparison of turbidity values for the two logged watersheds with a control


Turbidity
Thomas Creek—Logged
Tiger Creek——Logged
Mill Creek——Control
JTU
12
10
8
6
4
2
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
MONTH
1976

especially if it was dependent on settling ponds for removal of these particles. The deforested watersheds were not significantly different from the controls but were significantly different from Thomas Creek. In addition, one of the defoliated watersheds (South Fork) had significantly lower turbidity values than the other logged watershed (Tiger Creek). This indicates that tussock moth deforestation alone, without subsequent salvage logging operations, does not lead to increased turbidity.

Total phosphate values (Figure 20) exhibit similarities in seasonal pattern. The controls and Buck Creek (defoliated watershed) have patterns similar to the other four watersheds but exhibit consistently higher values. It is interesting to note that Buck Creek exhibits levels higher than the other deforested watersheds but not statistically different from the controls. This tends to indicate that the significant difference is due to characteristic properties of the individual watersheds and not to deforestation or subsequent logging.

Orthophosphate values (Figure 21) comprised only a small portion of the total phosphate and fluctuated within a narrow range for each watershed with similarities in seasonal patterns existing between all watersheds. The controls display consistently higher values than all of the other watersheds. Buck Creek (deforested watershed) has significantly higher values than the other two defoliated watersheds and the logged watersheds. Tiger Creek (logged

FIG. 20 Monthly ranges and means for total phosphate, July 1975 to December 1976

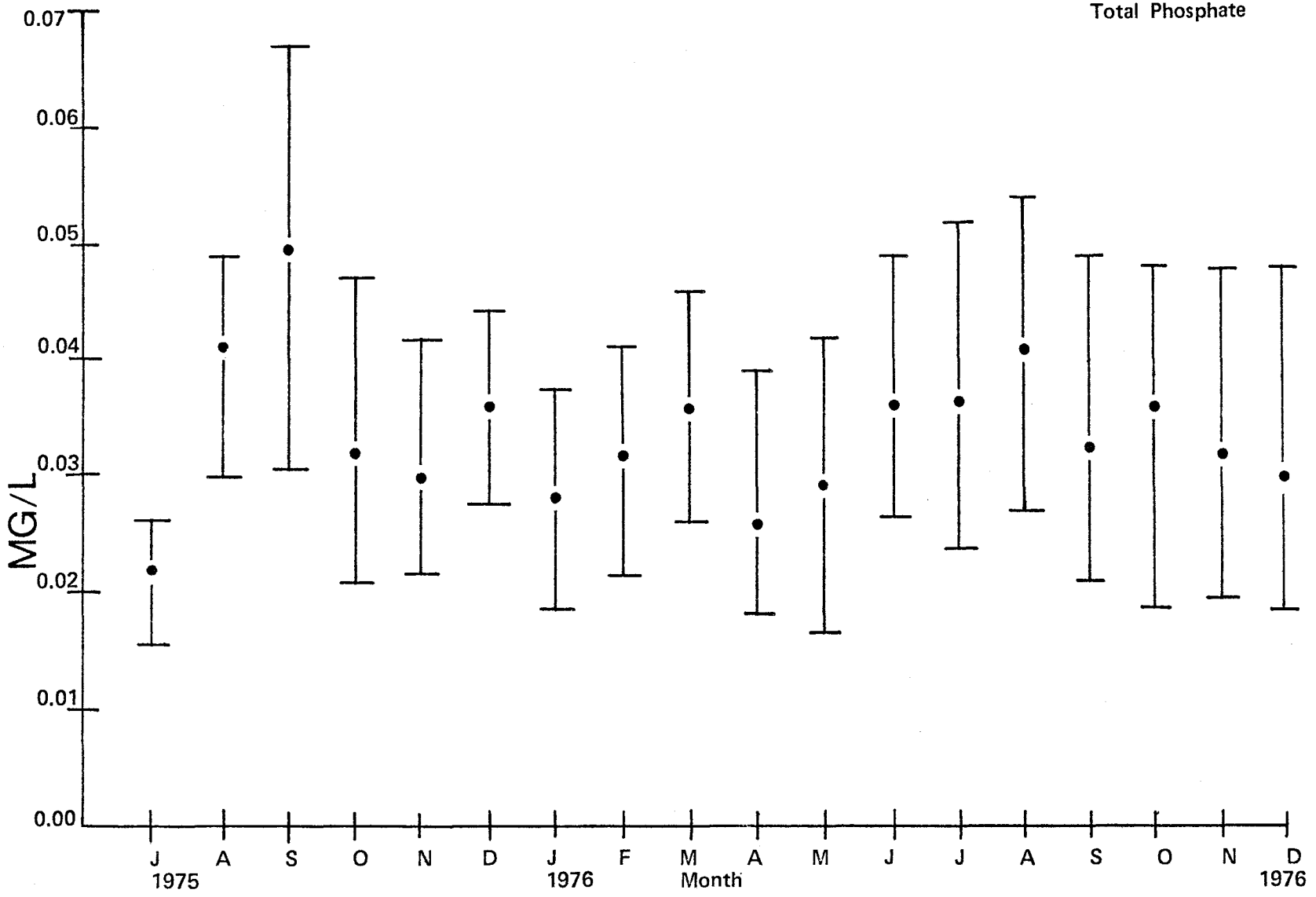
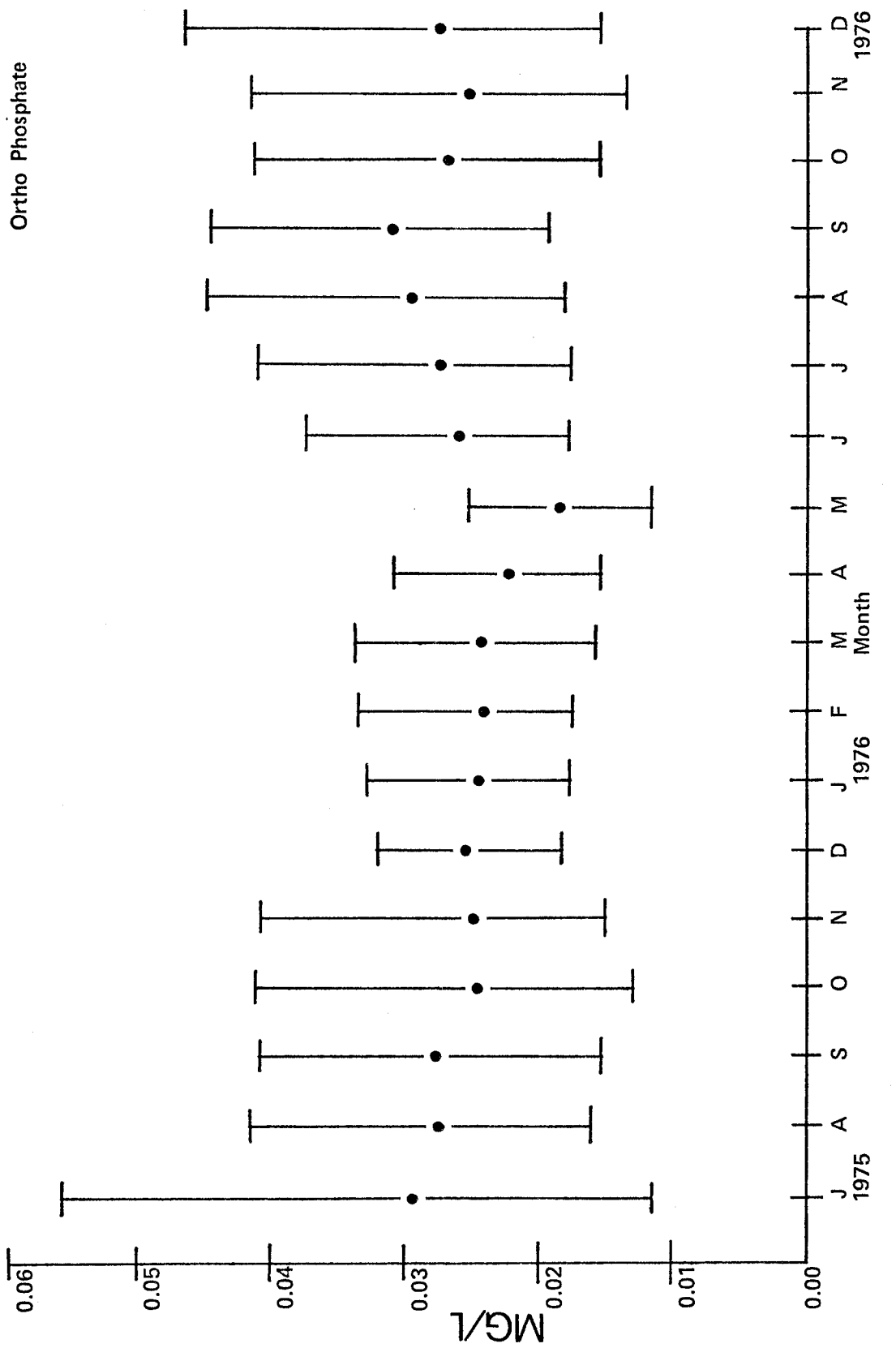

Total Phosphate
MG/L
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month
1976

FIG. 21 Monthly ranges and means for orthophosphate, July 1975 to December 1976

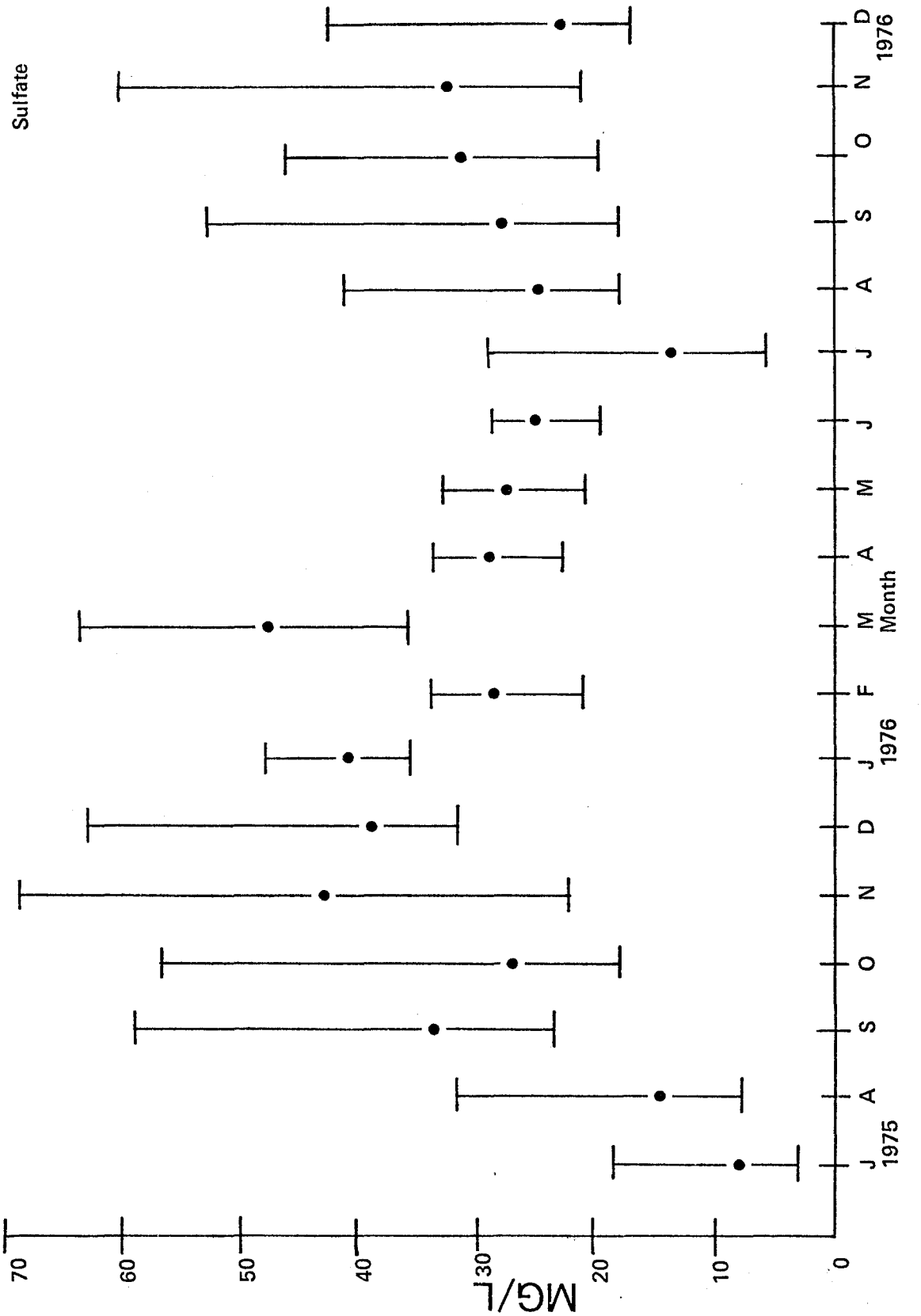

Ortho Phosphate
MG/L
0.06
0.05
0.04
0.03
0.02
0.01
0.00
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month

watershed) exhibits higher values than the other logged watershed (Thomas Creek) and than two of the defoliated watersheds (Spring Creek and South Fork), but the orthophosphate values were significantly lower than the controls and the other deforested watershed (Buck Creek). It is therefore believed that the significant difference is due to characteristics of each watershed and not to effects of tussock moth deforestation or logging.

In general, both types of phosphate exhibited higher levels for controls than the tussock moth deforested or logged watersheds. This is contrary to expected results if deforestation or subsequent logging were effecting removal of nutrients from the soil by increased runoff and due to soil disruption in logged watersheds. Therefore, the statistical difference is believed to be due to individual properties of the watershed not deforestation or subsequent logging operations.

The fluctuation patterns for sulfate (Figure 22) are similar between watersheds with some minor variations. Multiple comparisons with Tukey's method reveals that the significant difference involves Buck Creek (tussock moth defoliated watershed). Buck Creek is significantly different from the other two deforested watersheds and from the geographically removed control and logged watersheds, Mill and Tiger Creeks, respectively. However, there is no difference between Buck Creek and the other control or the other logged watershed. It is interesting to note that although

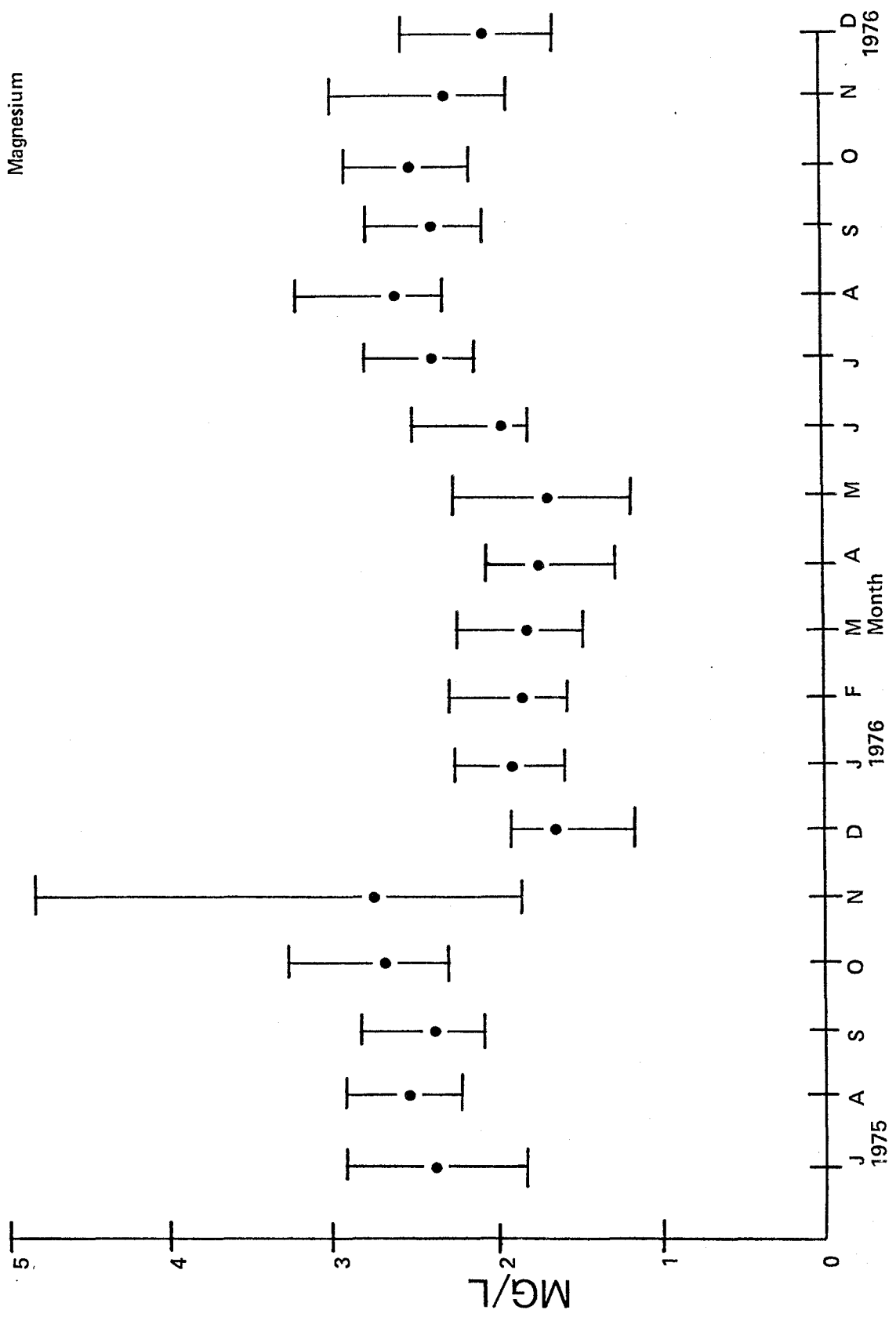
FIG. 22 Monthly ranges and means for sulfate, July 1975 to December 1976


Sulfate
MG/L
70
60
50
40
30
20
10
0
J
1975
A
S
O
N
D
J
1976
F
M
A
M
J
J
A
S
O
N
D
1976
Month

the monthly fluctuation is similar for all watersheds the seasonal fluctuation is reversed for Buck Creek. Buck Creek exhibits its highest yearly values in late summer and fall, starting to rise in August and falling in December, and its lowest values in the winter and spring. The other watersheds exhibit their highest yearly sulfate values in the winter and spring with lower values in the summer and fall. As a result of this seasonal difference and the fact that Buck Creek is significantly different from the other deforested watersheds, but not to its geographically adjacent control or logged watershed, it is believed that the difference is due to characteristics of Buck Creek and not tussock moth deforestation or logging.

Magnesium (Figure 23) shows similar seasonal patterns of fluctuation with Buck Creek (defoliated watershed) and Mill Creek (control watershed) being significantly different from both of the other defoliated watersheds and one of the logged watersheds (Thomas Creek). While Buck and Mill Creeks exhibited fluctuation patterns similar to the other watersheds they had consistently higher values for magnesium throughout the study period. If the tussock moth deforestation and logging were having an effect, you would expect all of the defoliated and logged watersheds to exhibit higher values than the controls. However, what is seen is one of the defoliated and one of the control watersheds being higher than the other deforested watersheds and even higher than one of the logged watersheds. As a result

FIG. 23 Monthly ranges and means for magnesium, July 1975 to December 1976


Magnesium
MG/L
5
4
3
2
1
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
1975
1976
Month

of this and the similarity in fluctuation patterns, it is believed that the difference in magnesium levels is due to inherent properties of Buck and Mill Creeks not tussock moth deforestation or logging.

The monthly fluctuation of potassium levels (Figure 24) on all watersheds is very similar. The only significant difference is attributable to consistently higher potassium values for Mill Creek (control watershed) than for the other control watershed, one of the defoliated watersheds (Spring Creek) and Tiger Creek (geographically adjacent logged watershed). Two facts indicate that the difference is due to some characteristic of Mill Creek and not to the effects of tussock moth defoliation or logging. First, Mill Creek potassium levels are higher than a defoliated and a logged watershed, rather than lower as would be expected if the tussock moth defoliation and logging were having an effect. And secondly, its values are higher than the other control (North Fork).

The seasonal fluctuation of sodium levels (Figure 25) is similar between all watersheds. The significant difference is attributable to North Fork (control) and Buck Creek (defoliated watershed), which are not statistically different from each other, but have consistently higher sodium levels than all other watersheds. In addition, there is a slight difference between two tussock moth deforested watersheds, Spring Creek and South Fork. This difference is barely detectable at the .05 alpha level using Tukey's

FIG. 24 Monthly ranges and means for potassium, July 1975 to December 1976

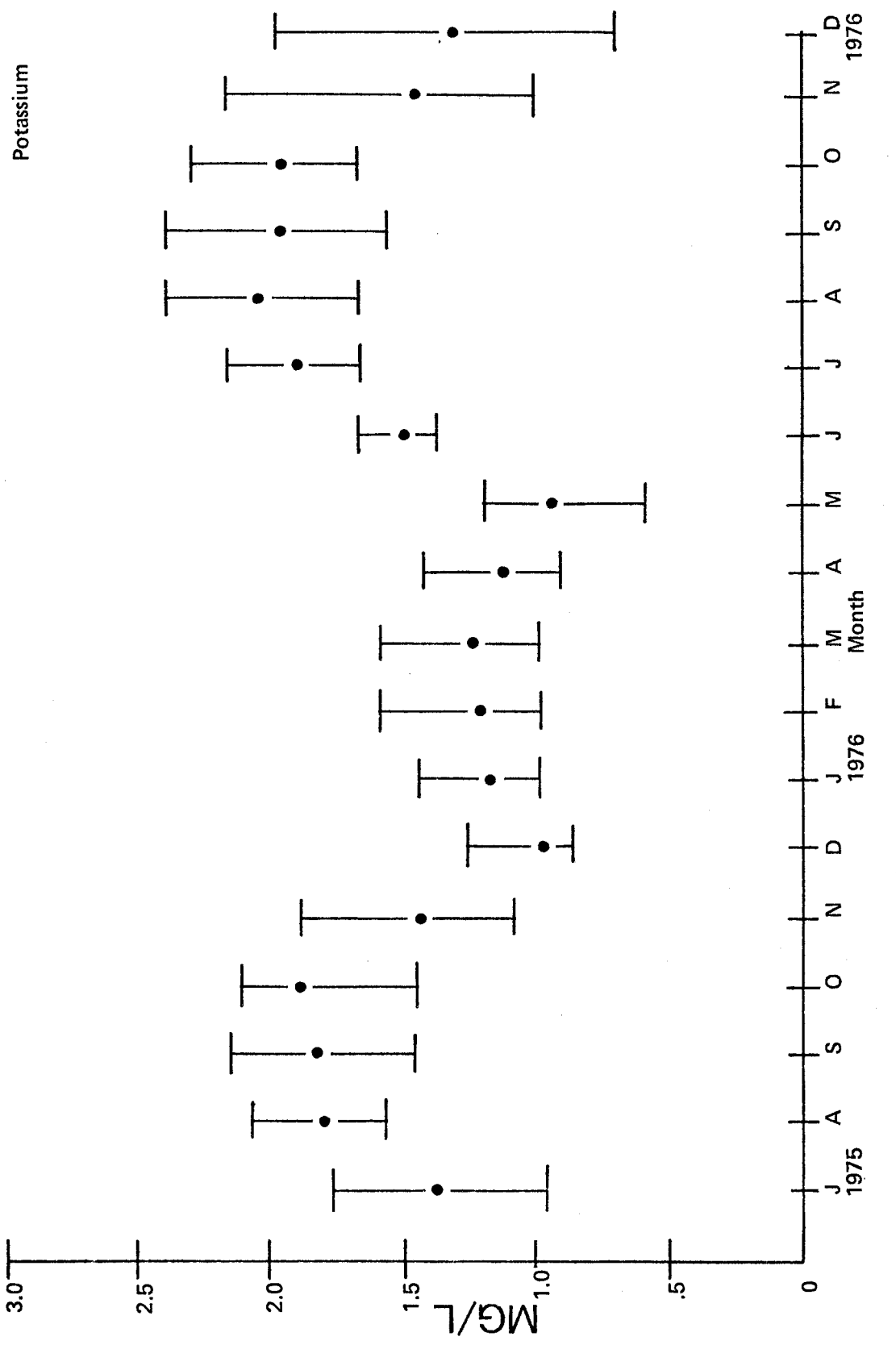
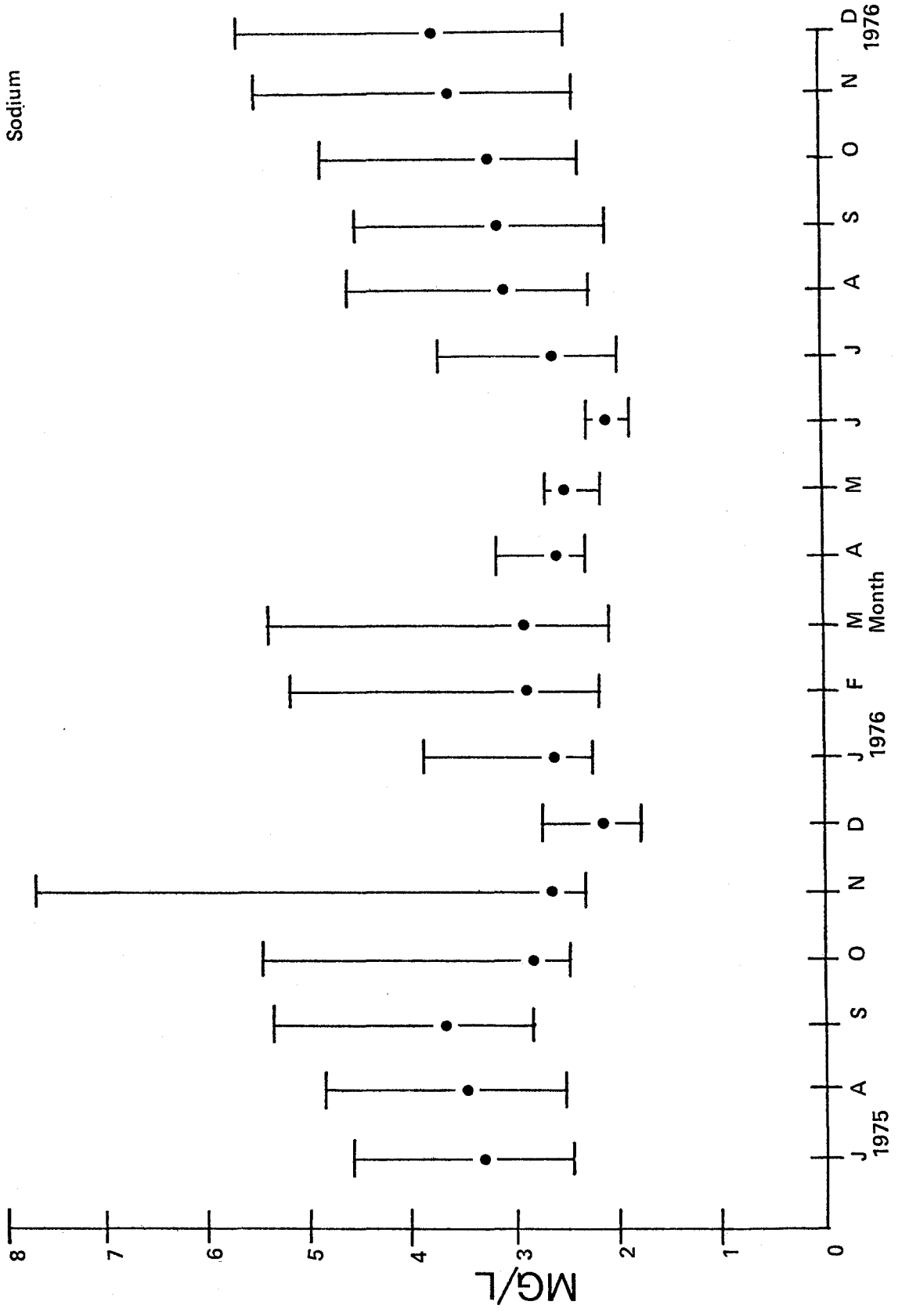

Potassium
MG/L
3.0
2.5
2.0
1.5
1.0
.5
0
J
1975
A
S
O
N
D
J
1976
F
M
A
M
J
J
A
S
O
N
D
1976
Month

FIG. 25 Monthly ranges and means for sodium, July 1975 to December 1976


Sodium
MG/L
0
1
2
3
4
5
6
7
8
J
1975
A
S
O
N
D
J
1976
F
M
A
M
J
J
A
S
O
N
D
1976
Month

method. The fact that a control and a tussock moth defoliated watershed have consistently higher sodium values than the other watersheds while having similar seasonal fluctuation is believed to indicate individual qualities of North Fork and Buck Creek, not effects of tussock moth deforestation or subsequent logging operations.

CONCLUSIONS

Ideally it would be desirable to have baseline data to determine the effects of Douglas-fir tussock moth deforestation and subsequent salvage logging operations on stream water quality. The use of data obtained before tussock moth damage occurred and logging operations began is the best and most efficient way to determine any effects on a watershed. Since this project was initiated as a result of the damage and no year around water quality analysis had been conducted on the watersheds in the area prior to infestation damage, no baseline data were available. In addition, streamflow data would be helpful. No funds were available for flow gauges on the study sites so relative seasonal flow changes were estimated by use of a reference point in each stream at the time of sampling. Flow data allow one to compare watersheds of different sizes precisely by using a factor such as cubic feet/second/square mile to compare parameter values. In addition, Snyder (14) reported, after the start of this study, that chemical concentrations may show an inverse relationship to

streamflow. This dilution effect results from a larger volume of water passing through the soil, but not removing a proportionally greater amount of chemicals. Snyder found the exception to this to be suspended sediment which increases in concentration proportionally to increased streamflow. Some of the watersheds in this study may have demonstrated such a dilution effect, especially during spring runoff periods, but without flow data it is impossible to determine if they did.

Without baseline and streamflow data, the most reasonable method to test for effects of tussock moth deforestation and subsequent salvage logging operations is by comparison of individual watersheds over the same time period, as has been done in this work. From the data obtained during this study it appears that nearly all differences between watersheds, determined statistically, are due to inherent properties of the watersheds rather than the effects of tussock moth deforestation or deforestation with subsequent salvage logging operations. The one exception is the significance demonstrated for turbidity. Increased turbidity may be correlated directly with logging operations on watersheds which suffered extensive tussock moth damage. The logging operations result in disruption of soil structure and destruction of ground cover (9). Together this allows precipitation runoff to remove more particulate matter and wash it into the stream. Hornbeck and Reinhart (9) reported that this occurs to varying degrees dependent

upon such things as slope of skid roads, locations of the skid roads in respect to the stream, and amount of vehicle travel off of designated skid roads. Therefore with careful attention to construction of skid roads and vehicle travel, effects of the tussock moth deforestation and subsequent logging, on stream water quality, as determined by this study, may be minimized and perhaps eliminated.

BIBLIOGRAPHY

1. American Public Health Association. 1971. Standard methods for the examination of water and wastewater. 13th Ed. American Public Health Association, New York.
2. Bethlahmy, N. 1974. A Colorado episode: Beetle epidemic, ghost forest, more streamflow. Paper presented at 47th Annual Meeting of the Northwest Scientific Association, Univ. of B.C., Vancouver.
3. Bormann, F.H. and G.E. Likens. 1967. Nutrient cycling. Science 155:424-429.
4. Clarke, F.W. 1924. The data of geochemistry. 5th Ed. U.S. Geological Survey Bull. 770, Washington, D.C.
5. Helvey, J.D. 1972. First-year effects of wildfire on water yield and stream temperature in North-Central Washington. Proc. of Symposium on "Watersheds in Transition". American Water Resource Assn., Proceedings Ser. 14:308-312.
6. Helvey, J.D. 1973. Watershed behavior after forest five in Washington. Proceedings of the Irrigation and Drainage Specialty Conference, American Society of Civil Engineers, New York.
7. Helvey, J.D., A.R. Tiedemann and W.B. Fowler. 1974. Some climatic and hydrologic effects of wildfire in Washington State. Tall Timbers Fire Ecology Conference, Tallahassee.

8. Hibbert, A.R. 1967. Forest treatment effects on water yield. Forest Hydrology, W.E. Sapper and H.W. Lutt, Eds., Pergaman Press, New York.

9. Hornbeck, J.W. and K.G. Reinhart. 1964. Water quality and soil erosion as affected by logging in steep terrain. Journal of Soil and Water Conservation 19:23-27.

10. Hsu, S.C. and J.L. Lockwood. 1975. Powdered chitin agar as a selective medium for enumeration of actinomycetes in water and soil. Applied Microbiology 29:422-426.

11. Kunkle, Samuel H. and James R. Meiman. 1968. Sampling bacteria in a mountain stream. Hydrology Papers, No. 28, Colordao State University, Fort Collins.

12. Likens, G.E. 1970. Effects of deforestation on water quality. Proceedings of Symposium on Interdisciplinary Aspects of Water Management, American Society of Civil Engineers, New York.

13. Likens, Gene E. and F.H. Bormann. 1971. Nutrient cycling in ecosystems. Proceedings Biology Colloquium, Oregon State University, Corvallis.

14. Snyder, Gordon G. 1976. The northern rocky mountain water quality benchmark system: A procedure for stratifying the natural chemical and physical quality of stream water. USDA Forest Service, Washington, D.C.

15. Tiedemann, A.R. 1973. Stream chemistry following a forest fire and urea fertilization in North-Central Washington. USDA Forest Service Research Note, Portland.

16. Tiedemann, A.R. and J.D. Helvey. 1973. Nutrient ion losses in streamflow after fire and fertilization in Eastern Washington. (Abstr.) Bull. Ecol. Soc. Amer. 54(1):20.

17. U.S. Environmental Protection Agency. 1974. Manual of methods for chemical analysis of water and wastes. U.S. Environmental Protection Agency, Washington, D.C.