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Ecological survey, upper James River, Surry Nuclear Power Station site, August 1974

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Progress Report

to

Virginia Electric & Power Company

Ecological Survey - Upper James River

Surry Nuclear Power Station Site

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Introduction

In May of 1969 field surveys to characterize selected biological communities in the Hog Island area of the James River were begun. The objective of these surveys has been to determine if significant changes occurred in the species composition or population levels of certain communities which could be related to the operation of the nuclear power generation station. Although during the period of study, methods and stations have been changed to adjust the study to changing regulations, its basic character has remained. Communities studied have included benthos, zoo- and phytoplankton and fouling organisms.

The primary emphasis during the study has been centered on the benthic community which has been continuously monitored since the spring of 1969. Beginning in June of 1972, zooplankton were sampled on a monthly basis at seven stations and in January of 1973 a similar program for phytoplankton was initiated. Previous plankton monitoring had been accomplished through productivity determinations. In June of 1973 studies to determine zooplankton mortality caused by entrainment in the thermal plume were begun.

This report presents: 1) a status report on the data accumulated during the period from January 1974 to July 1974 and 2) an evaluation of the benthic data collected from the spring of 1969 through 1973.

Due to personnel changes and scheduling delays, not all of the samples collected have been analyzed. In addition, no entrainment studies were conducted during the past six month period. Two entrainment studies are scheduled to be conducted during August and September. In these trials we will utilize total counts on preserved samples and determine the ATP levels on field samples in an attempt to discriminate between live and dead zooplankters. This change is necessary since the staining techniques attempted previously have proven unsuccessful.

Results (January - June 1974)

Phytoplankton

Total counts and dominant phytoplankton species collected during the months of January through June are shown in Tables 1-6. Phytoplankton biomass increased from a low of $\sim$70 cells/ml in January to a peak of $\sim$1700 cells/ml in June. A decrease in phytoplankton abundance occurred in late spring when densities fell from $\sim$1500 cells/ml in April to $\sim$550 cells/ml in May. Concurrent with the density decrease, *Melosira* declined as the dominant organism. It was present as the dominant phytoplankter at all of the stations sampled in April and was not found as a dominant at any of the stations sampled in May. The average temperature increase between the two sampling dates was 6°C. Temperatures averaged 17.5°C in April and 23.5°C in May.

Phytoplankton densities were generally lower during April, May and June of 1974 than for the same months in 1973. The average cell counts for these months were 1250/ml in 1974 and 3648/ml in 1973.

Zooplankton

Zooplankton collected from each of the seven river stations during the months of January through June are listed in Tables 7-13. Throughout the study period zooplankton densities were considerably higher at the upstream stations. A large bloom of zooplankters (Acartia, rotifers, and copepods) was recorded at Jamestown Island and at two of the Cobham Bay stations in April. The average density of zooplankters at the station nearest the outfall was 12/l compared to an average density over the study area of 8.5/l. Mean density of zooplankton organisms at the two stations in closest proximity to the plume (CBS and HPS) was 7.6/l compared to the overall mean of 8.5/l.

Benthos

Benthic samples were collected in February, May, June and July; however, data from only the February and May samplings are available at this time. Tables 14 and 15 summarize the data on the benthic communities.

Fouling Organisms

The organisms collected on the fouling plates during the study period are shown in Table 16.

Benthic Community Composition
1969 - 1974

As discussed in the February report, a more complete analysis of the benthic data collected during the study period would be undertaken and presented in this report. Although some additional work remains to be done, the majority of comparisons have been completed and are summarized below, following a brief introduction on the techniques utilized.

Biotic Indices and Water Quality

Mathematical techniques have been used to describe community structure or to express the relationships among samples or species. Community structure means the ways in which the biological resources (number, biomass, energy flow, etc.) are distributed among the constituent species in a community. Many techniques have been developed in the past few years to describe community structure. Those utilized in this report are described below.

Species Diversity Measures

Species diversity has often been related to water quality in biological surveys. Measurement of species diversity is popular because of its utility and attractive because of the theoretical relationships between diversity and community stability. The most widely accepted concept of species diversity is that it is a function of the number of species present (species richness or abundance) and the evenness with which individuals are distributed among the species (evenness or equitability).

The most commonly used diversity index is that of Shannon (1966) which expresses the amount of information content per individual. In other terms it is the amount of uncertainty in predicting the specific identity of a randomly chosen individual from an assemblage. The more species there are and the more evenly they are represented, the higher this uncertainty. The index generally indicated by H' is given by:

$$H' = -\sum_{i=1}^{S} P_i \log P_i$$

where S = number of species in the sample and P_i = the proportion of the i^{th} species in the sample. Base 2 logarithms are often used and the index has a dimension of bits/individual. Many additional diversity indices have been used and many have been reviewed by Hurlbert (1971). Comparisons of species diversity indices should be done with caution. In addition to depending on sample size, diversity measures are also sensitive to sampling technique.

The simplest measure of the species richness component of species diversity is the number of species in a collection. But because this depends on sample size this number is usually standardized by relating it to the number of individuals in the sample. Margalef's richness index, which is widely used, defines species richness as

$$SR = S-1/\ln N$$

where S is the number of species and N the number of individuals in a sample.

Classification and Ordination Techniques

The relationships between samples or between species can be investigated by computing similarity indices based on the species composition of these samples or the distribution patterns of the species over a series of samples, respectively. When the relationships between samples are considered it is called a "normal" analysis, and when interspecies relationships are considered it is called an "inverse" analysis. A similarity index is computed between all pairs of samples (species in the inverse analysis), producing a symmetrical (sample by sample) matrix of similarity values.

A great many similarity indices have been used that reflect either the qualitative composition of samples (co-occurrence of species in the reverse analysis) or, to varying degrees, the quantitative composition of samples.

Appraisals of the data, as Boesch (1973) noted in Hampton Roads, indicated that at least two of the dominant species were fairly ubiquitously distributed. Therefore a classification strategy which is unbiased towards dominance, yet includes both quantitative and qualitative criteria appeared most useful. Stephenson, et al. (1973) have found that the 'Canberra metric' coefficient fulfills these needs.

If X_{1j} and X_{2j} are the numbers of the j species at two sites, then the coefficient for comparing two locations is defined by:

$$d_{1\&2} = \frac{1}{n} \sum_{j}^{n} \frac{\left| X_{1j} - X_{2j} \right|}{(X_{1j} + X_{2j})}$$

Classifications may be discreet and nonhierarchical (e.g. Fager's recurrent group analysis) or more often hierarchical. Hierarchical classifications present the intersample relationships in the form of a branching dendrogram. A number of clustering strategies exist by which dendrograms are formed from a similarity matrix. In this report we have chosen the use of a flexible sorting strategy which has the advantage that the intensity of clustering is variable, depending upon the valve chosen for B, as defined by Stephenson et al., (1973). The value used for B in these analysis was the now conventional level of -0.25.

Hog Island - Benthic Species Diversity

A summary of the benthic species diversity indices for all stations in the study area from 1969 to 1974 is presented in Figure 1. Figure 2 presents the same data but with those stations located in the plume separated from the "control" stations. The identification of those stations located in the plume was based on both field observations made by Dr. Fang's group and the model predictions of Dr. Pritchard.

As can be seen in Figure 2, with the exception of 1969, both the control and plume stations follow very similar patterns in terms of the diversity of benthic organisms. The drastic reduction in diversity shown for the overall area in Figure 1 during the summer of 1969 is related to Hurricane Camille. A similar, although less drastic, depression in June of 1972 is also related to a salinity reduction that was caused by tropical storm Agnes. From inspection of these data it does not appear that the operation of the power station has affected benthic diversity.

Hog Island - Benthic Species Richness

A summary of the benthic species richness indices for all the stations in the study area from 1969 to 1974 is presented in Figure 3. Figure 4 presents the same data, but with those stations located in the plume separated from the control stations.

The depressions in richness as a result of the storms in 1969 and 1972 were also shown in the diversity data. However, when considering richness alone, two other notable drops are evident. The one which occurred in fall of 1970 is due to a "bloom" of Gammarus which greatly inflated N while not concurrently increasing the number of species. The other noticeable depression during the summer months of 1973 is not related to a large increase in the number of individuals, but rather to a reduction in the number of species present. The cause of this reduction is not known. It may be related to the operation of the station, since no unusual meterological events occurred during this period; however, any such conclusion must be confirmed. If a similar pattern is noted in the summer 1974 samples, considerable credence would be lent to this hypothesis.

Classification Analysis

Dendrograms were constructed to compare benthic community similarity at the various stations as a function of both season and year.

Figures 5, 6, 7 and 8 show the relationships between stations in the spring of 1969, 70, 72 and 73 respectively. The circled stations are those located in closest proximity to the thermal plume. Inspection of these figures shows little continuity between years for the various station groupings. The proximity of the stations to one another (see Figure 9) does not appear to produce pairs nor does their general location, i.e. upstream or downstream.

Figures 10 and 11 show the relationships between stations in the summers of 1971 and 1973. As was the case in the spring comparisons, the similarity between stations does not appear to be related to station proximity, nor was any regrouping of similar or dissimilar station groups evident as a consequence of plant operation.

Comparisons between the station groupings in the falls of 1971 and 1973 are shown in Figures 12 and 13. Those stations located in the plume appeared somewhat more closely related in the fall of 1971 before the plant went into operation than after its operation in 1973.

In Figure 14 the contrasts between all of the stations sampled in the summers of 1971, 72 and 73 are shown, while Tables 17 and 18 give similar data for the spring and summer seasons. Inspection of the figure shows that yearly groupings rather than station similarities predominate, indicating that the plant has not affected benthic community structure.

References

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Table 1

James River Phytoplankton

January 1974

Station	Total Cells/ml	Dominant Organisms
DWS	30	*Melosira* sp. *Cyclotella* sp. *Nitzschia* spp.
Intake-River	30	*Melosira* sp. *Cyclotella* sp. *Nitzschia* spp.
Intake-Canal	50	*Melosira* sp. *Nitzschia* spp. *Cyclotella* sp.
HPS	50	*Melosira* sp. *Cyclotella* sp. *Nitzschia* spp.
Discharge-River (CBS)	60	*Melosira* sp. *Cyclotella* sp. *Nitzschia* spp.
Discharge-Canal	120	*Navicula* sp. *Melosira* sp. *Nitzschia* spp. *Cyclotella* sp.
CBN	70	*Melosira* sp. *Nitzschia* spp. *Cyclotella* sp.
Cobham Bay	100	*Melosira* sp. *Nitzschia* spp. *Cyclotella* sp.
J. I.	150	*Melosira* sp. *Nitzschia* spp. *Cyclotella* sp.

Table 2

James River Phytoplankton

February 1974

Station	Total Cells/ml	Dominant Organisms
DWS	50	*Melosira* sp. *Nitzschia* spp. *Chroomonas* spp.
Intake-River	60	*Melosira* sp. *Nitzschia* spp. *Chroomonas* spp.
Intake-Canal	40	*Melosira* sp. *Cyclotella* sp. *Nitzschia Kützingiana*
HPS	70	*Melosira* sp. *Nitzschia Kützingiana* *Cryptomonas* sp.
Discharge-River (CBS)	50	*Melosira* sp. *Nitzschia* spp. *Cyclotella* sp.
Discharge-Canal	60	*Melosira* sp. *Nitzschia* spp. *Cyclotella* sp.
CBN	50	*Melosira* sp. *Cyclotella* sp. *Nitzschia* spp.
Cobham Bay	100	*Melosira* sp. *Nitzschia Kützingiana* *Cryptomonas* sp.
J. I.	200	*Melosira* sp. *Nitzschia Kützingiana* *Dinobryon* sp.

Table 3

James River Phytoplankton

March 1974

Station	Total Cells/ml	Dominant Organisms
DWS	500	*Melosira* sp. *Nitzschia Kützingiana* *Cyclotella* sp.
Intake-River	100	*Melosira* sp. *Nitzschia Kützingiana* *Nitzschia paradoxa*
Intake-Canal		
HPS	300	*Melosira* sp. *Nitzschia Kützingiana* *Cyclotella* sp.
Discharge-River (CBS)	100	*Melosira* sp. *Nitzschia Kützingiana* *Cyclotella* sp.
Discharge-Canal		
CBN	300	*Nitzschia Kützingiana* *Melosira* sp. *Cyclotella* sp.
Cobham Bay	400	*Melosira* sp. *Nitzschia Kützingiana* *Cyclotella* sp.
J. I.	400	*Melosira* sp. *Nitzschia Kützingiana* *Cyclotella* sp.

Table 4

James River Phytoplankton

April 1974

Station	Total Cells/ml	Dominant Organisms
DWS	1600	*Melosira* sp. *Chroomonas* sp. *Nitzschia Kützingiana* *Cryptomonas* sp.
Intake-River	2600	*Melosira* sp. *Nitzschia Kützingiana* *Chroomonas* sp.
Intake-Canal		
HPS	800	*Melosira* sp. *Nitzschia Kützingiana*
Discharge-River (CBS)	1200	*Melosira* sp. *Nitzschia Kützingiana* *Chroomonas* sp. *Cryptomonas* sp.
Discharge-Canal		
CBN	2000	*Melosira* sp. *Chroomonas* sp. *Nitzschia Kützingiana* *Cryptomonas* sp.
Cobham Bay	1300	*Melosira* sp. *Chroomonas* sp. *Nitzschia Kützingiana* *Cryptomonas* sp.
J. I.	2500	*Melosira* sp. *Nitzschia Kützingiana* *Chroomonas* sp. *Cryptomonas* sp.

Table 5

James River Phytoplankton

May 1974

Station	Total Cells/ml	Dominant Organisms
DWS	500	*Chroomonas* sp. *Cyclotella* sp. 3 µ flagellates
Intake-River	500	*Chroomonas* sp. *Nitzschia Kützingiana* *Cyclotella* sp.
Intake-Canal		
HPS	500	*Nitzschia Kützingiana* *Chroomonas* sp. *Cyclotella* sp.
Discharge River (CBS)	500	*Nitzschia Kützingiana* *Chroomonas* sp. *Cyclotella* sp.
Discharge-Canal		
CBN	600	*Nitzschia Kützingiana* *Chroomonas* sp. *Cyclotella* sp.
Cobham Bay	600	*Chroomonas* sp. *Cyclotella* sp. *Nitzschia Kützingiana*
J. I	700	*Chroomonas* sp. *Cyclotella* sp. *Nitzschia Kützingiana*

Table 6

James River Phytoplankton

June 1974

Station	Total Cells/ml	Dominant Organisms
DWS	2600	*Cyclotella* sp. *Chroomonas* sp. *Melosira* sp.
Intake-River	1300	*Cyclotella* sp. *Chroomonas* sp. *Nitzschia Kützingiana*
Intake-Canal		
HPS	1800	*Nitzschia Kützingiana* *Cyclotella* sp. *Chroomonas* sp.
Discharge-River (CBS)	2400	*Cyclotella* sp. *Chroomonas* sp. *Melosira* sp.
Discharge-Canal		
CBN	700	*Nitzschia Kützingiana* *Chroomonas* sp. *Cyclotella* sp.
Cobham Bay	1800	*Chroomonas* sp. *Cyclotella* sp. *Nitzschia Kützingiana*
J. I.	1200	*Chroomonas* sp. *Cyclotella* sp. *Nitzschia Kützingiana*

Table 7

Cobham Bay

	1974					
Organism/l	Jan.	Feb.	Mar.	Apr.	May	Jun.
Acartia sp. copepodid	0.61	0.16	0.13	<20		1.31
Acartia tonsa		0.03	0.01			
Barnacle nauplius						
Bosmina sp.	0.07	0.06				0.43
Copepod nauplius	1.30	0.35	10.62	<20	0.03	28.33
Cyclopoid copepod	0.25	0.30	0.21		0.01	0.36
Daphnia	0.04		0.01			
Eurytemora sp.						0.02
Gastropod larva						0.02
Harpacticoid copepod		0.05	0.01			
Pelecypod larvae						
Polyphemus pediculus						
Polychaete larvae						
Rotifer	0.25	0.02		<20		
Tunicate larvae						
Total/l	2.52	0.97	10.99	<60	0.04	30.47

Table 8

Cobham Bay South

Organism/1	Jan.	Feb.	Mar.	Apr.	May	Jun.
				1974		
Acartia sp. copepodid	0.26	0.35	0.05	<20		0.58
Acartia tonsa			0.01			
Barnacle nauplius			0.01			0.29
Bosmina sp.						0.08
Copepod nauplius	1.60	0.24	2.31	<20	0.07	5.17
Cyclopoid copepod	0.16	0.11	.20		0.01	0.69
Daphnia						
Eurytemora sp.						0.03
Gastropod larva						0.01
Harpacticoid copepod			0.01			
Pelecypod larvae						
Polyphemus pediculus						
Polychaete larvae						0.01
Rotifer	0.03		0.03	<20		
Tunicate larvae						
Total/1	2.05	0.70	2.62	<60	0.08	6.86

Table 9

Cobham Bay North

Organism/1	1974 Jan.	Feb.	Mar.	Apr.	May	Jun.
Acartia sp. copepodid	0.16	1.26	0.27	0.09	0.13	2.45
Acartia tonsa	0.02	0.31				0.05
Barnacle nauplius						0.01
Bosmina sp.	0.03	0.02	0.03	0.05	2.15	0.18
Copepod nauplius	1.10		1.11	0.77	7.15	18.03
Cyclopoid copepod	0.13	0.23	0.26	0.08	1.02	0.99
Daphnia						
Eurytemora sp.		0.04				0.08
Gastropod larva						
Harpacticoid copepod						
Pelecypod larvae						
Polyphemus pediculus						
Polychaete larvae						0.01
Rotifer	0.37		0.12	0.04		
Tunicate larvae						
Total/1	1.81	1.86	1.79	1.03	10.45	21.8

Table 10

Hog Point South

Organism/1	Jan.	Feb.	Mar.	Apr.	May	Jun.
				1974		
Acartia sp. copepodid	0.20	0.24	0.05	0.01	0.09	2.12
Acartia tonsa				0.02		0.02
Barnacle nauplius						0.23
Bosmina sp.					0.05	0.01
Copepod nauplius	0.46	0.39	1.45	0.37	7.40	3.72
Cyclopoid copepod	0.21	0.31	0.05	0.27	0.05	1.05
Daphnia						
Eurytemora sp.						0.24
Gastropod larva						
Harpacticoid copepod						
Pelecypod larvae						
Polyphemus pediculus						
Polychaete larvae		0.04			0.01	0.04
Rotifer	0.06		0.04			
Tunicate larvae						
Total/1	0.93	0.98	1.59	0.67	7.60	7.43

Table 11

Deep Water Shoals

Organism/1	1974 Jan.	Feb.	Mar.	Apr.	May	Jun.
Acartia sp. copepodid	0.44		0.03	0.04	0.01	0.01
Acartia tonsa	0.04		0.01	0.01		
Barnacle nauplius			0.03			
Bosmina sp.	0.03			0.03	0.02	
Copepod nauplius	3.33	0.01	0.33	4.68	1.31	1.43
Cyclopoid copepod	0.14	0.01	0.01	0.12	0.01	
Daphnia						
Eurytemora sp.						
Gastropod larva						
Harpacticoid copepod		0.01	0.01			
Pelecypod larvae						0.03
Polyphemus pediculus						
Polychaete larvae			0.01			0.01
Rotifer	0.05		0.02	0.09	0.02	0.04
Tunicate larvae						
Total/1	4.03	0.03	0.44	4.97	1.37	1.52

Table 12

Intake Canal

Organism/1	Jan. 1974	Feb. 1974	Mar. 1974	Apr. 1974	May 1974	Jun. 1974
Acartia sp. copepodid	0.15	0.02	0.03	0.22	0.17	0.17
Acartia tonsa	0.06		0.01	0.01		
Barnacle nauplius			0.03			0.03
Bosmina sp.				0.03		
Copepod nauplius	0.42	0.22	0.32	0.70	3.83	0.63
Cyclopoid copepod	0.23	0.10	0.01	0.18	0.04	0.04
Daphnia						
Decapod zoea						0.02
Eurytemora sp.						
Gastropod larva						0.32
Harpacticoid copepod		0.03	0.01			
Pelecypod larvae			0.01			
Polyphemus pediculus						
Polychaete larvae		0.01			0.02	0.28
Rotifer			0.02			0.25
Tunicate larvae						
Total/1	0.86	0.38	0.44	1.14	4.06	1.74

Table 13

Jamestown Island

Organism/l	1974 Jan.	Feb.	Mar.	Apr.	May	Jun.
Acartia sp. copepodid	0.35	0.41	0.20	<20		2.33
Acartia tonsa		0.03	0.05			
Barnacle nauplius						
Bosmina sp.	0.03		0.01		1.05	1.00
Copepod nauplius	2.33	0.89	16.26	<20	5.41	4.65
Cyclopoid copepod	0.12	0.44	0.24		0.30	1.70
Daphnia						
Eurytemora sp.						0.44
Gastropod larva						
Harpacticoid copepod		0.03				
Pelecypod larvae						
Polyphemus pediculus		0.01				
Polychaete larvae						
Rotifer	0.24	0.01	0.73	<20		
Tunicate larvae			0.01			
Total/l	3.07	1.82	17.50	<60	6.76	10.12

Table 14

Species, Number of Individuals and Total Wet Weight

(Without Clam Shell) in Grams at Each Station (Benthos)

May 1974

	Stations															
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mollusks																
Rangia cuneata	50	15	3	22	13	52	13	11	6	10	31	17	7	14	37	22
Congeria leucophaeta	2							2			6					
Macoma mitchelli				1		1								2		1
Macoma balthica																
Corbicula manilensis	1					1						1		1		
Hydrobia sp.		2		42	1	11	9		4		4					
Mya arenaria																
Brachidontes recurvus																
Annelids																
Scolecolepides viridis			1		10	1			21	18				2		1
Nereis succinea		1	4			1	3				1	2		2		
Lysippides grayi																
Polydora ligni																
Laeonereis culveri																
Heteromastus filiformis					1			2								
Unid. capitellids																
Unid. oligochaetes	2	1	1		1	2			2		1	5				

Table 14

Species	Stations: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Amphipods																
Gammarus sp.	3	1	1	3		1	1	7	8	14	21	1		6	3	8
Corophium lacustre								21				1	1		3	
Lepidactylus dytiscus										4						
Leptocheirus plumulosus		2					3		5	6	1		3	2	4	24
Monoculodes edwardsi																
Caprellidae (unid.)																1
Isopods																
Cyathura polita																
Edotea triloba																
Chiridotea almyra					3		1				2					
Dipteran larvae	10		4			1	1		1	2		9				
Nemerteans									1		2					
Hydroids					x						x					
Biomass (grams)	10.6	4.0	1.7	3.7	2.9	2.8	3.0	0.6			8.0	2.9	1.4	1.8	3.1	0.6

Table 15

Species, Number of Individuals and Total Wet Weight

(Without Clam Shells in Grams at Each Station (Benthos)

February 1974

Species	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mollusks																
Rangia cuneata	33	14	1	24	12	27	1	16		11	15			3		2
Congeria leucophaeta								8		21						
Macoma mitchelli						1	1							2	5	1
Macoma balthica																
Mya arenaria																
Brachidontes recurvus																
Annelids																
Scolecolepides viridis	1				3					3	2		1	2		2
Nereis succinea		1				2		1	4	3	1	2				
Lysippides grayi																
Polydora ligni								1								
Laeonereis culveri																
Heteromastus filiformis											2					
Unid. capitellids																
Unid. oligochaetes	3	2	1	4	5	32	3	1		2	4			9		
Amphipods																
Gammarus sp.	1				1			1		1	2					
Corophium lacustre					1			3	1	29		2				
Leptocheirus plumulosus									2			1				16
Lepidactylus dytiscus									2							
Monoculodes edwardsi																

Table 15
-2-

Species	Stations 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Isopods																
Cyathura polita																
Edotea triloba																
Chiridotea almyra																
Dipteran larvae																
Coelotanypus sp.						3										
Cryptochironomus sp.					1	2							1			
Nemerteans (unid.)					1						4					
Nematodes (unid.)						1										
Biomass (grams)	6.0	3.0	0.6	4.8	2.2	9.8		2.0		1.5	3.5	0.1		0.2		0.1

Table 16

Fouling Organisms

	No./dm^2			
	Jan. '73 to Jan. '74	Jan.-Feb.	Mar.-April	May-June
Station (CBN)				
Balanus improvisus	Lost	3.3	2.4	140.0
Balanus eburneus		2.0	3.0	2.9
Corophium sp.		-	-	-
Station (CBS)				
Balanus improvisus	Lost	2.0	28.9	98.7
Balanus eburneus		-	-	14.0
Corophium sp.		7.0	-	-
Membranipora tenuis		-	-	17.2
Station (DWS)				
Balanus improvisus	Lost	10.0	14.7	75.0
Balanus eburneus		-	51.2	53.0
Corophium sp.		-	-	2.0
Membranipora tenuis		-	-	11.3

Table 17

NO. GRPS	LEVEL	CLUSTERS GROUPS	SAMPLES INCLUDED
79	0.8571	P2 3 AND P3 7	P2 3,P3 7,
78	0.8333	P016 AND P312	P016,P312,
77	0.7442	P0 4 AND P2 2	P0 4,P2 2,
76	0.7064	P0 2 AND P0 8	P0 2,P0 8,
75	0.6875	P3 2 AND P3 3	P3 2,P3 3,
74	0.6667	P3 1 AND P9 1	P3 1,P9 1,
73	0.6629	P1 6 AND P2 6	P1 6,P2 6,
72	0.6100	P0 5 AND P011	P0 5,P011,
71	0.6000	P9 3 AND P9 6	P9 3,P9 6,
70	0.5821	P0 2 AND P014	P0 2,P0 8,P014,
69	0.5772	P1 9 AND P9 2	P1 9,P9 2,
68	0.5704	P1 5 AND P2 4	P1 5,P2 4,
67	0.5643	P3 8 AND P313	P3 8,P313,
66	0.5529	P210 AND P3 5	P210,P3 5,
65	0.5438	P3 6 AND P315	P3 6,P315,
64	0.5308	P0 4 AND P2 1	P0 4,P2 1,P2 2,
63	0.5086	P1 4 AND P9 5	P1 4,P9 5,
62	0.5072	P0 5 AND P2 8	P0 5,P011,P2 8,
61	0.5048	P0 3 AND P3 2	P0 3,P3 2,P3 3,
60	0.4944	P010 AND P112	P010,P112,
59	0.4786	P912 AND P916	P912,P916,
58	0.4663	P116 AND P212	P116,P212,
57	0.4600	P9 4 AND P913	P9 4,P913,
56	0.4397	P013 AND P1 8	P013,P1 8,
55	0.4333	P211 AND P310	P211,P310,
54	0.4311	P1 4 AND P9 8	P1 4,P9 5,P9 8,
53	0.4231	P010 AND P012	P010,P012,P112,
52	0.4222	P314 AND P316	P314,P316,
51	0.4173	P0 1 AND P311	P0 1,P311,
50	0.4142	P1 5 AND P213	P1 5,P2 4,P213,

Table 17
-2-

49	0.3967	P1 2 AND P114	P1 2,P114,
48	0.3875	P0 9 AND P214	P0 9,P214,
47	0.3836	P1 9 AND P113	P1 9,P113,P9 2,
46	0.3819	P2 5 AND P210	P2 5,P210,P3 5,
45	0.3729	P0 4 AND P0 6	P0 4,P0 6,P2 1,P2 2,
44	0.3690	P3 8 AND P9 3	P3 8,P313,P9 3,P9 6,
43	0.3534	P010 AND P013	P010,P012,P013,P1 8,P112,
42	0.3528	P0 1 AND P0 7	P0 1,P0 7,P311,
41	0.3464	P0 5 AND P1 5	P0 5,P011,P1 5,P2 4,P2 8,P213,
40	0.3380	P1 3 AND P1 7	P1 3,P1 7,
39	0.3356	P3 1 AND P3 4	P3 1,P3 4,P9 1,
38	0.3251	P115 AND P116	P115,P116,P212,
37	0.3167	P015 AND P915	P015,P915,
36	0.3078	P9 9 AND P911	P9 9,P911,
35	0.2867	P0 5 AND P216	P0 5,P011,P1 5,P2 4,P2 8,P213,P216,
34	0.2743	P9 4 AND P914	P9 4,P913,P914,
33	0.2732	P115 AND P215	P115,P116,P212,P215,
32	0.2685	P110 AND P111	P110,P111,
31	0.2545	P2 3 AND P9 7	P2 3,P3 7,P9 7,
30	0.2531	P0 1 AND P0 3	P0 1,P0 3,P0 7,P3 2,P3 3,P311,
29	0.2312	P1 1 AND P3 1	P1 1,P3 1,P3 4,P9 1,
28	0.2247	P9 9 AND P910	P9 9,P910,P911,
27	0.2010	P0 4 AND P211	P0 4,P0 6,P2 1,P2 2,P211,P310,
26	0.1895	P1 2 AND P2 9	P1 2,P114,P2 9,
25	0.1738	P0 5 AND P1 6	P0 5,P011,P1 5,P1 6,P2 4,P2 6,P2 8,P213,P216,
24	0.1698	P015 AND P2 7	P015,P2 7,P915,
23	0.1561	P016 AND P314	P016,P312,P314,P316,
22	0.1528	P0 9 AND P1 9	P0 9,P1 9,P113,P214,P9 2,
21	0.1138	P110 AND P3 6	P110,P111,P3 6,P315,
20	0.1034	P1 2 AND P115	P1 2,P114,P115,P116,P2 9,P212,P215,
19	0.0674	P2 3 AND P3 8	P2 3,P3 7,P3 8,P313,P9 3,P9 6,P9 7,
18	0.0585	P0 1 AND P010	P0 1,P0 3,P0 7,P010,P012,P013,P1 8,P112,P3 2,P3 3,P311,

0.0530	P015 AND P3 9	P015,P2 7,P3 9,P915,
0.0514	P9 9 AND P912	P9 9,P910,P911,P912,P916,
0.0456	P015 AND P1 3	P015,P1 3,P1 7,P2 7,P3 9,P915,
0.0338	P1 4 AND P2 5	P1 4,P2 5,P210,P3 5,P9 5,P9 8,
0.0159	P0 2 AND P1 1	P0 2,P0 8,P014,P1 1,P3 1,P3 4,P9 1,
-0.0231	P0 9 AND P015	P0 9,P015,P1 3,P1 7,P1 9,P113,P2 7,P214,P3 9,P9 2,P915,
-0.0596	P0 1 AND P110	P0 1,P0 3,P0 7,P010,P012,P013,P1 8,P110,P111,P112,P3 2,P3 3,P3 6,P311,P315,
-0.0681	P2 3 AND P9 4	P2 3,P3 7,P3 8,P313,P9 3,P9 4,P9 6,P9 7,P913,P914,
-0.0687	P0 4 AND P0 5	P0 4,P0 5,P0 6,P011,P1 5,P1 6,P2 1,P2 2,P2 4,P2 6,P2 8,P211,P213,P216,P310,
-0.0743	P1 2 AND P1 4	P1 2,P1 4,P114,P115,P116,P2 5,P2 9,P210,P212,P215,P3 5,P9 5,P9 8,
-0.1682	P0 9 AND P9 9	P0 9,P015,P1 3,P1 7,P1 9,P113,P2 7,P214,P3 9,P9 2,P9 9,P910,P911,P912,P915,P916,
-0.2429	P0 9 AND P1 2	P0 9,P015,P1 2,P1 3,P1 4,P1 7,P1 9,P113,P114,P115,P116,P2 5,P2 7,P2 9,P210,P212,P214,P215,P3 5,P3 9,P9 2,P9 5,P9 8,P9 9,P910,P911,P912,P915,P916,
-0.3571	P0 4 AND P0 9	P0 4,P0 5,P0 6,P0 9,P011,P015,P1 2,P1 3,P1 4,P1 5,P1 6,P1 7,P1 9,P113,P114,P115,P116,P2 1,P2 2,P2 4,P2 5,P2 6,P2 7,P2 8,P2 9,P210,P211,P212,P213,P214,P215,P216,P3 5,P3 9,P310,P9 2,P9 5,P9 8,P9 9,P910,P911,P912,P915,P916,
-0.3899	P0 1 AND P0 4	P0 1,P0 3,P0 4,P0 5,P0 6,P0 7,P0 9,P010,P011,P012,P013,P015,P1 2,P1 3,P1 4,P1 5,P1 6,P1 7,P1 8,P1 9,P110,P111,P112,P113,P114,P115,P116,P2 1,P2 2,P2 4,P2 5,P2 6,P2 7,P2 8,P2 9,P210,P211,P212,P213,P214,P215,P216,P3 2,P3 3,P3 5,P3 6,P3 9,P310,P311,P315,P9 2,P9 5,P9 8,P9 9,P910,P911,P912,P915,P916,
-0.4051	P0 2 AND P2 3	P0 2,P0 8,P014,P1 1,P2 3,P3 1,P3 4,P3 7,P3 8,P313,P9 1,P9 3,P9 4,P9 6,P9 7,P913,P914,
-0.5790	P0 2 AND P016	P0 2,P0 8,P014,P016,P1 1,P2 3,P3 1,P3 4,P3 7,P3 8,P312,P313,P314,P316,P9 1,P9 3,P9 4,P9 6,P9 7,P913,P914,
-0.6692	P0 1 AND P0 2	P0 1,P0 2,P0 3,P0 4,P0 5,P0 6,P0 7,P0 8,P0 9,P010,P011,P012,P013,P014,P015,P016,P1 1,P1 2,P1 3,P1 4,P1 5,P1 6,P1 7,P1 8,P1 9,P110,P111,P112,P113,P114,P115,P116,P2 1,P2 2,P2 3,P2 4,P2 5,P2 6,P2 7,P2 8,P2 9,P210,P211,P212,P213,P214,P215,P216,P3 1,P3 2,P3 3,P3 4,P3 5,P3 6,P3 7,P3 8,P3 9,P310,P311,P312,P313,P314,P315,P316,P9 1,P9 2,P9 3,P9 4,P9 5,P9 6,P9 7,P9 8,P9 9,P910,P911,P912,P913,P914,P915,P916,
-0.6692		ALL ONE GROUP

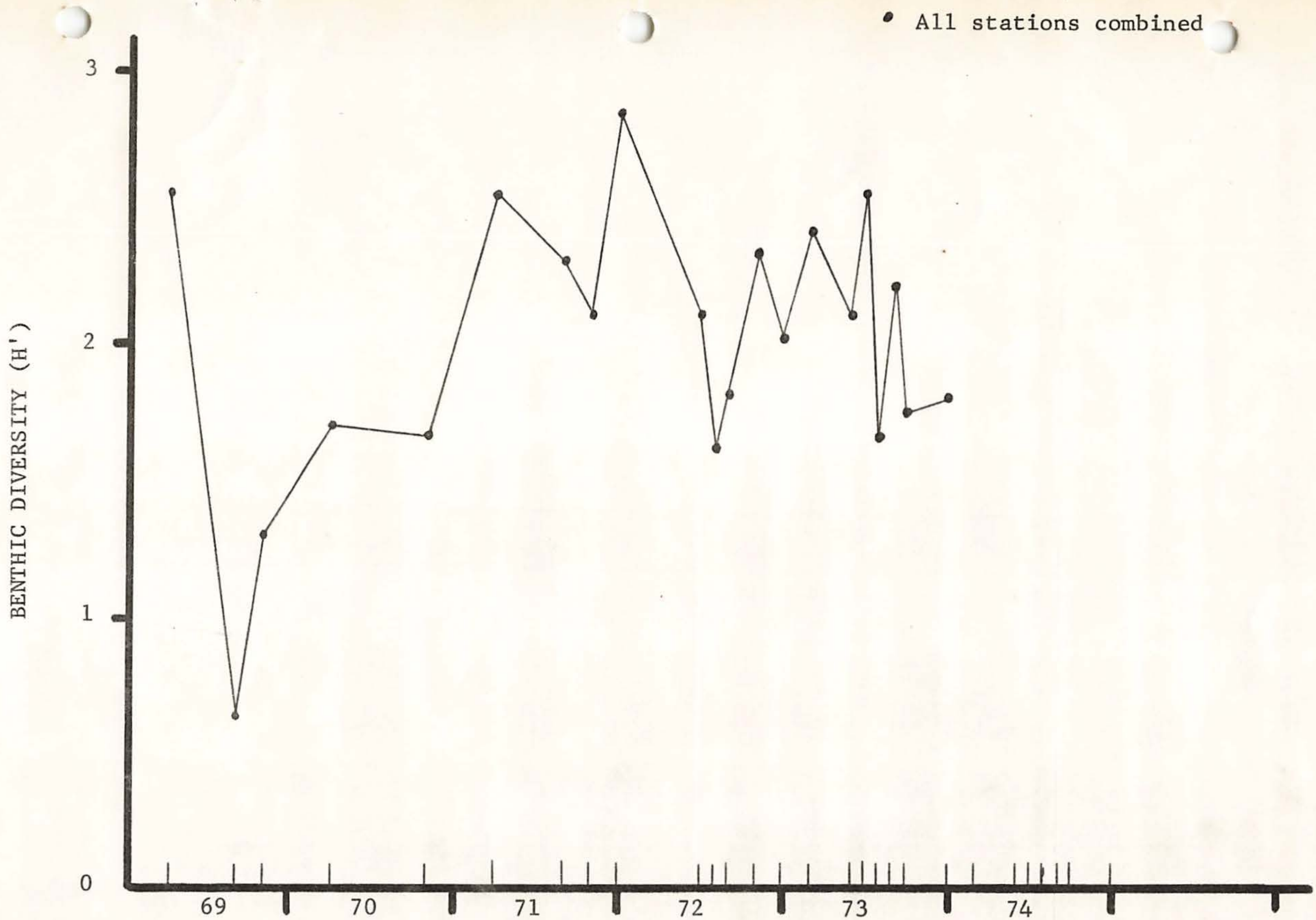
Table 18

NO. GRPS	LEVEL	CLUSTERS GROUPS	SAMPLES INCLUDED
78	0.9444	A1 1 AND A3 2	A1 1,A3 2,
77	0.8790	A2 4 AND A214	A2 4,A214,
76	0.8262	A3 6 AND A313	A3 6,A313,
75	0.7208	A1 9 AND A3 6	A1 9,A3 6,A313,
74	0.6667	A2 8 AND A913	A2 8,A913,
73	0.6250	A2 5 AND A9 3	A2 5,A9 3,
72	0.6239	A0 8 AND A013	A0 8,A013,
71	0.6139	A3 7 AND A310	A3 7,A310,
70	0.6068	A116 AND A3 4	A116,A3 4,
69	0.6037	A0 7 AND A115	A0 7,A115,
68	0.6016	A1 4 AND A1 8	A1 4,A1 8,
67	0.5728	A0 9 AND A213	A0 9,A213,
66	0.5429	A012 AND A015	A012,A015,
65	0.5399	A0 3 AND A0 7	A0 3,A0 7,A115,
64	0.5214	A3 5 AND A9 9	A3 5,A9 9,
63	0.5199	A0 3 AND A012	A0 3,A0 7,A012,A015,A115,
62	0.5089	A0 5 AND A016	A0 5,A016,
61	0.5000	A2 7 AND A312	A2 7,A312,
60	0.4833	A1 6 AND A113	A1 6,A113,
59	0.4827	A0 4 AND A0 8	A0 4,A0 8,A013,
58	0.4825	A010 AND A014	A010,A014,
57	0.4693	A3 1 AND A3 9	A3 1,A3 9,
56	0.4668	A1 3 AND A210	A1 3,A210,
55	0.4433	A1 5 AND A9 7	A1 5,A9 7,
54	0.4350	A914 AND A916	A914,A916,
53	0.4333	A912 AND A915	A912,A915,
52	0.4319	A114 AND A9 1	A114,A9 1,
51	0.4249	A0 5 AND A910	A0 5,A016,A910,
50	0.4174	A1 9 AND A2 5	A1 9,A2 5,A3 6,A313,A9 3,
49	0.4095	A2 9 AND A3 3	A2 9,A3 3,

Table 18
-2-

48	0.4052	A2 4 AND A216	A2 4,A214,A216,
47	0.4027	A116 AND A3 5	A116,A3 4,A3 5,A9 9,
46	0.3941	A2 6 AND A2 7	A2 6,A2 7,A312,
45	0.3641	A1 2 AND A3 7	A1 2,A3 7,A310,
44	0.3506	A0 6 AND A1 6	A0 6,A1 6,A113,
43	0.3490	A2 2 AND A2 8	A2 2,A2 8,A913,
42	0.3372	A0 2 AND A011	A0 2,A011,
41	0.3356	A1 5 AND A1 7	A1 5,A1 7,A9 7,
40	0.3333	A9 2 AND A9 8	A9 2,A9 8,
39	0.3120	A0 1 AND A0 3	A0 1,A0 3,A0 7,A012,A015,A115,
38	0.3096	A010 AND A112	A010,A014,A112,
37	0.3000	A314 AND A316	A314,A316,
36	0.2985	A9 4 AND A911	A9 4,A911,
[illegible]	0.2906	A211 AND A311	A211,A311,
34	0.2621	A1 5 AND A215	A1 5,A1 7,A215,A9 7,
33	0.2607	A0 6 AND A9 5	A0 6,A1 6,A113,A9 5,
32	0.2575	A3 8 AND A9 6	A3 8,A9 6,
31	0.2528	A116 AND A2 6	A116,A2 6,A2 7,A3 4,A3 5,A312,A9 9,
30	0.2457	A2 3 AND A212	A2 3,A212,
29	0.2334	A0 5 AND A010	A0 5,A010,A014,A016,A112,A910,
28	0.2141	A2 9 AND A3 1	A2 9,A3 1,A3 3,A3 9,
27	0.2050	A0 9 AND A1 3	A0 9,A1 3,A210,A213,
26	0.1904	A114 AND A2 1	A114,A2 1,A9 1,
25	0.1822	A110 AND A9 4	A110,A9 4,A911,
24	0.1789	A2 2 AND A914	A2 2,A2 8,A913,A914,A916,
23	0.1613	A1 2 AND A1 4	A1 2,A1 4,A1 8,A3 7,A310,
22	0.1474	A0 6 AND A9 2	A0 6,A1 6,A113,A9 2,A9 5,A9 8,
21	0.1436	A211 AND A314	A211,A311,A314,A316,
20	0.1329	A3 8 AND A912	A3 8,A9 6,A912,A915,
19	0.0877	A0 9 AND A1 5	A0 9,A1 3,A1 5,A1 7,A210,A213,A215,A9 7,
18	0.0874	A0 2 AND A0 4	A0 2,A0 4,A0 8,A011,A013,
17	0.0457	A1 1 AND A114	A1 1,A114,A2 1,A3 2,A9 1,
[illegible]	0.0315	A1 2 AND A1 9	A1 2,A1 4,A1 6,A1 9,A2 5,A3 6,A3 7,A310,A313,A9 3,

15	0.0300	A0 2 AND A0 5	A0 2,A0 4,A0 5,A0 8,A010,A011,A013,A014,A016,A112, A910,
14	-0.0070	A2 9 AND A3 8	A2 9,A3 1,A3 3,A3 8,A3 9,A9 6,A912,A915,
13	-0.0164	A0 9 AND A116	A0 9,A1 3,A1 5,A1 7,A116,A2 6,A2 7,A210,A213,A215, A3 4,A3 5,A312,A9 7,A9 9,
12	-0.0256	A0 6 AND A110	A0 6,A1 6,A110,A113,A9 2,A9 4,A9 5,A9 8,A911,
11	-0.0614	A2 3 AND A315	A2 3,A212,A315,
10	-0.0703	A0 1 AND A0 2	A0 1,A0 2,A0 3,A0 4,A0 5,A0 7,A0 8,A010,A011,A012, A013,A014,A015,A016,A112,A115,A910,
9	-0.1075	A0 6 AND A211	A0 6,A1 6,A110,A113,A211,A311,A314,A316,A9 2,A9 4, A9 5,A9 8,A911,
8	-0.2063	A0 9 AND A1 2	A0 9,A1 2,A1 3,A1 4,A1 5,A1 7,A1 8,A1 9,A116,A2 5, A2 6,A2 7,A210,A213,A215,A3 4,A3 5,A3 6,A3 7,A310, A312,A313,A9 3,A9 7,A9 9,
7	-0.2184	A0 6 AND A2 3	A0 6,A1 6,A110,A113,A2 3,A211,A212,A311,A314,A315, A316,A9 2,A9 4,A9 5,A9 8,A911,
6	-0.2371	A2 2 AND A2 9	A2 2,A2 8,A2 9,A3 1,A3 3,A3 8,A3 9,A9 6,A912,A913, A914,A915,A916,
5	-0.2668	A0 6 AND A2 2	A0 6,A1 6,A110,A113,A2 2,A2 3,A2 8,A2 9,A211,A212, A3 1,A3 3,A3 8,A3 9,A311,A314,A315,A316,A9 2,A9 4, A9 5,A9 6,A9 8,A911,A912,A913,A914,A915,A916,
4	-0.3202	A0 9 AND A2 4	A0 9,A1 2,A1 3,A1 4,A1 5,A1 7,A1 8,A1 9,A116,A2 4, A2 5,A2 6,A2 7,A210,A213,A214,A215,A216,A3 4,A3 5, A3 6,A3 7,A310,A312,A313,A9 3,A9 7,A9 9,
3	-0.4344	A0 6 AND A1 1	A0 6,A1 1,A1 6,A110,A113,A114,A2 1,A2 2,A2 3,A2 8, A2 9,A211,A212,A3 1,A3 2,A3 3,A3 8,A3 9,A311,A314, A315,A316,A9 1,A9 2,A9 4,A9 5,A9 6,A9 8,A911,A912, A913,A914,A915,A916,
2	-0.6019	A0 6 AND A0 9	A0 6,A0 9,A1 1,A1 2,A1 3,A1 4,A1 5,A1 6,A1 7,A1 8, A1 9,A110,A113,A114,A116,A2 1,A2 2,A2 3,A2 4,A2 5, A2 6,A2 7,A2 8,A2 9,A210,A211,A212,A213,A214,A215, A216,A3 1,A3 2,A3 3,A3 4,A3 5,A3 6,A3 7,A3 8,A3 9, A310,A311,A312,A313,A314,A315,A316,A9 1,A9 2,A9 3, A9 4,A9 5,A9 6,A9 7,A9 8,A9 9,A911,A912,A913,A914, A915,A916,
1	-0.8007	A0 1 AND A0 6	A0 1,A0 2,A0 3,A0 4,A0 5,A0 6,A0 7,A0 8,A0 9,A010, A011,A012,A013,A014,A015,A016,A1 1,A1 2,A1 3,A1 4, A1 5,A1 6,A1 7,A1 8,A1 9,A110,A112,A113,A114,A115, A116,A2 1,A2 2,A2 3,A2 4,A2 5,A2 6,A2 7,A2 8,A2 9, A210,A211,A212,A213,A214,A215,A216,A3 1,A3 2,A3 3, A3 4,A3 5,A3 6,A3 7,A3 8,A3 9,A310,A311,A312,A313, A314,A315,A316,A9 1,A9 2,A9 3,A9 4,A9 5,A9 6,A9 7, A9 8,A9 9,A910,A911,A912,A913,A914,A915,A916,
1	-0.8007		ALL ONE GROUP



All stations combined
BENTHIC DIVERSITY (H')
3
2
1
0
69
70
71
72
73
74

Figure 1

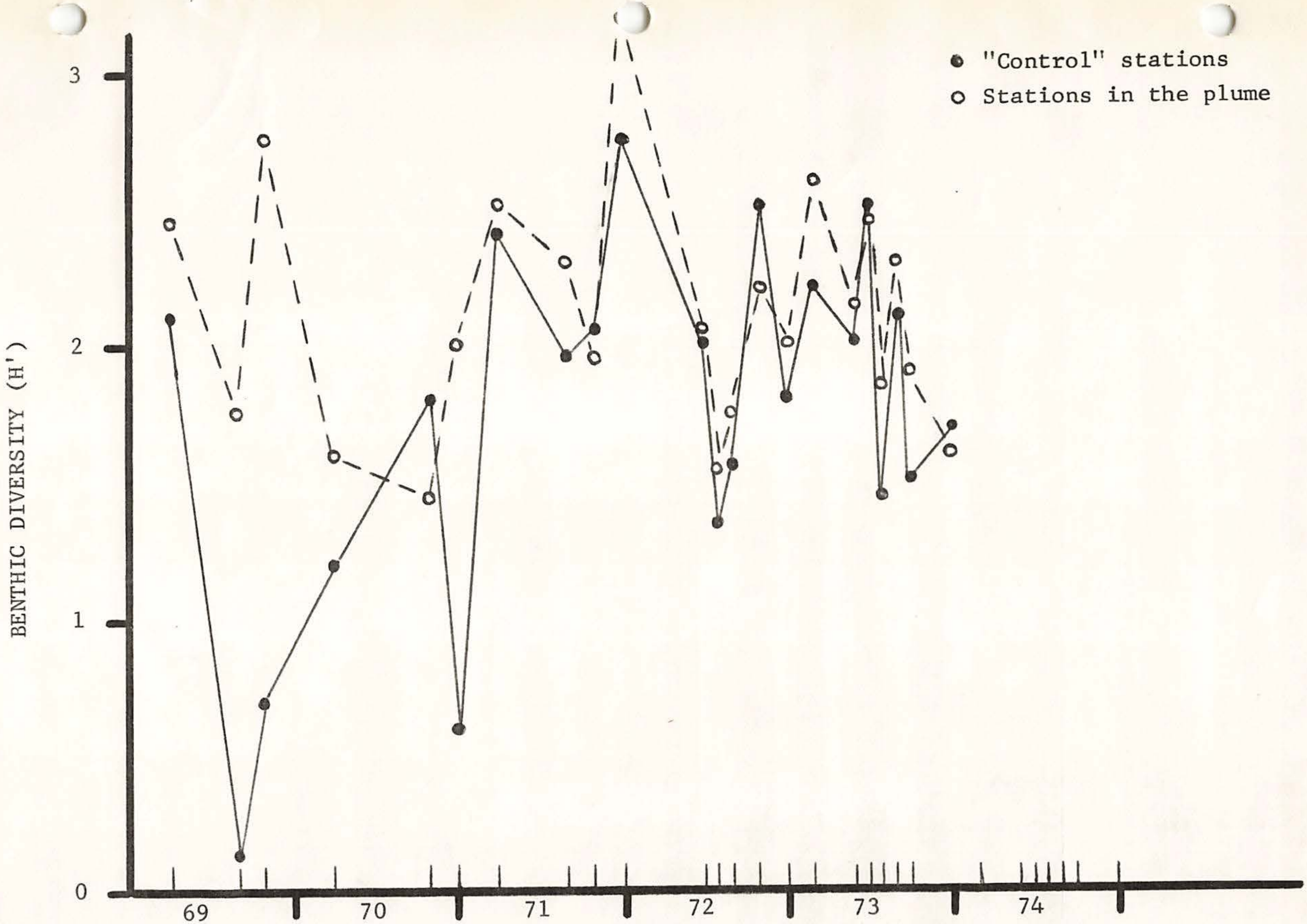
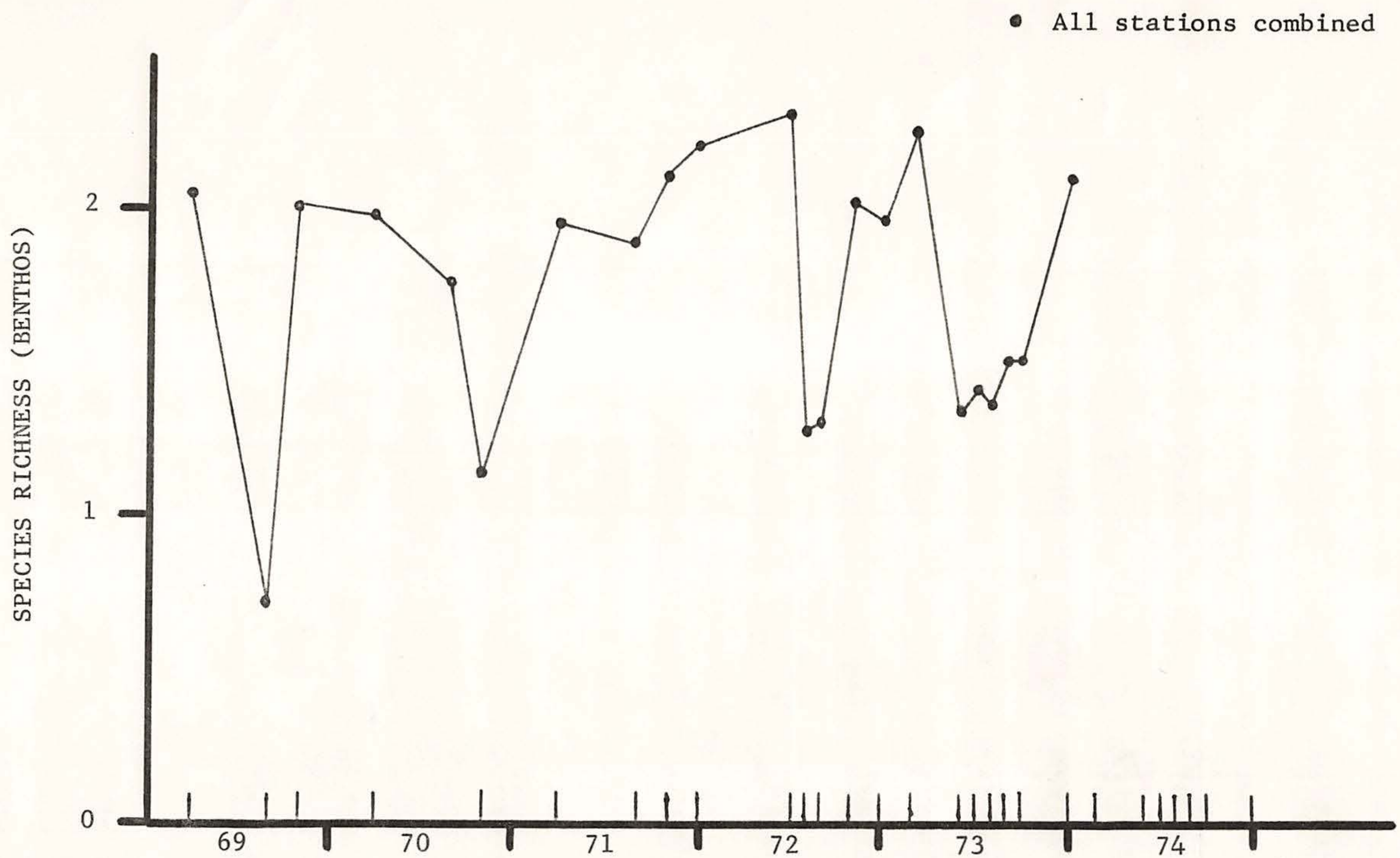
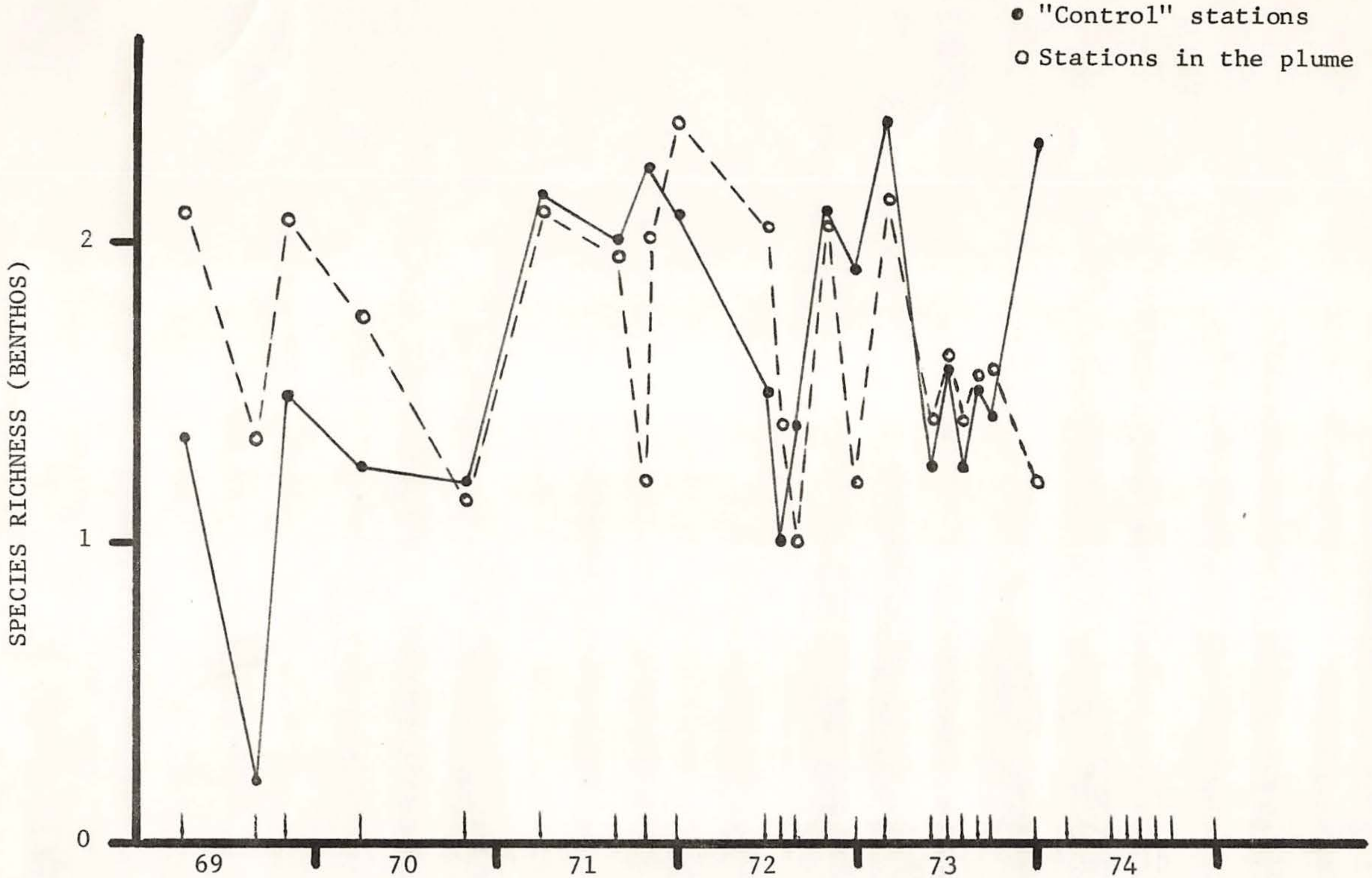

"Control" stations
Stations in the plume
BENTHIC DIVERSITY (H')
3
2
1
0
69
70
71
72
73
74

Figure 2



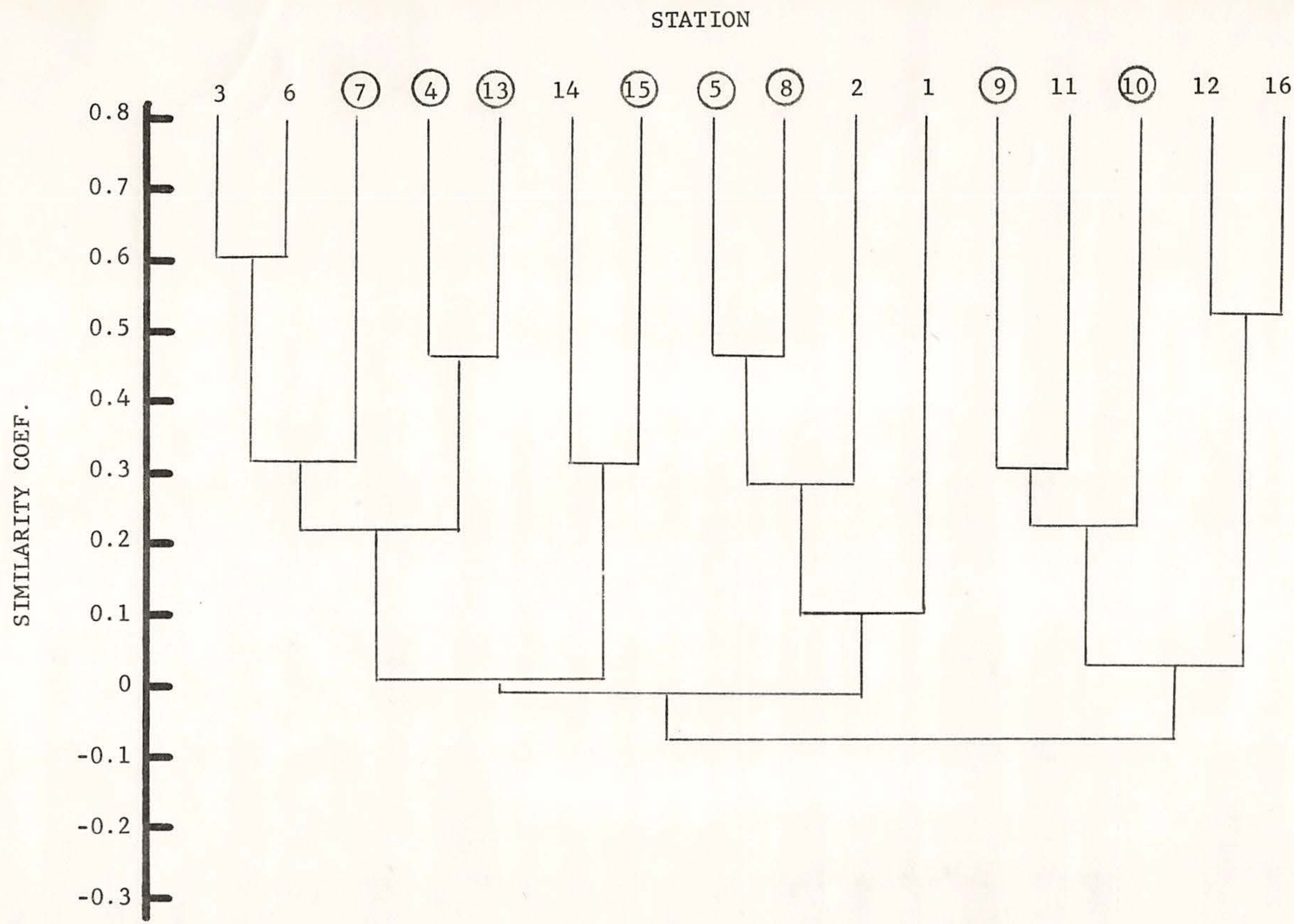
All stations combined
SPECIES RICHNESS (BENTHOS)
0
1
2
69
70
71
72
73
74

Figure 3



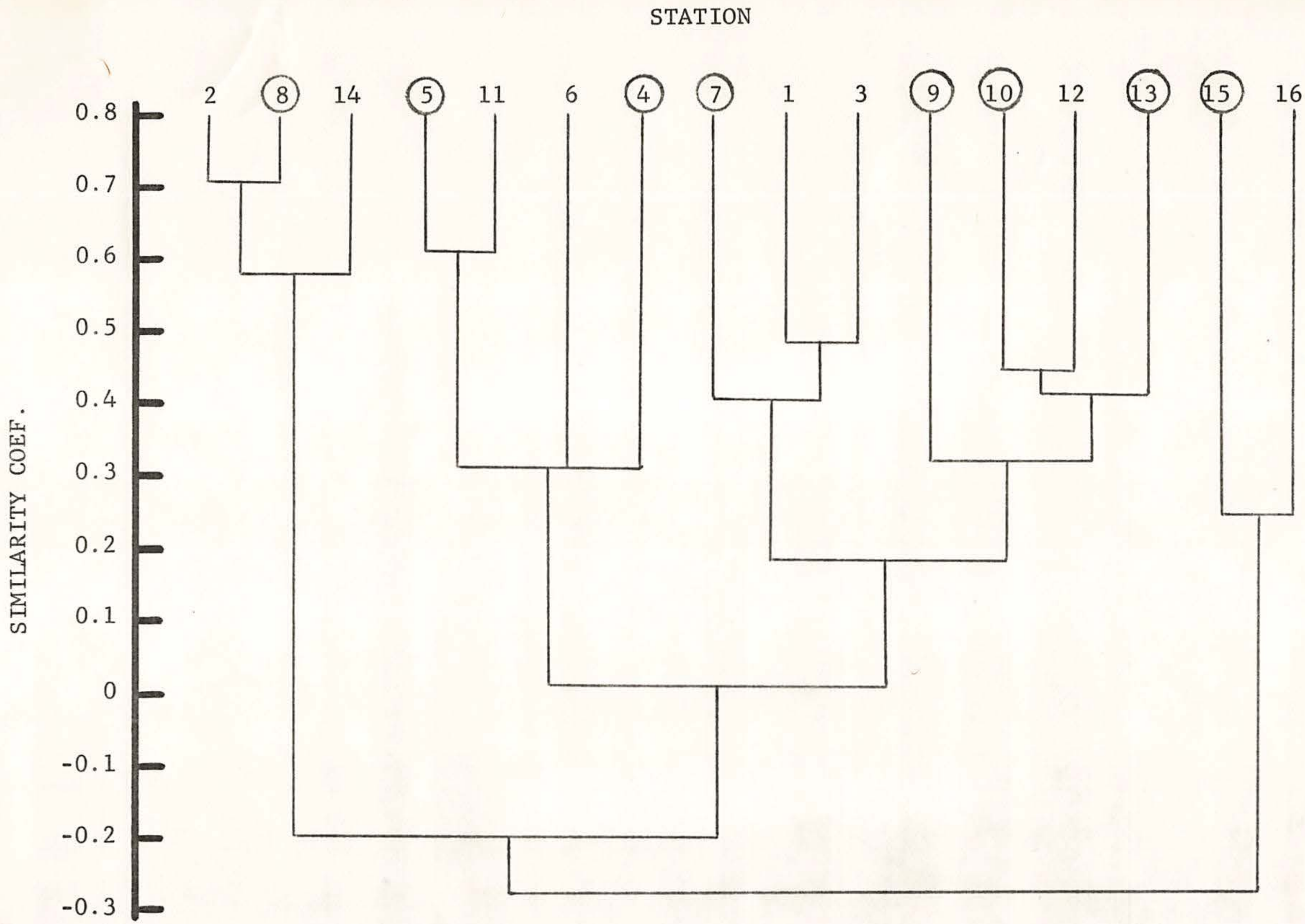
• "Control" stations
o Stations in the plume
SPECIES RICHNESS (BENTHOS)
2
1
0
69
70
71
72
73
74

Figure 4



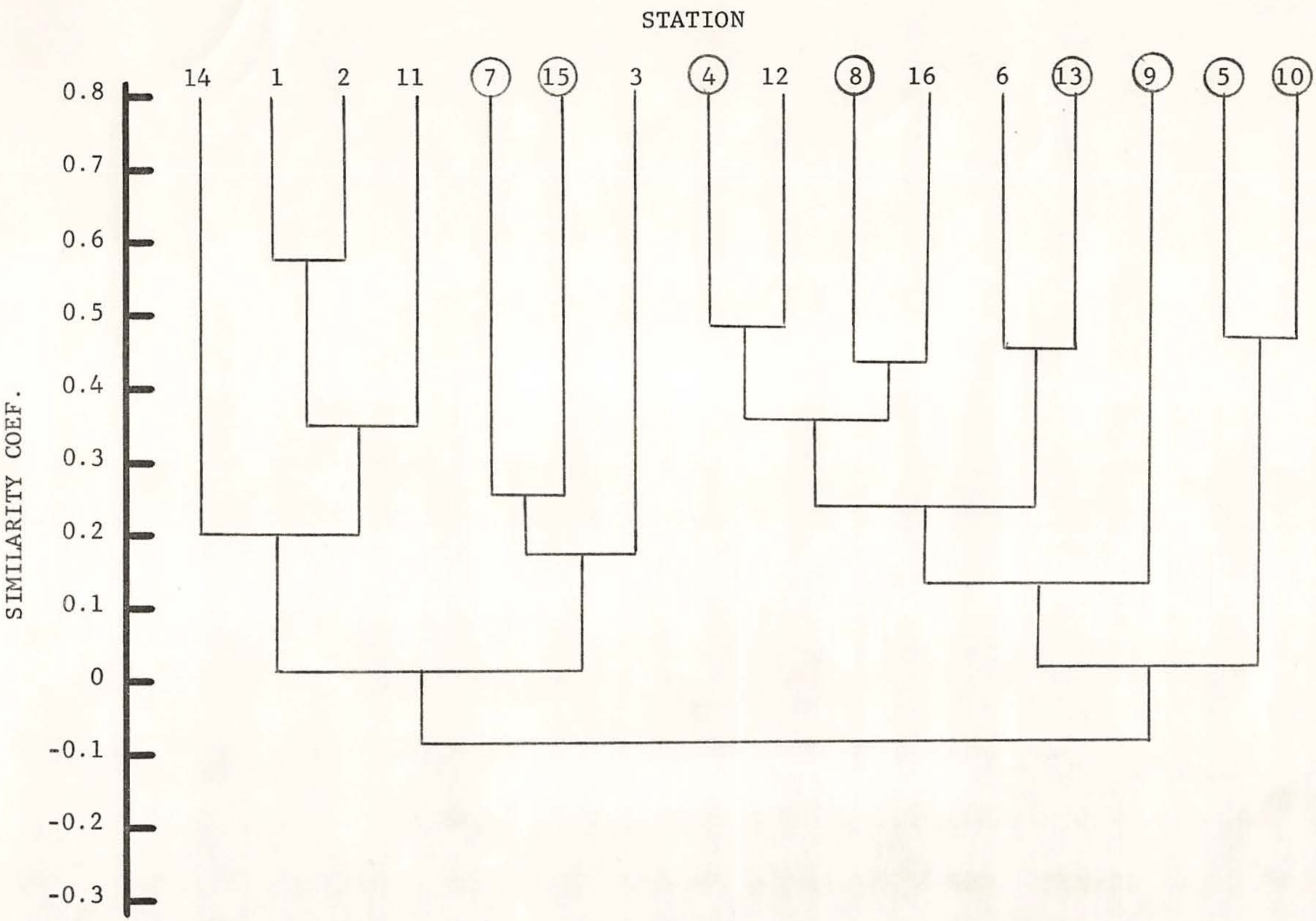
SPRING 1969

Figure 5



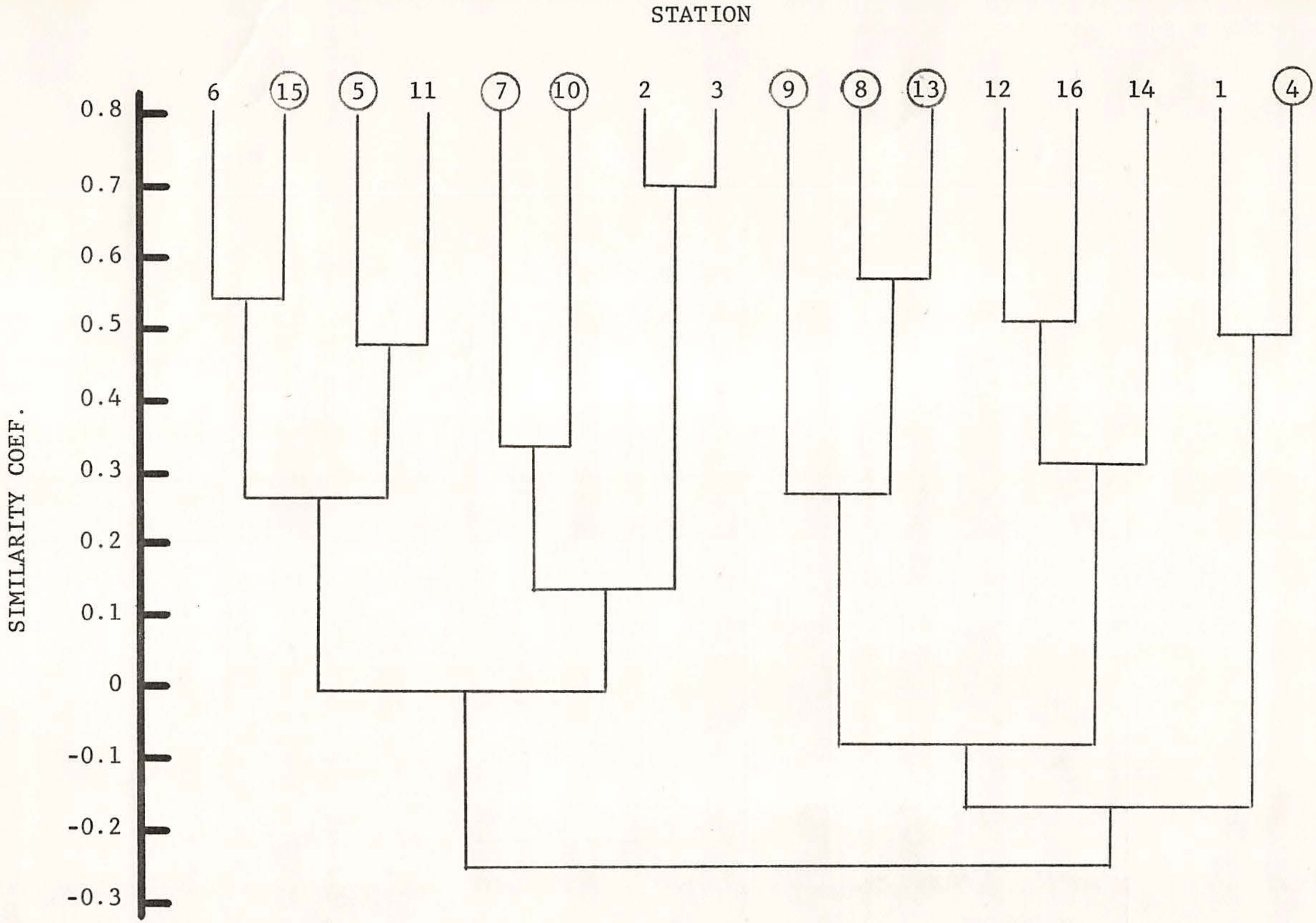
SPRING 1970

Figure 6



SPRING 1972

Figure 7



SPRING 1973

Figure 8

JAMES RIVER SAMPLING STATIONS

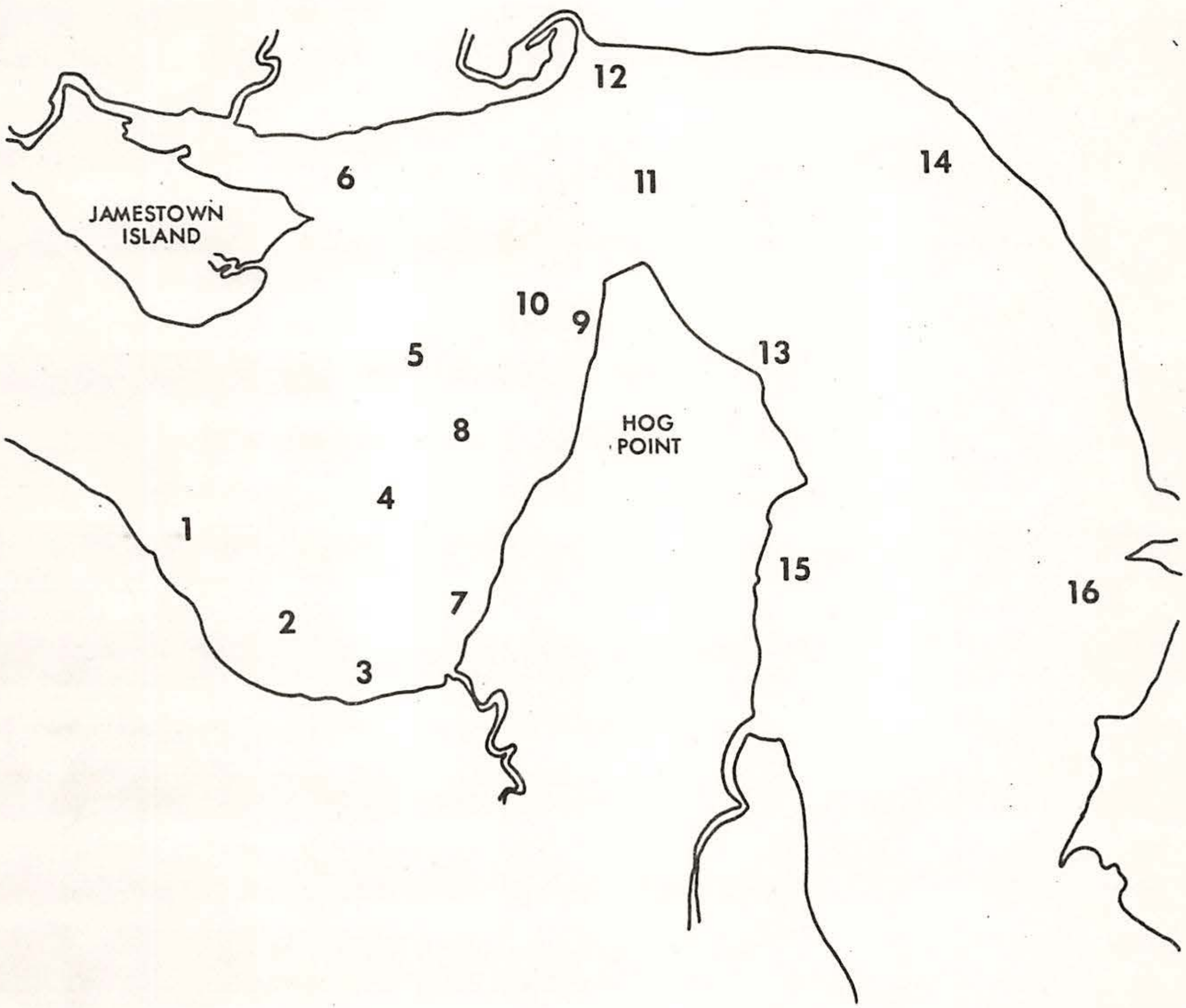
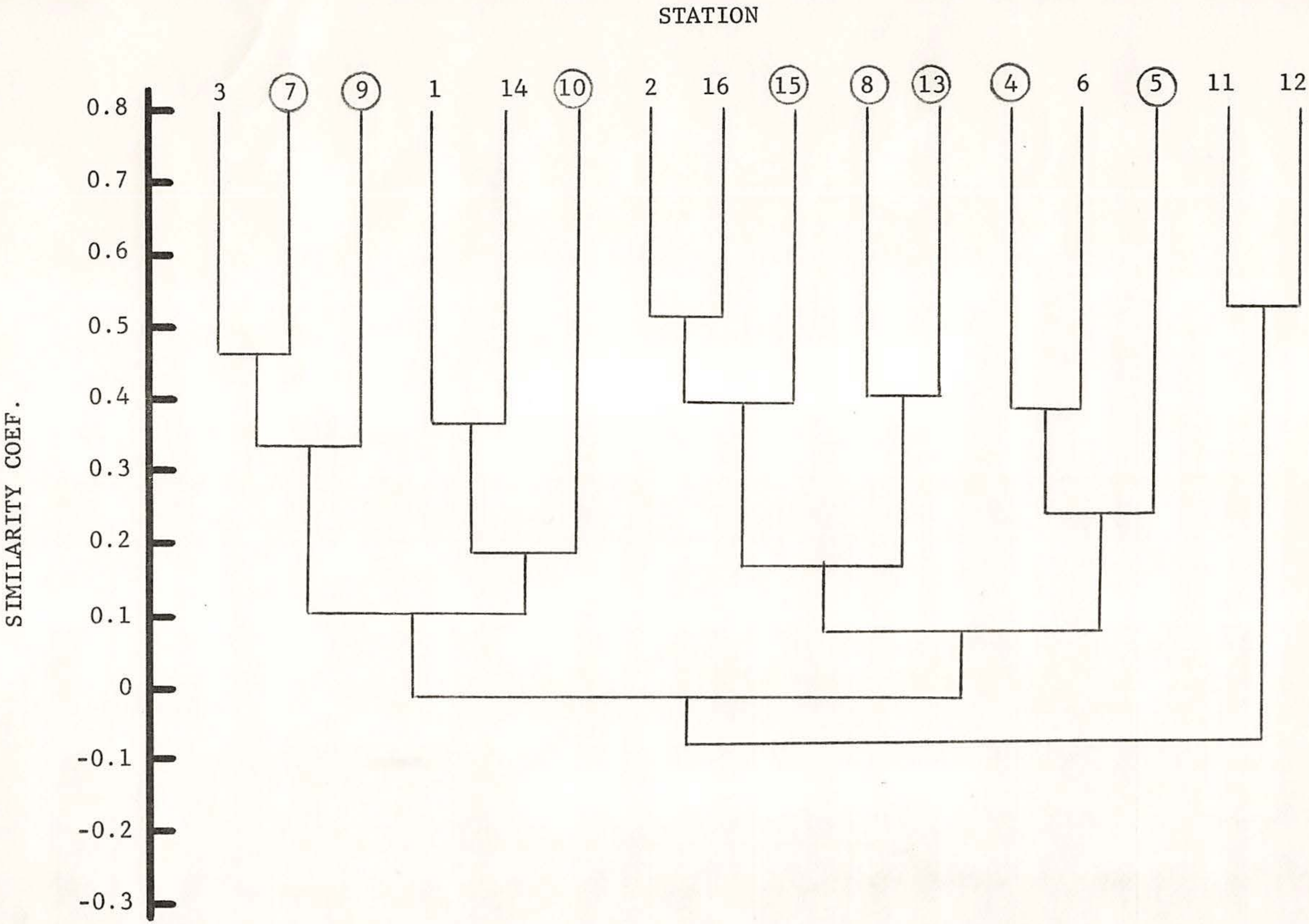
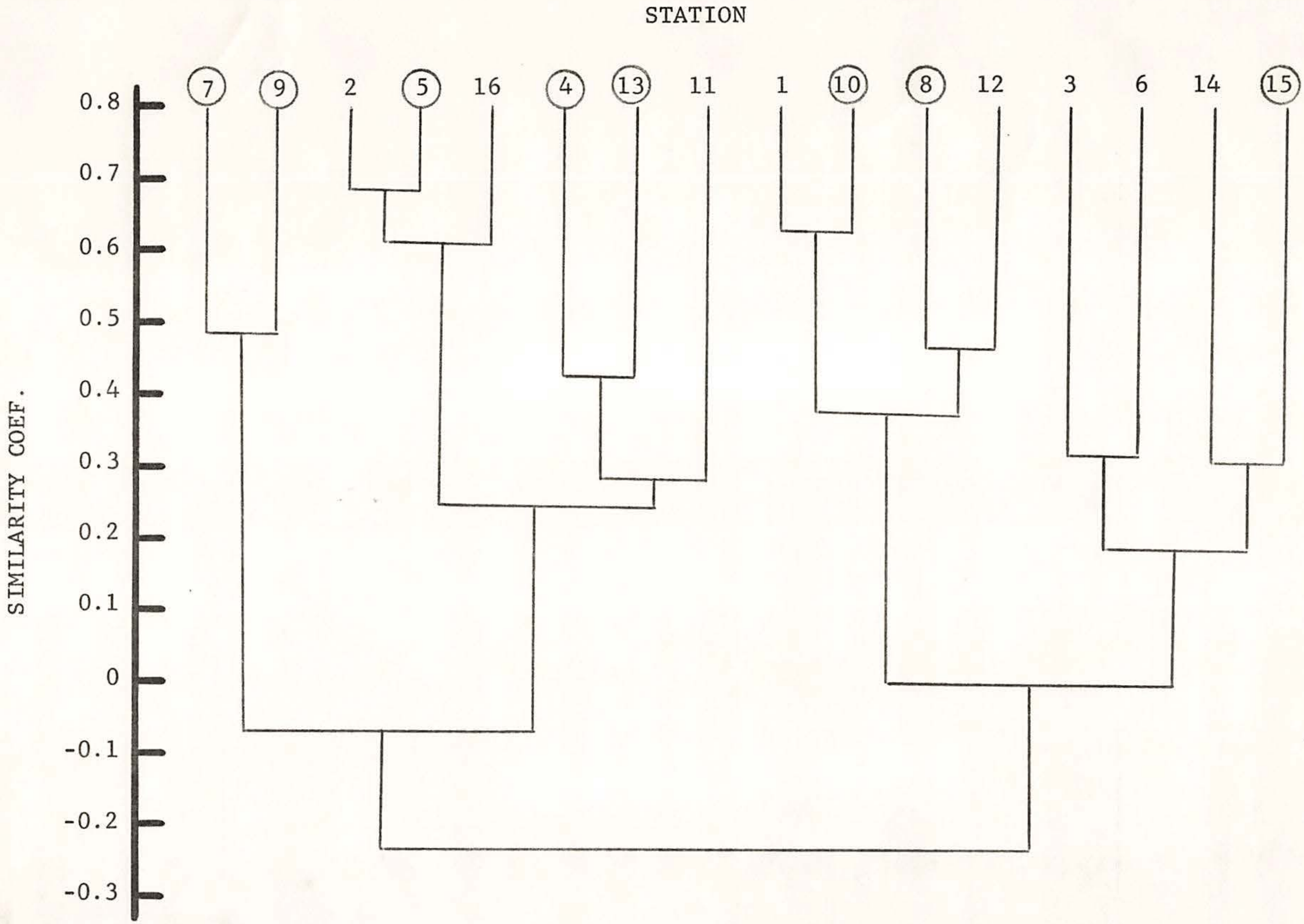


Figure 9



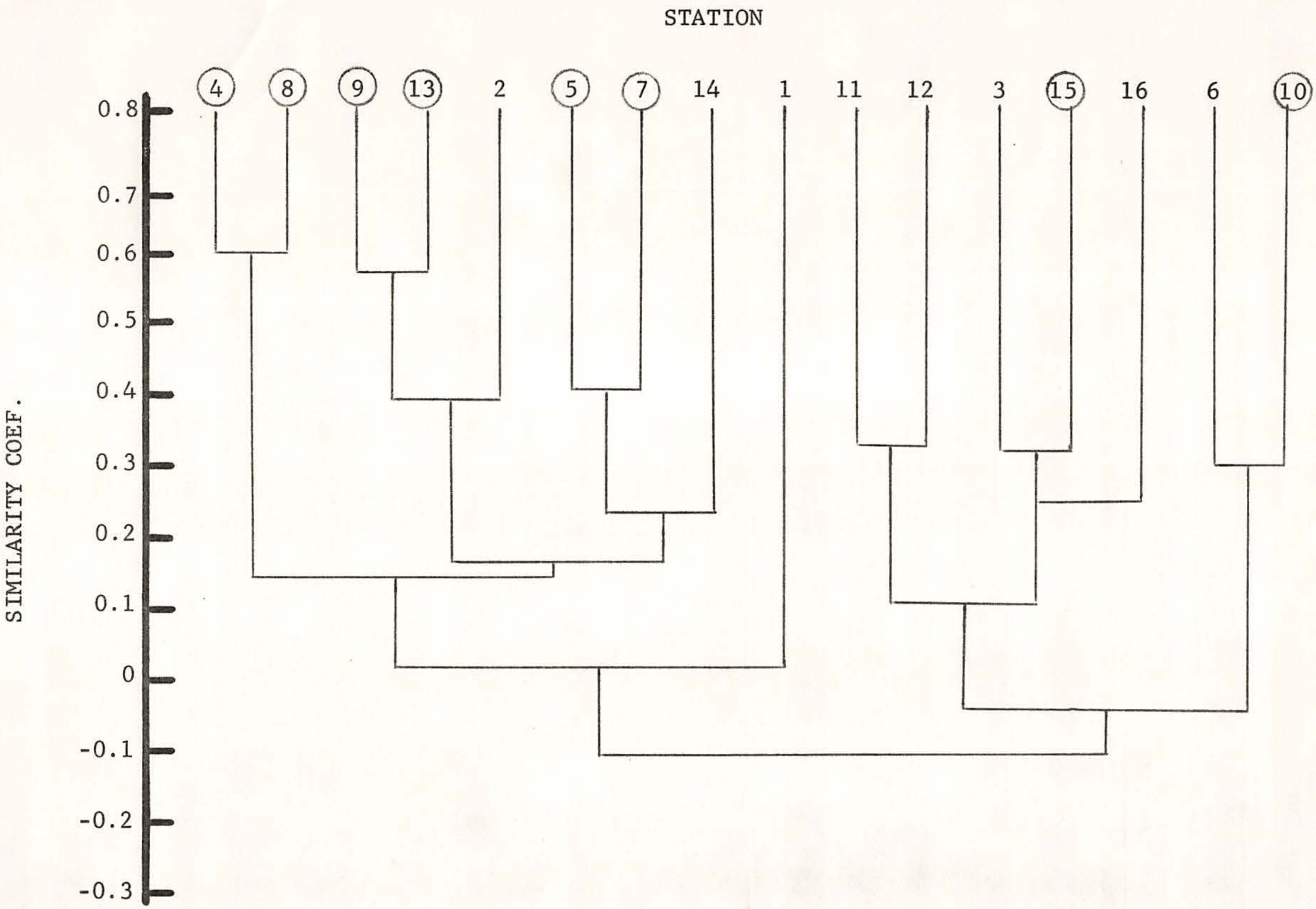
SUMMER 1971

Figure 10



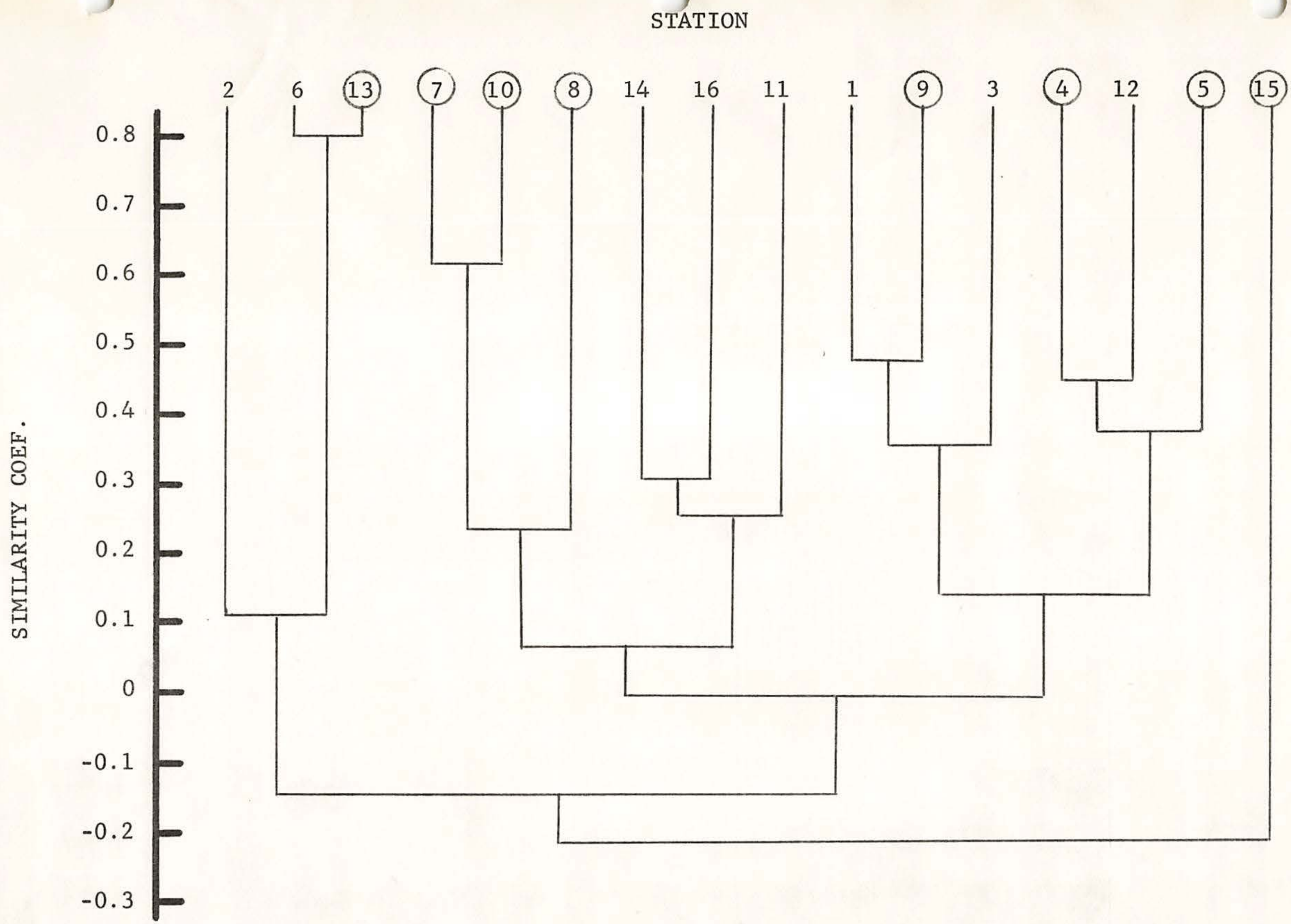
SUMMER 1973

Figure 11



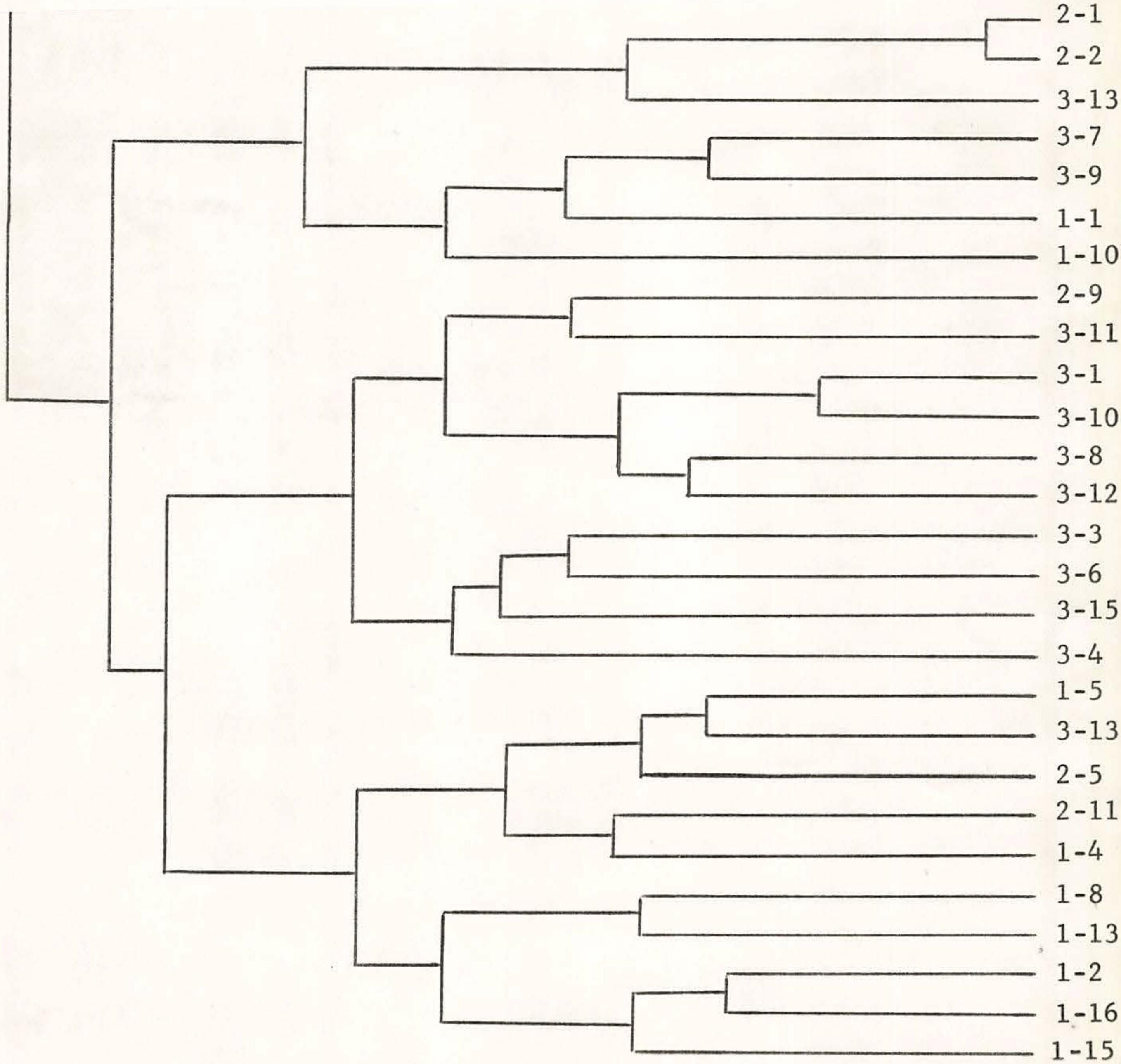
FALL 1971

Figure 12



FALL 1973

Figure 13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1-15

Figure 14

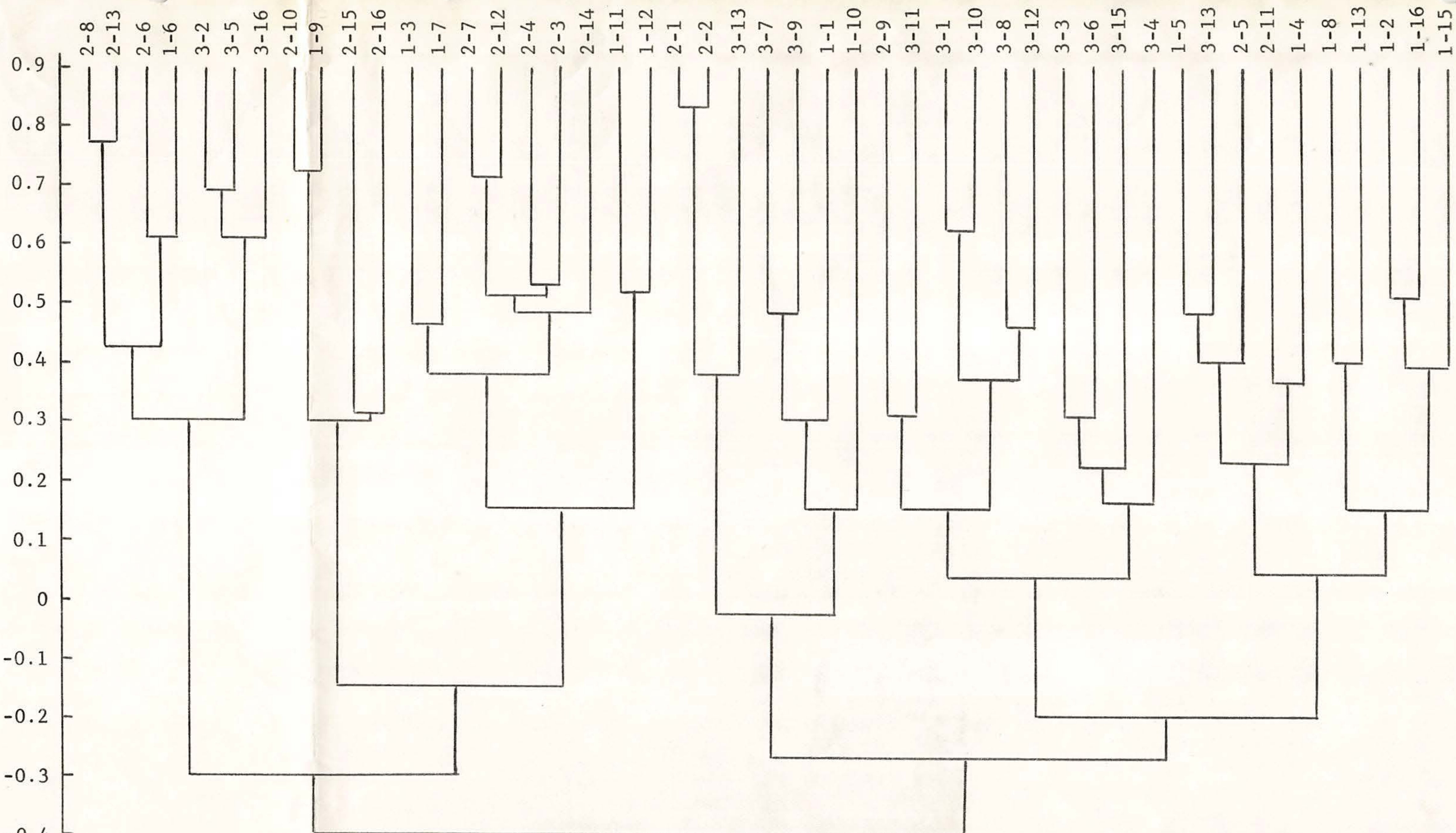
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Figure 14