ENVIRONMENTAL STUDIES,

SOUTH TEXAS OUTER CONTINENTAL SHELF,

BIOLOGY AND CHEMISTRY

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CHAPTER ELEVEN

PHYTOPLANKTON AND PRODUCTIVITY

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ABSTRACT

The 1977 phytoplankton and productivity studies consisted of (1) water column light extinction measurements; (2) phytoplankton species counts; (3) chlorophyll a determinations; (4) carbon uptake determinations; and (5) continuous measurement of surface chlorophyll a, temperature and salinity along Transect II. General methods for 2, 3 and 4 are presented in flow charts.

Secchi depth generally increased offshore except when unusual interdigitation of turbid and clear water coincided with station samples. Biomass generally decreased offshore both as chlorophyll a concentration and cell numbers. The nanno-fraction dominated the chlorophyll a values. The diatoms dominated inshore while the coccolithophorids dominated offshore. Carbon uptake paralleled the biomass patterns, but were less variable across the shelf. Assimilation numbers identified May as an especially efficient month for growth; along shelf gradients suggest that Transects I, II and III were more productive than Transect IV.

Depth profiles identified variable vertical structure during the seasonal cruises. The nanno-fraction dominated the water column at all depths especially in spring and fall.

Monthly samples along Transect II demonstrated the seasonal changes that occurred in biomass and production. The spring bloom began with a netphytoplankton peak followed by a nannophytoplankton peak. In the fall, the size fractions occurred in reverse order. The continuous measurements along Transect II clearly defined the physical processes (run-off, upwelling, wind mixing) that resulted in increases in phytoplankton biomass during 1977. *Skeletonema costatum* was the dominant netphytoplankter.

The interrelationships among Secchi depth, phytoplankton abundances, and chlorophyll a were good. Carbon uptake was anomalously high during May. A distinction can be made between the effect of Mississippi River water and more local run-off.

INTRODUCTION

The 1977 BLM-STOCS contract provided for a number of phytoplankton-related analyses: 1) measure the light extinction of the water column; 2) enumerate phytoplankton species; 3) determine chlorophyll a concentrations in net-and nannophytoplankton fractions; 4) determine the absolute carbon uptake in the net- and nannophytoplankton fractions; and 5) continuously measure chlorophyll a, temperature, and conductivity from the surface waters along Transect II. The two latter studies were performed for the first time in 1977 and significantly contributed to a broader understanding of STOCS processes.

Each of those measurements was backed by extensive literature. Water column light measurements including Secchi depth were reviewed by Strickland (1958). Jerlov and Steeman-Nielsen (1974) provided a recent discussion of biologically pertinent optical oceanography. Steidinger (in El-Sayed *et al.*, 1972) discussed phytoplankton species enumerations in the eastern Gulf of Mexico. Parsons *et al.* (1977) reviewed the applications of the chlorophyll a and ^{14}C techniques. Steeman-Nielsen (1975) specifically summarized various aspects of marine photosynthesis. Malone (1971) considered the implications of relative photosynthesis in the net- and nannophytoplankton fractions. Platt and Denman (1975) demonstrated the utility of continuously measured *in vivo* fluorescence to characterize phytoplankton spatial heterogeneity.

Historical data on the phytoplankton of the STOCS area is generally confined to the previous years of the BLM program. Two reports (Van Baalen, 1976 and Kamykowski *et al.*, 1977) summarize the data collections during 1975 and 1976, respectively. Additional information that may be generalized to the STOCS area is available in El Sayed *et al.* (1972).

MATERIAL AND METHODS

Samples for the various analyses were collected as shown in Table 11.1. The methodology for each measurement is discussed below.

Light Extinction

Secchi depth determinations were made at each station. The use of the LAMBDA submarine photometer depended on weather conditions and instrument availability. The latter data was collected at 53 out of 87 possible stations for a success rate of 61%.

Chlorophyll a and Carbon Uptake Determinations

30-ℓ Niskin Bottle

Chlorophyll *a*

3-5 ℓ of water filtered through 20 µm Nytex mesh; 2-4 ℓ of filtrate filtered through 0.4 µm 47 mm NUCLEPORE filter (3 filters) with gentle suction; time 30-40 minutes

↓

Place filters in CORNING 8446 rubes and freeze immediately; return samples to lab

↓

Add 4 ml of 90% acetone (redistilled) and approximately 1 mg $NaHCO_3$, disturb with glass rod, extract at room temperature in dark for 1 hr

↓

Filter through fine porosity sintered glass filter (CORNING 36060, size 15F), wash tube and filter and make to 5 ml

↓

Record absorbance 570 to 710 nm, 1 cm cuvette, CARY 118 c spectrophotometer, acidify sample and rerun spectrum

↓

SCOR-UNESCO values are used in the following discussion

Carbon Uptake

12 125-ml reagent bottles filled with seawater; 6 are clear and 6 are wrapped with black PVC tape; each bottle inoculated with 5 µCi ^{14}C labeled sodium bicarbonate; incubated 3 hr; all 12 bottles in temperature-controlled light box

↓

Following termination of incubation, 3 clear and 3 dark bottles filtered through 20 µm Nytex screen and filtrate filtered through 0.45 µm millipore HA filter; other 3 clear and 3 dark bottles only filtered through 0.45 µm membrane filter

↓

All membrane filters transferred to individual scintillation vials prefilled with toluene fluor. Stored for laboratory counts of activity on PACKARD Liquid Scintillation Counter

↓

Additional sample collected for determination of alkalinity

↓

Light bottle values without dark subtraction are used in the following discussion

TABLE 11.1

SAMPLING SCHEME FOR 1977

Light Extinction:

Seasonal - Transect I, III, IV, Stations 1, 2, 3;
Transect II, Stations 1, 2, 3, 4, 5, 6;
Hospital Rock, Southern Bank;

Monthly - Transect II, Stations 1, 2, 3, 4, 5, 6

Phytoplankton Species:

Seasonal - Transect I, II, III, IV, Stations 1, 2, 3;
Depth: surface and half-photic zone.

Monthly - Transect II, Stations 1, 2, 3;
Depth: surface and half photic zone

Chlorophyll a:

Seasonal - Transect I, II, III, IV, Stations 1, 2, 3;
Depth: surface and half-photic zone

Monthly - Transect II, Stations 1, 2, 3;
Depth: surface, half-photic zone, bottom

Carbon Uptake:

Seasonal - Transect I, II, III, IV, Stations 1, 2, 3;
Depth: surface

Monthly - Transect II, Stations 1, 2, 3;
Depth: surface

Continuous Chlorophyll a, Temperature, Conductivity:

Seasonal - Transect II, Stations continuous between
3 and Port Aransas jetties; Depth: ~ 2 meters

Monthly - Transect II, Stations continuous between
3 and Port Aransas jetties; Depth: ~ 2 meters

Phytoplankton Counts

Same 30-ℓ Niskin Bottle

↓

Preserve 1 ℓ water in 2% formalin solution; 250 ml water in Lugol's solution; return to lab

↓

Pour preserved water aliquot into 10, 50, or 100 ml settling chamber (ZEISS), let stand for 24 hr.

↓

Examine quantitative section of slide at 200X magnification on an inverted microscope; record species and abundances. Use ZEISS compound scope for species verification

↓

Examine quantitative section of slide at 400X magnification on an inverted microscope, record coccolithophorid and nannoflagellate abundances

↓

Return counted aliquots to sample bottle; settle total volume; siphon off supernatant until 10 ml remains; archive remaining liquid and cells

Continuous Chlorophyll a, Temperature and Conductivity

A continuous record of *in vivo* fluorescence (TURNER DESIGNS Fluorometer), temperature and conductivity (MARTEK TDC) was made for near-surface seawater available in the R/V LONGHORN's wet lab. Periodically data were collected on *in vivo* chlorophyll a, temperature and salinity to calibrate continuous measurements. Information on chlorophyll a, temperature and salinity has been reported at one mile intervals along Transect II.

RESULTS

The results presented herein analyze the data for significant patterns and trends. The raw data are included in Appendix J.

Seasonal Surface Patterns

The seasonal surface patterns of measured parameters are given in Figures 11.1-11.9. Secchi depth was determined by water column turbidity resulting from suspended sediments or phytoplankton biomass. Figure 11.1 provides the general impression of decreasing turbidity (*i.e.* increasing Secchi depth) offshore. This general trend was subject to occasional reversals depending on the specific water masses occurring at a geographic location during the sampling. Occasionally, turbid water occurred offshore of clearer inshore water.

Figure 11.2 provides an index of phytoplankton biomass as measured by chlorophyll a. A general offshore decrease is evident. Inshore, Transects II, III and IV displayed biomass peaks in winter and fall. Offshore, the highest concentration generally occurred in winter; phytoplankton biomass was low in spring and fall.

The relative contributions of the chlorophyll a fraction larger (net) and smaller (nanno) than 20 μm are compared in Figure 11.3. The nanno-fraction generally dominated the biomass across the shelf; especially in offshore waters. Dominance of the nanno-fraction was less in winter than in spring and fall.

Figure 11.4 presents the pattern of carbon uptake in the STOCS area. This parameter was more evenly distributed across the shelf than the biomass measure. This impression was primarily derived from the high offshore activity in spring.

Figure 11.5 compares the relative activity in the net and nanno-fractions. As suggested by Figure 11.3, the nanno-fraction generally dominated carbon uptake across the shelf. This dominance was at its maximum in the offshore stations during spring and fall.

Figure 11.6 presents the pattern of the assimilation number

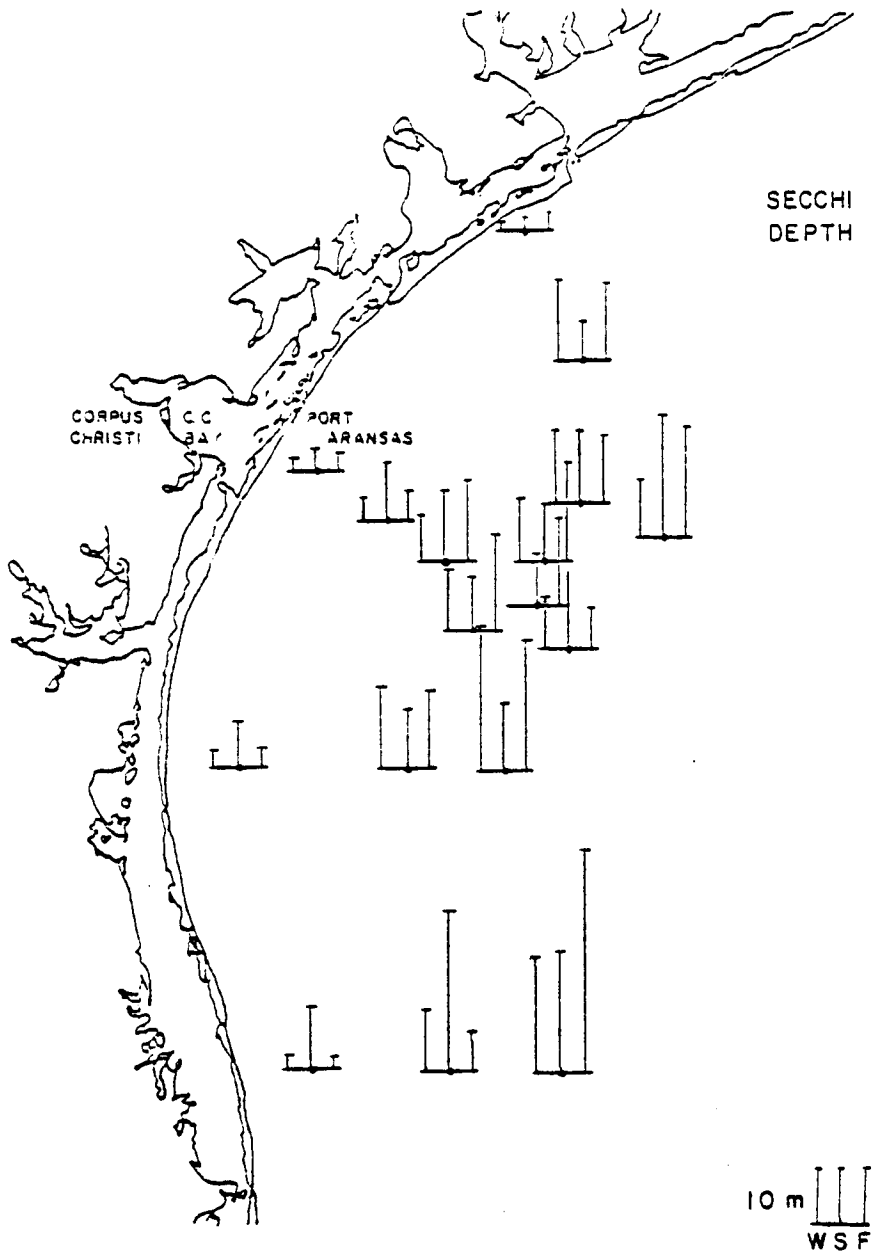


Figure 11.1 Seasonal Secchi Depth (m) Variation in the STOCS Study Area (W=winter, S=spring, F=fall).

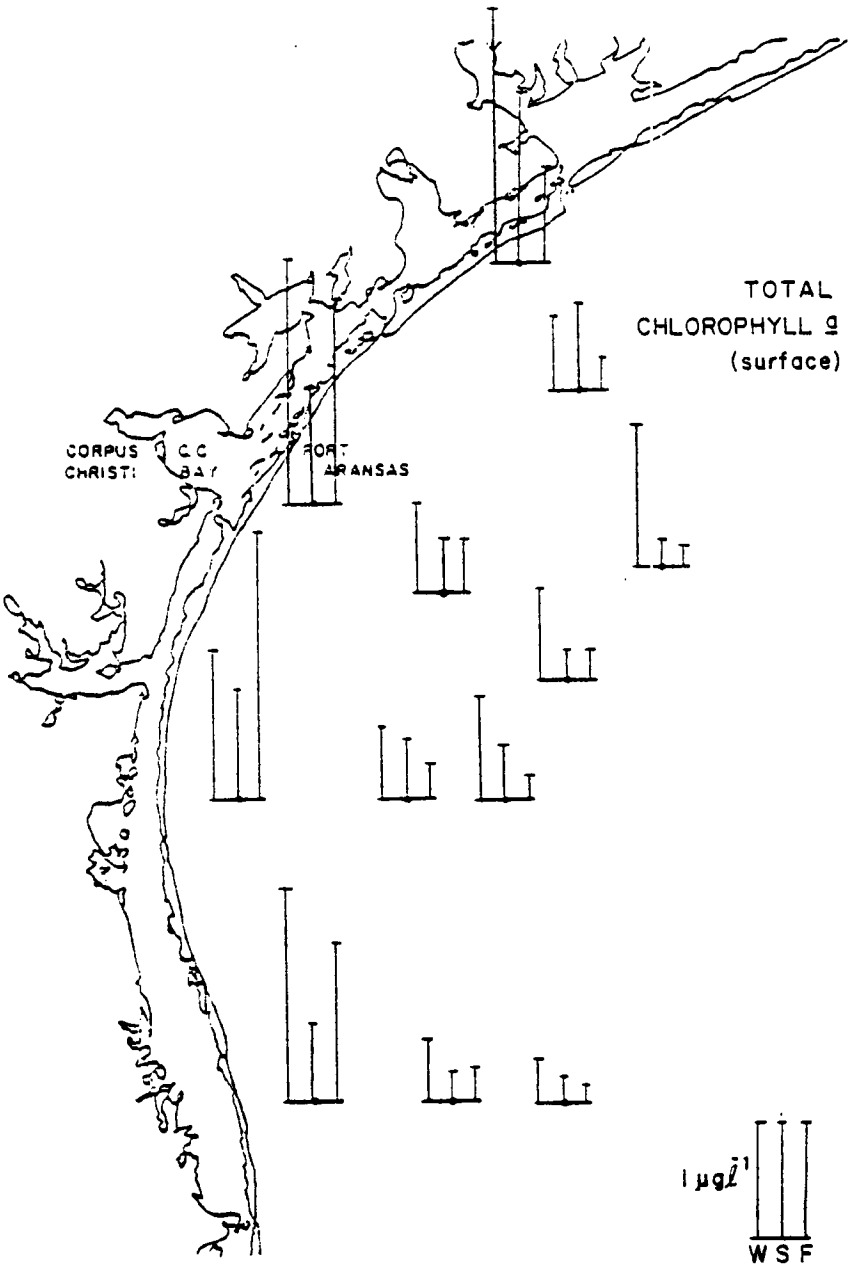


Figure 11.2 Seasonal Total Chlorophyll a ($\mu g\ \ell^{-1}$) Variation at the Surface in the STOCS Study Area.

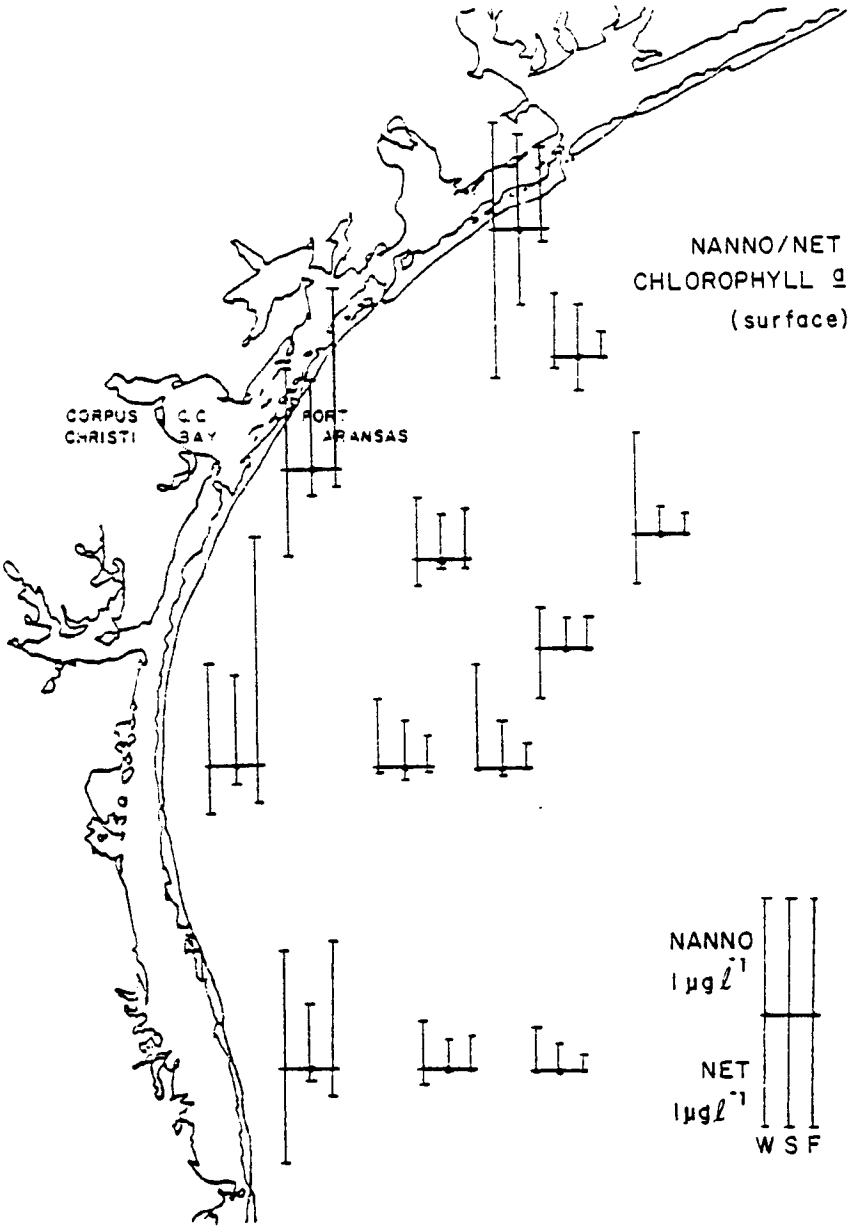


Figure 11.3 Seasonal Nanno- and Netphytoplankton Chlorophyll a ($\mu g\ \ell^{-1}$) Variation at the Surface in the STOCS Study Area.

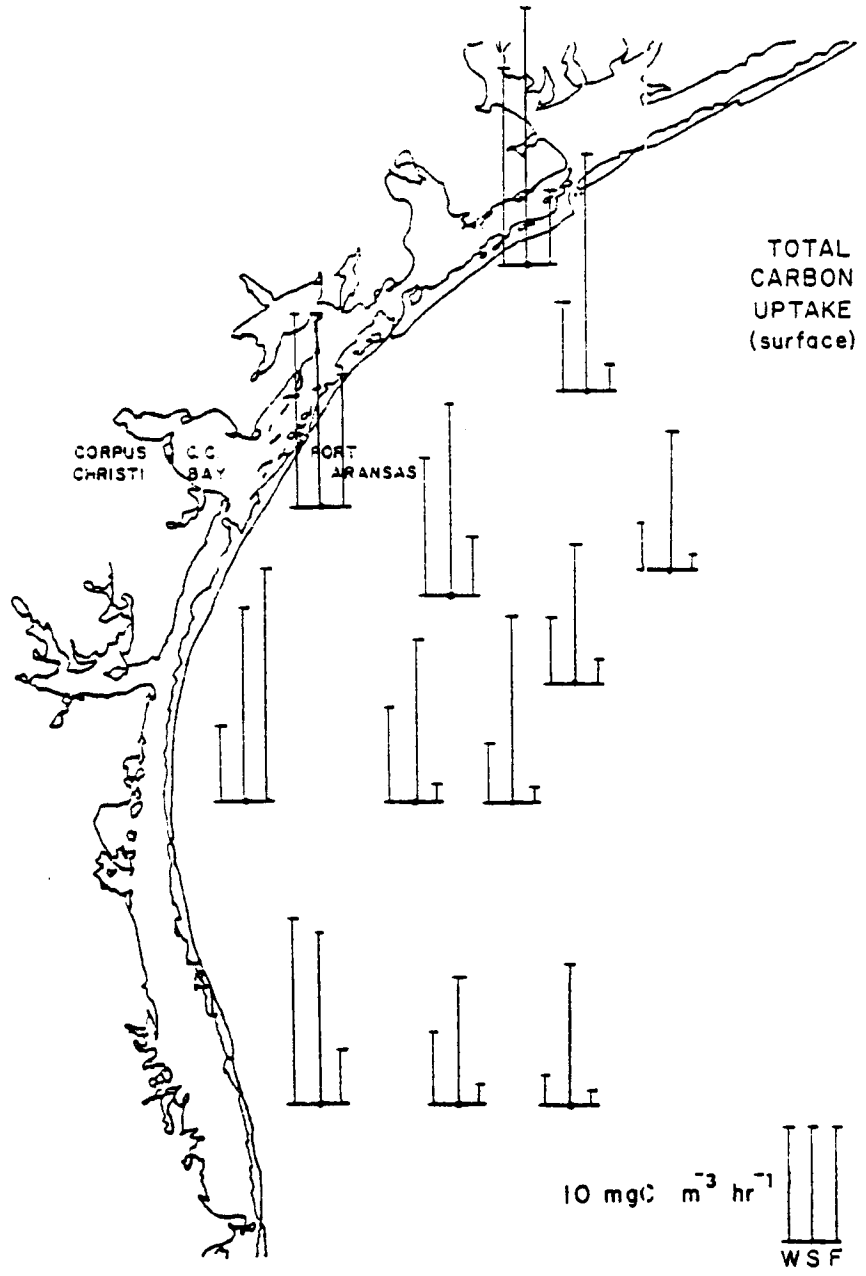


Figure 11.4 Seasonal Carbon Uptake (mg C m^{-3} hr^{-1}) Variation at the Surface of the STOCS Study Area.

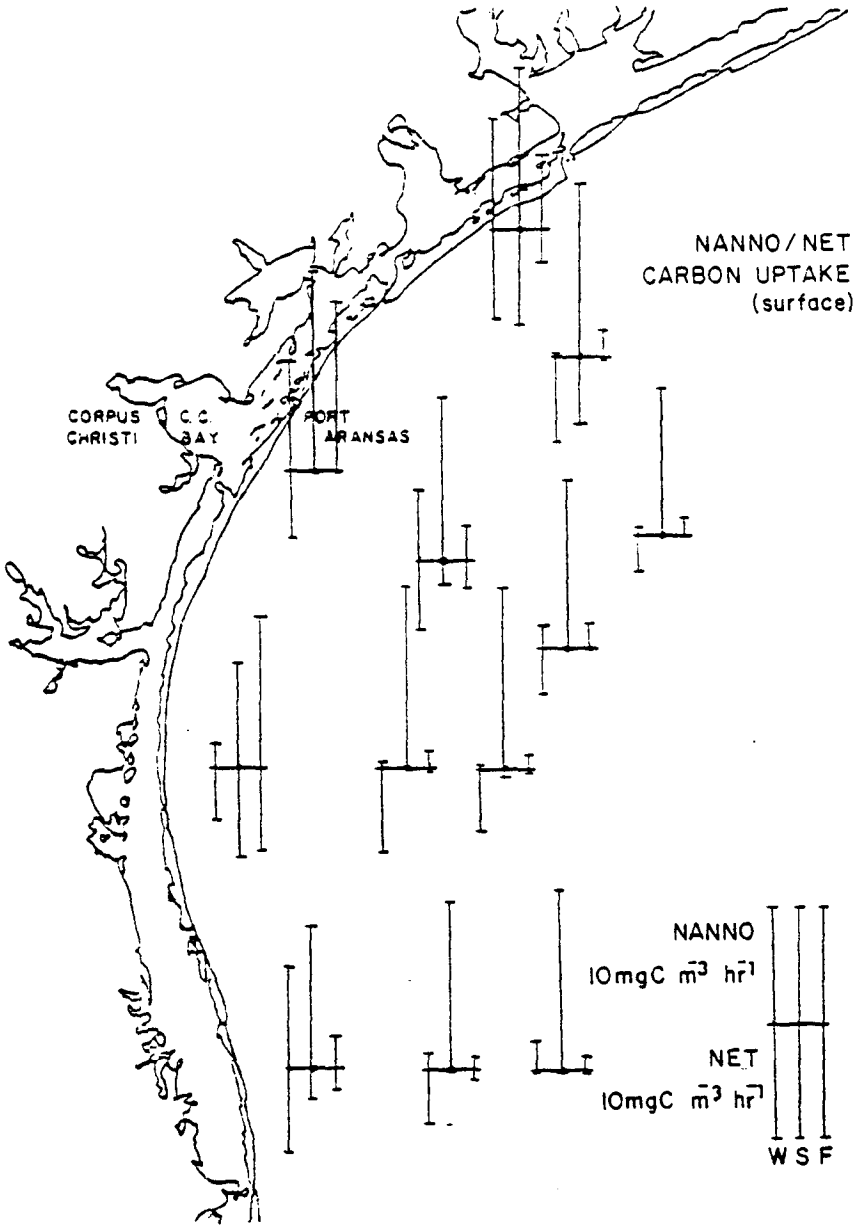


Figure 11.5 Seasonal Nanno- and Netphytoplankton Carbon Uptake (mg C m^{-3} hr^{-1}) Variation at the Surface in the STOCS Study Area.

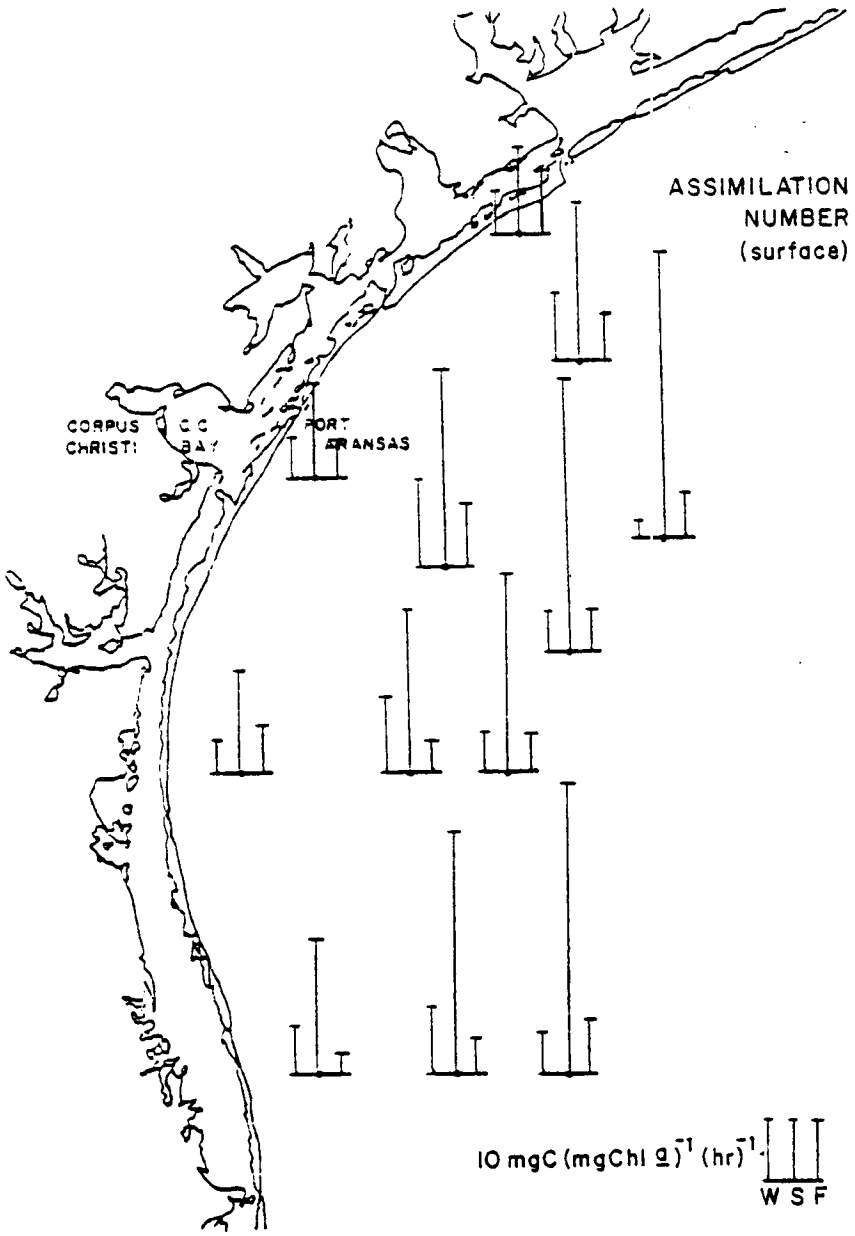


Figure 11.6 Seasonal Assimilation Number [mg C(mg Chl$\underline{a}$)$^{-1}$(hr^{-1})] Variation at the Surface in the STOCS Study Area.

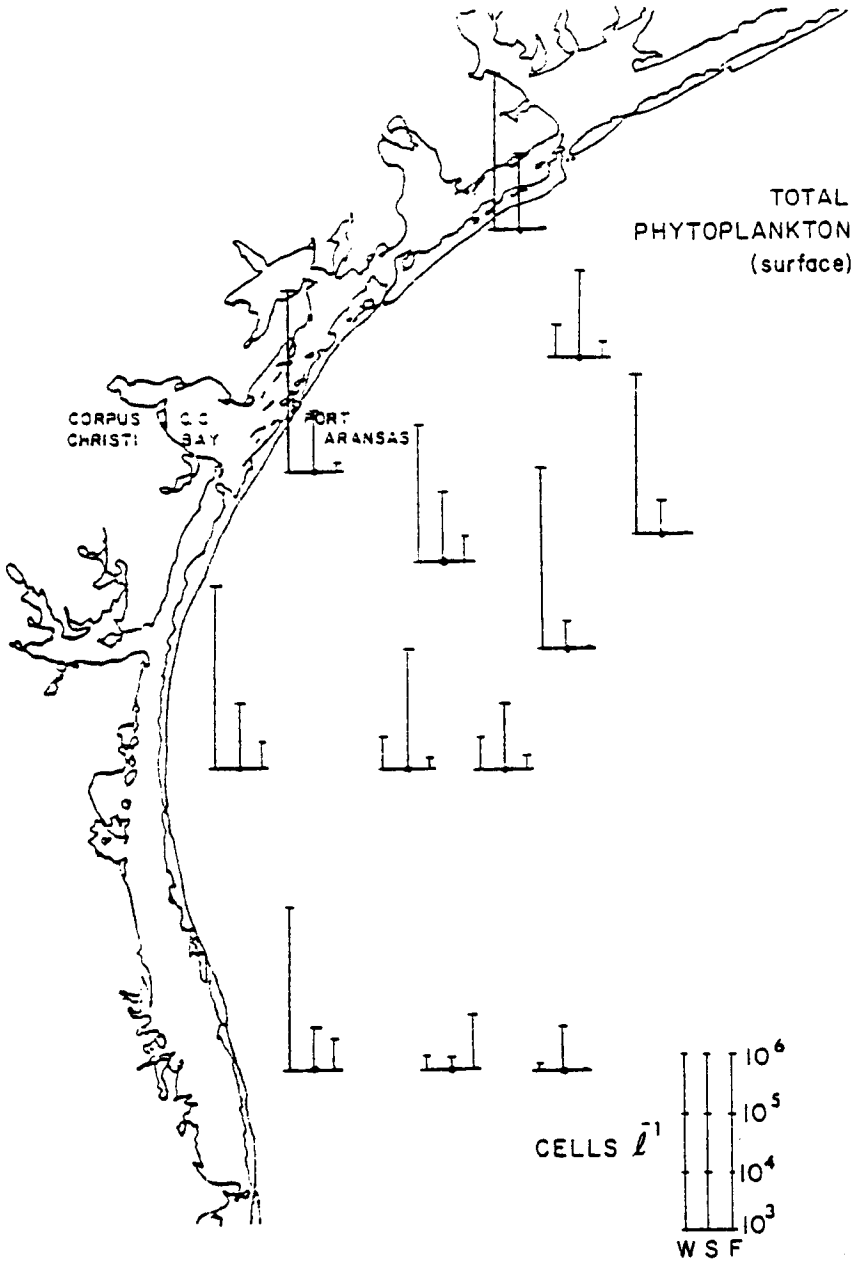


Figure 11.7 Seasonal Phytoplankton Abundance (Cells ℓ^{-1}) Variation at the Surface in the STOCS Study Area.

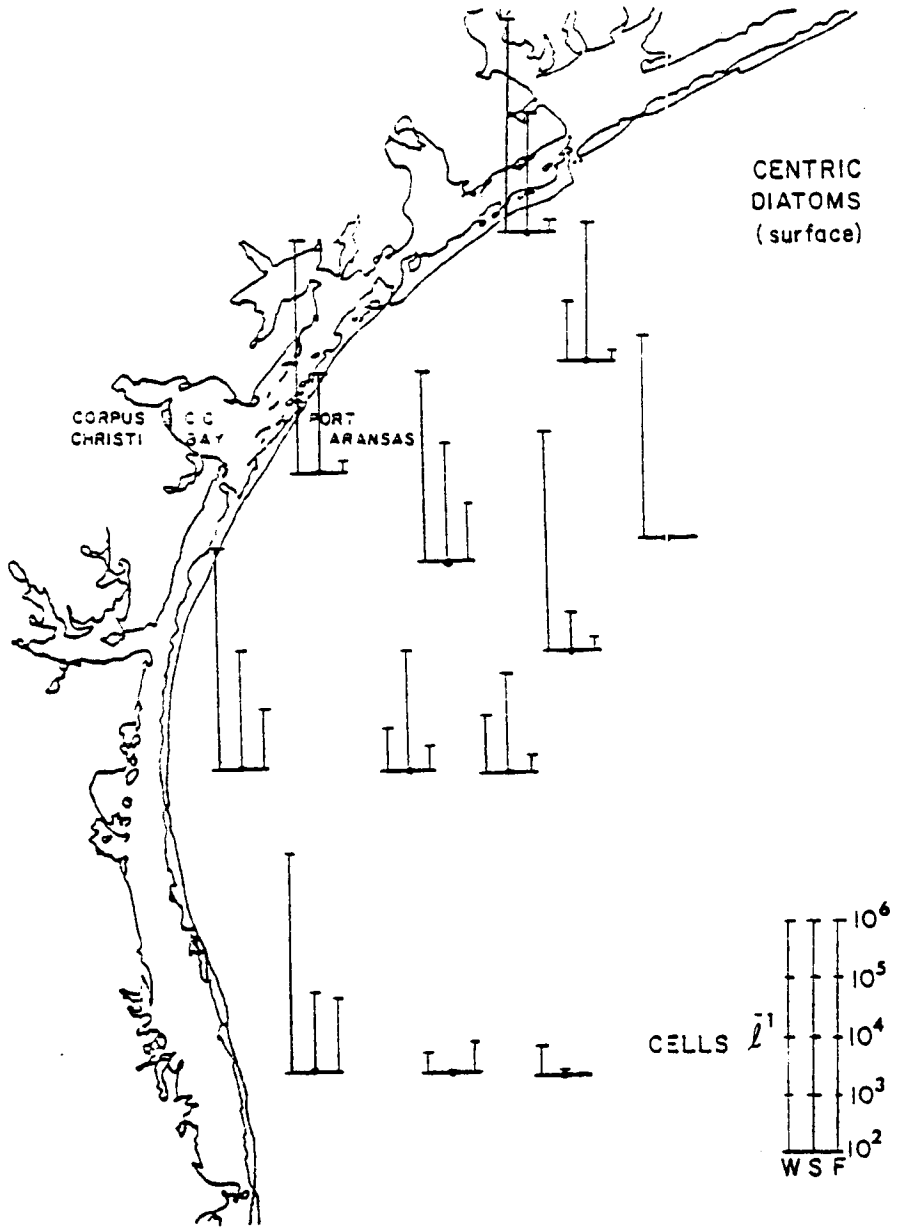


Figure 11.8 Seasonal Centric Diatom Counts (Cells ℓ^{-1}) Variation in the STOCS Study Area.

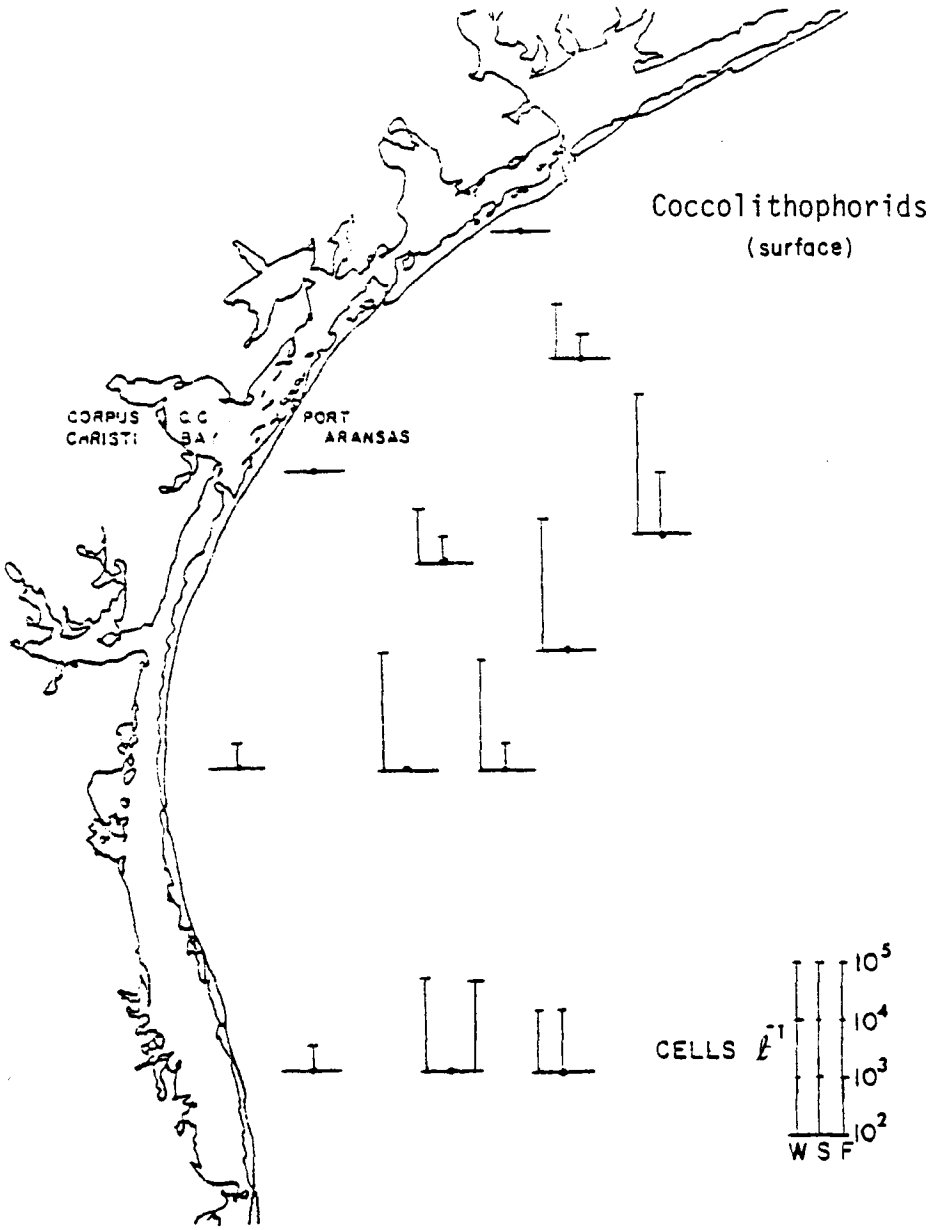


Figure 11.9 Seasonal Coccolithophorid Counts (Cells ℓ^{-1}) Variation in the STOCS Study Area.

[mg C (mg Chl a)$^{-1}$(hr)$^{-1}$]. Previous oceanographic experience has suggested that this ratio may be related to the growth climate (nutrients, temperature, salinity) at a geographic location. A high rate of carbon fixation per unit chlorophyll a may be related to better growth conditions. If this is true, the spring cruise sampled organisms that were doing well, especially offshore. The ratio also exhibited high values at certain stations during winter; it was uniformly low during fall.

The STOCS pattern of total phytoplankton counts is displayed in Figure 11.7. These values included estimates of both the net- and nanno-fractions. As with the chlorophyll a data in Figure 11.2, the quantity of phytoplankton decreased offshore. Seasonally, the individual stations displayed unique patterns depending on the location. The inshore stations showed decreasing cell numbers through the year; the offshore stations were more variable.

Figures 11.8 and 11.9 help in the interpretation of the phytoplankton class distribution. Diatoms (Figure 11.8) generally dominated inshore and decreased in abundance offshore. One important exception occurred at Stations 3/I and 3/II in winter. Coccolithophorids (Figure 11.9), in contrast, were more abundant offshore and decreased in influence as the coast was approached. They tended to be more abundant in winter and spring than in fall.

A north-south trend was apparent in some of the seasonal plots (Figures 11.1 - 11.9). Transects I, II and III appeared more productive than Transect IV. This suggested a major northerly source for phytoplankton growth materials.

Depth Patterns

The seasonal depth patterns of phytoplankton biomass are given in Figures 11.10 - 11.11. Figure 11.10 shows the depth pattern of net chlorophyll a. Station 1, all transects, had the highest concentration in winter; net chlorophyll a was uniformly distributed throughout the water column. During spring, Station 1/I maintained relatively high concentrations; Stations 1/II, 1/III and 1/IV decreased to fall values. Station 2, all transects, exhibited low concentrations except for somewhat higher values at Station 2/I throughout the water column in spring and at Station 2/IV near bottom in winter and spring. Stations 3, all transects, exhibited significant vertical structure at low concentrations during winter. Surface concentrations were relatively high at 3/I and 3/II; subsurface concentrations were relatively high at 3/III and 3/IV. Spring and fall concentrations were uniformly low.

Figure 11.11 shows the depth pattern of nanno-chlorophyll a. The concentrations were generally higher than those observed in the net-chlorophyll a fraction and exhibited more variability. Station 1/I was highest in winter and decreased through spring and fall. Stations 1/II and 1/III were highest in fall with similar values in winter and spring. Station 1/IV had similar concentrations throughout the three cruises. Station 2, all transects, displayed the highest concentration in winter. Spring and fall concentrations were similar except at all depths of 2/I and the bottom of 2/IV. Stations 3, all transects, exhibited relatively high surface nanno-chlorophyll a in winter with uniformly low concentrations in spring and fall.

Monthly Temporal Patterns

Figures 11.12 - 11.21 display the monthly (nine cruises) temporal patterns of the various measurements at various depths along Transect II.

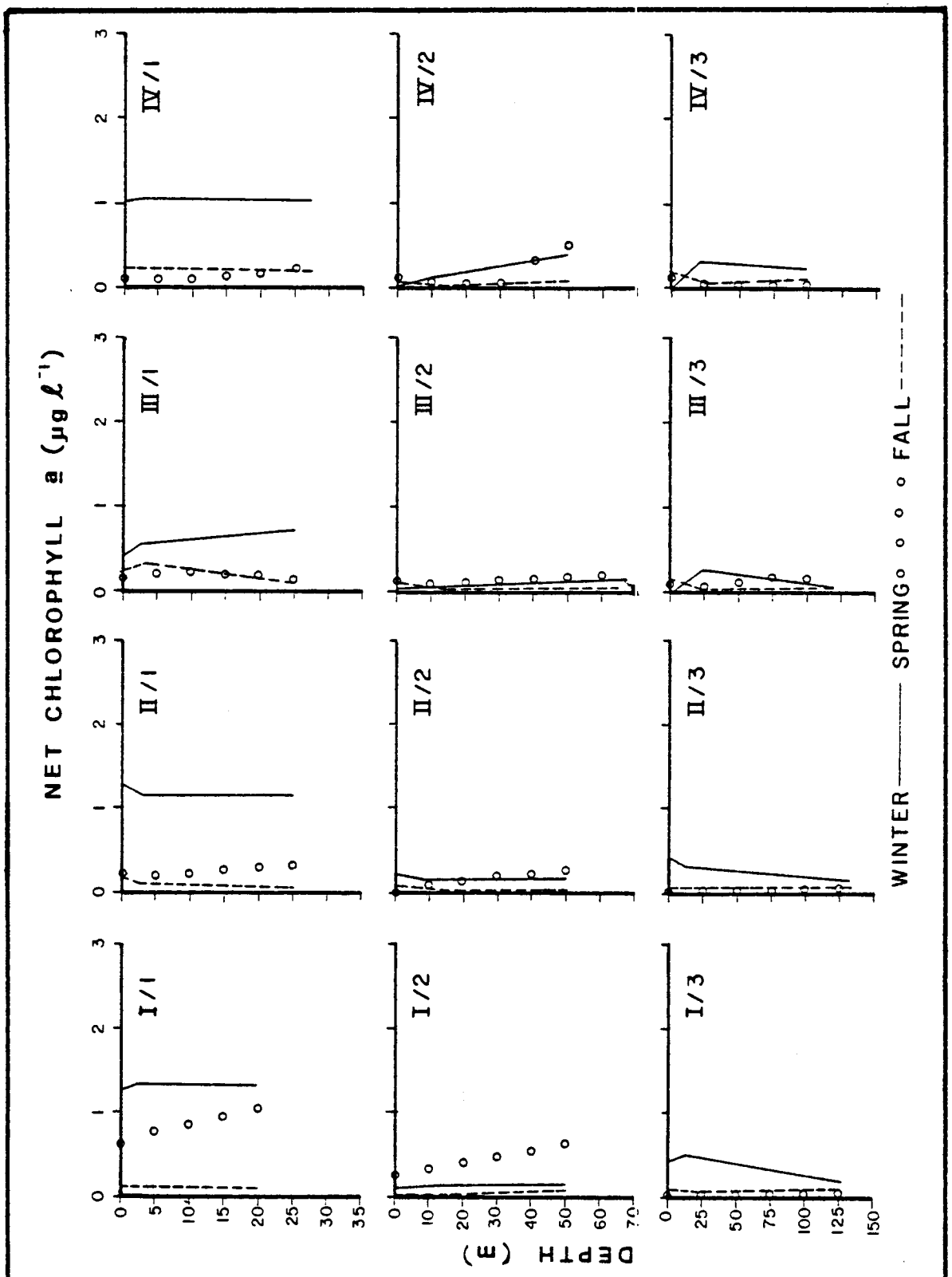


Figure 11.10 Seasonal Depth Variation of Netphytoplankton Chlorophyll a (µg ℓ^{-1}) in the STOCS Study Area.

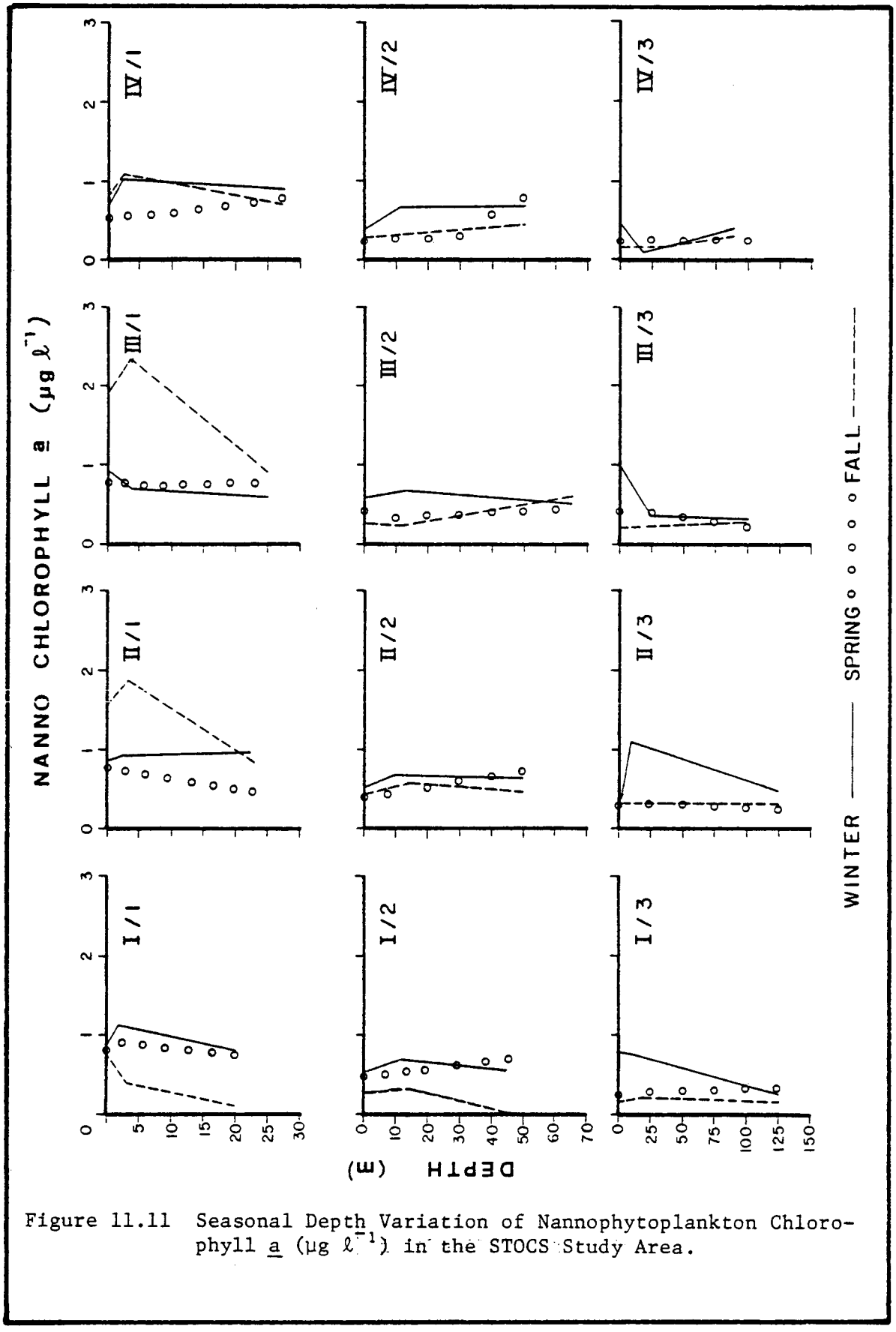


Figure 11.11 Seasonal Depth Variation of Nannophytoplankton Chlorophyll a (µg ℓ^{-1}) in the STOCS Study Area.

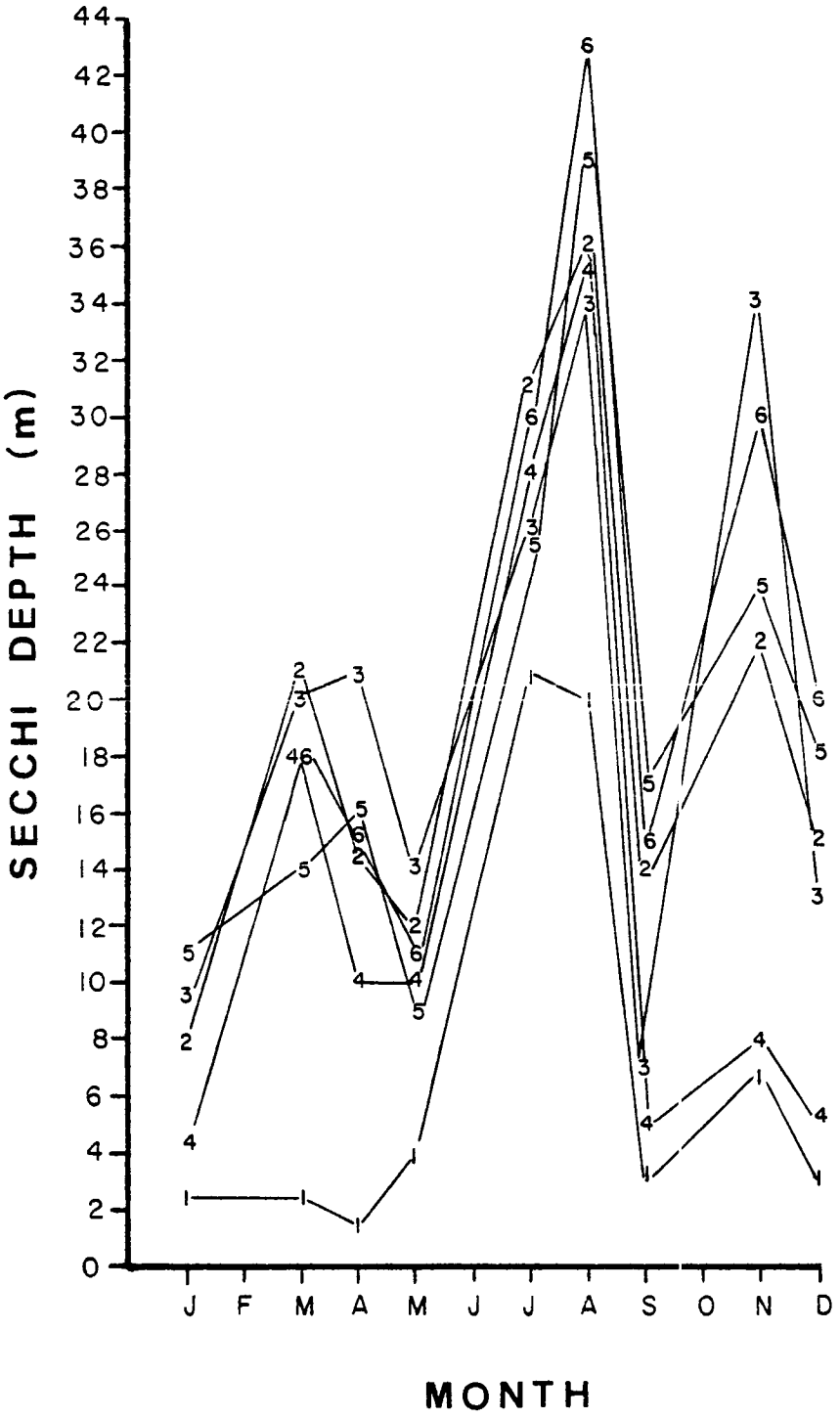


Figure 11.12 Monthly Variation in Secchi Depth (m) Along Transect II.

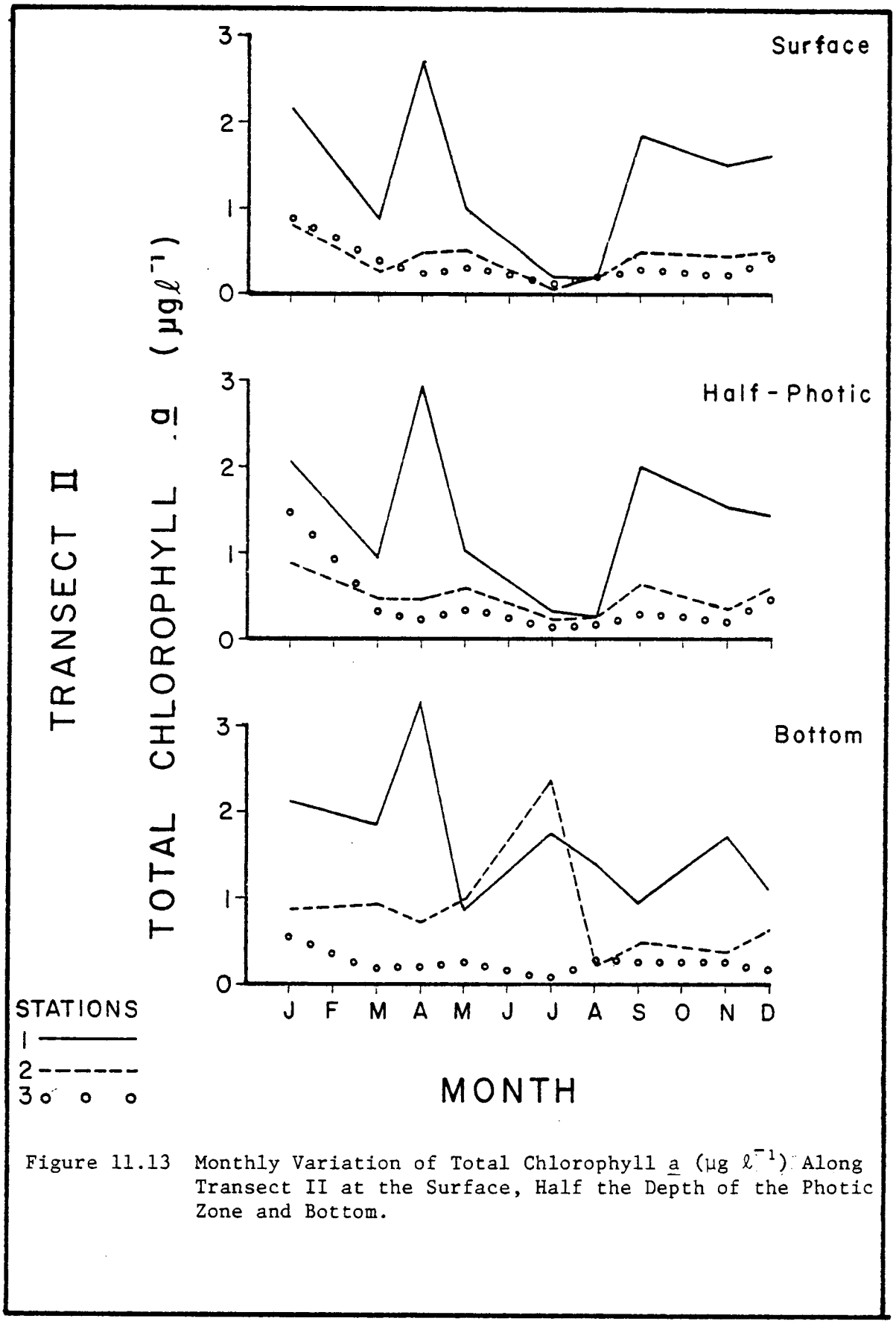


Figure 11.13 Monthly Variation of Total Chlorophyll a ($\mu g\ \ell^{-1}$) Along Transect II at the Surface, Half the Depth of the Photic Zone and Bottom.

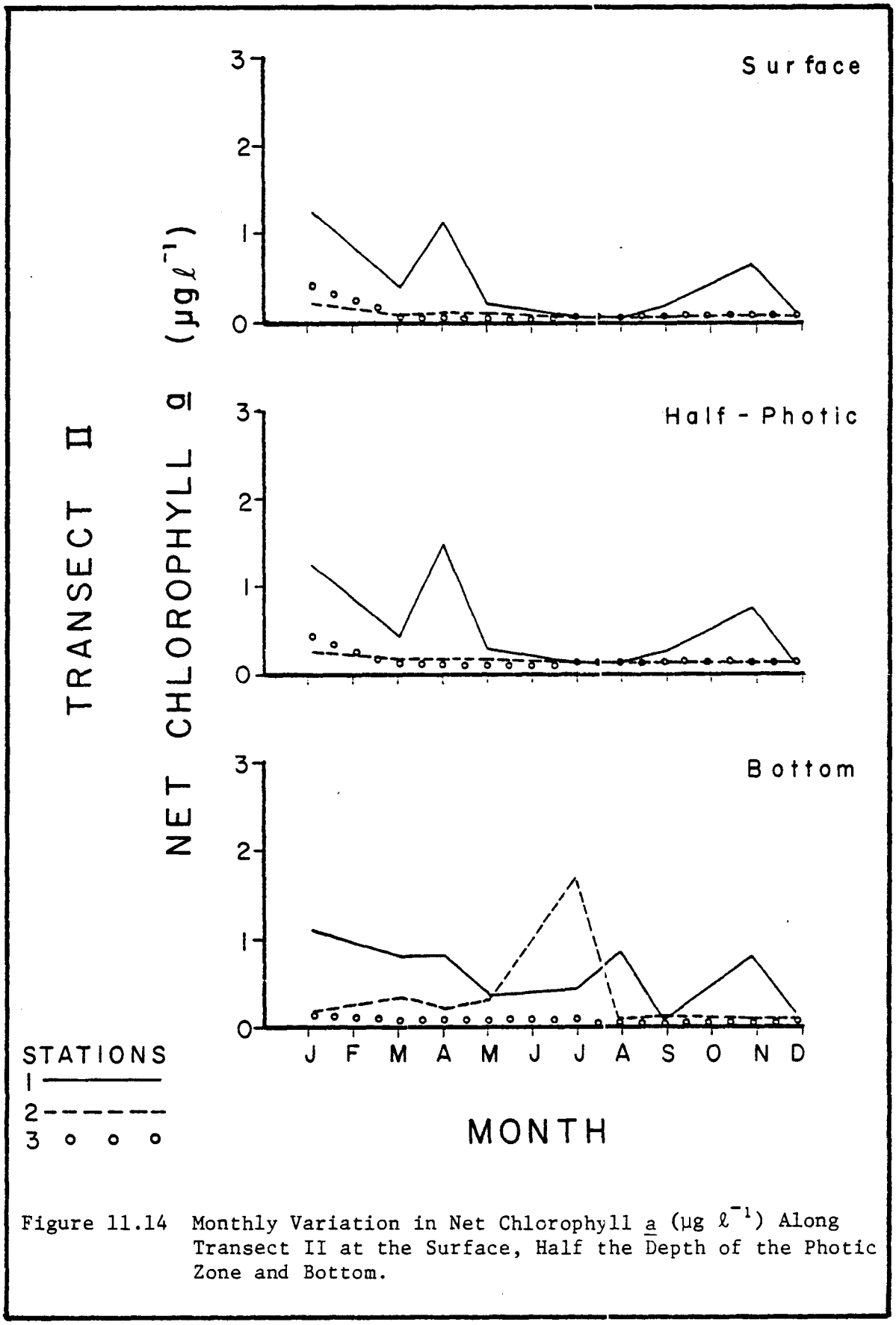


Figure 11.14 Monthly Variation in Net Chlorophyll a (µg ℓ^{-1}) Along Transect II at the Surface, Half the Depth of the Photic Zone and Bottom.

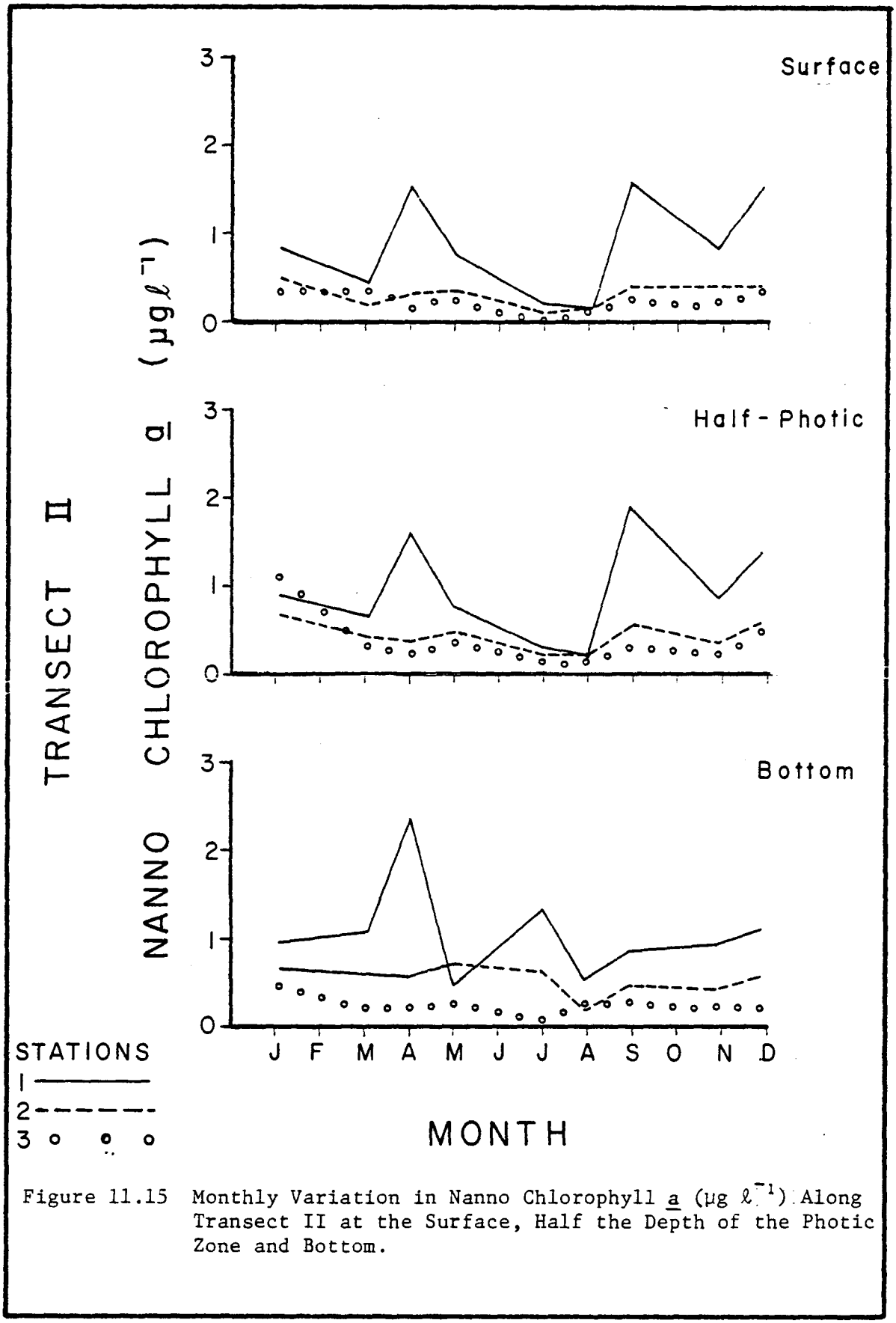


Figure 11.15 Monthly Variation in Nanno Chlorophyll a ($\mu g\ \ell^{-1}$) Along Transect II at the Surface, Half the Depth of the Photic Zone and Bottom.

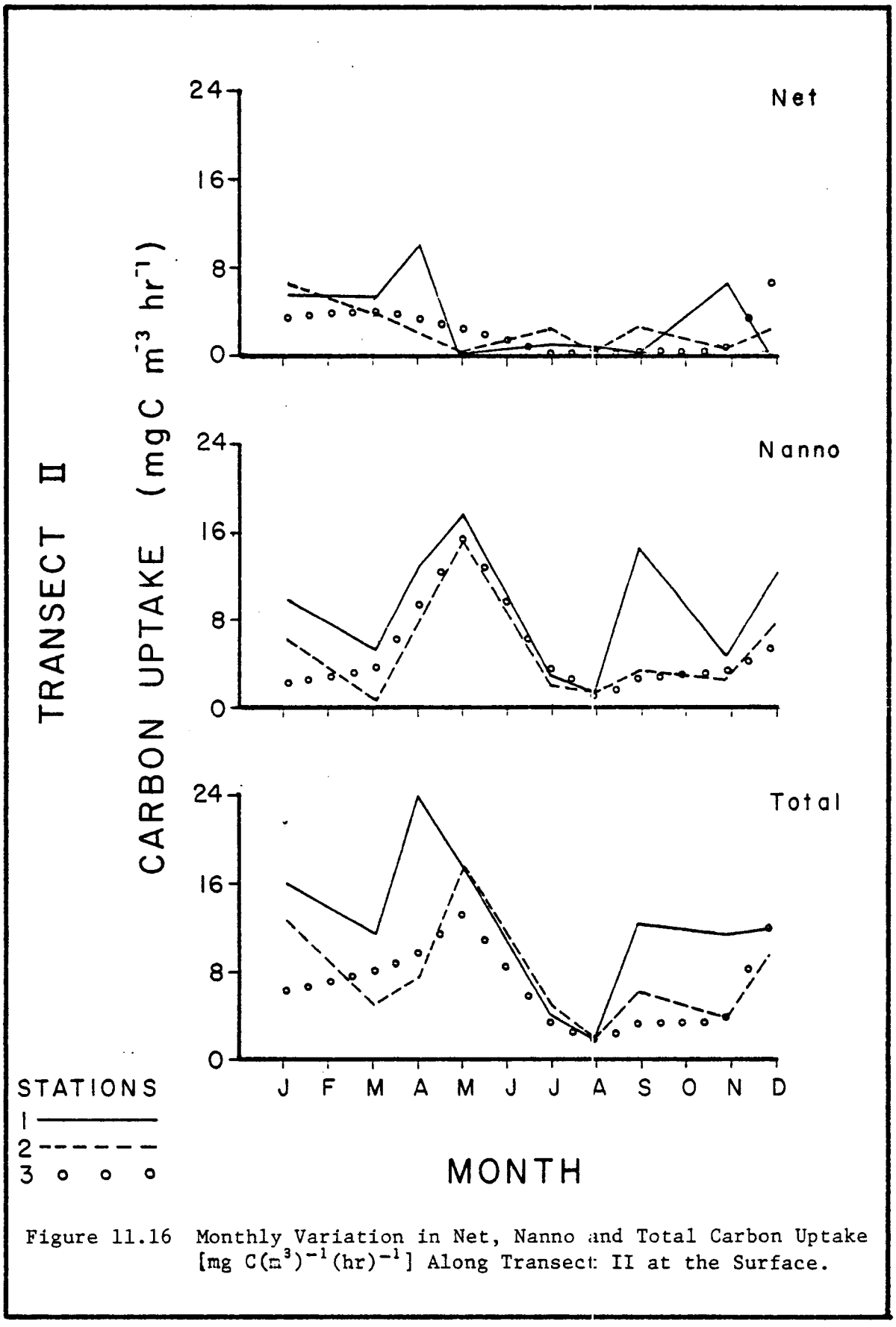


Figure 11.16 Monthly Variation in Net, Nanno and Total Carbon Uptake [mg $C(m^3)^{-1}(hr)^{-1}$] Along Transect II at the Surface.

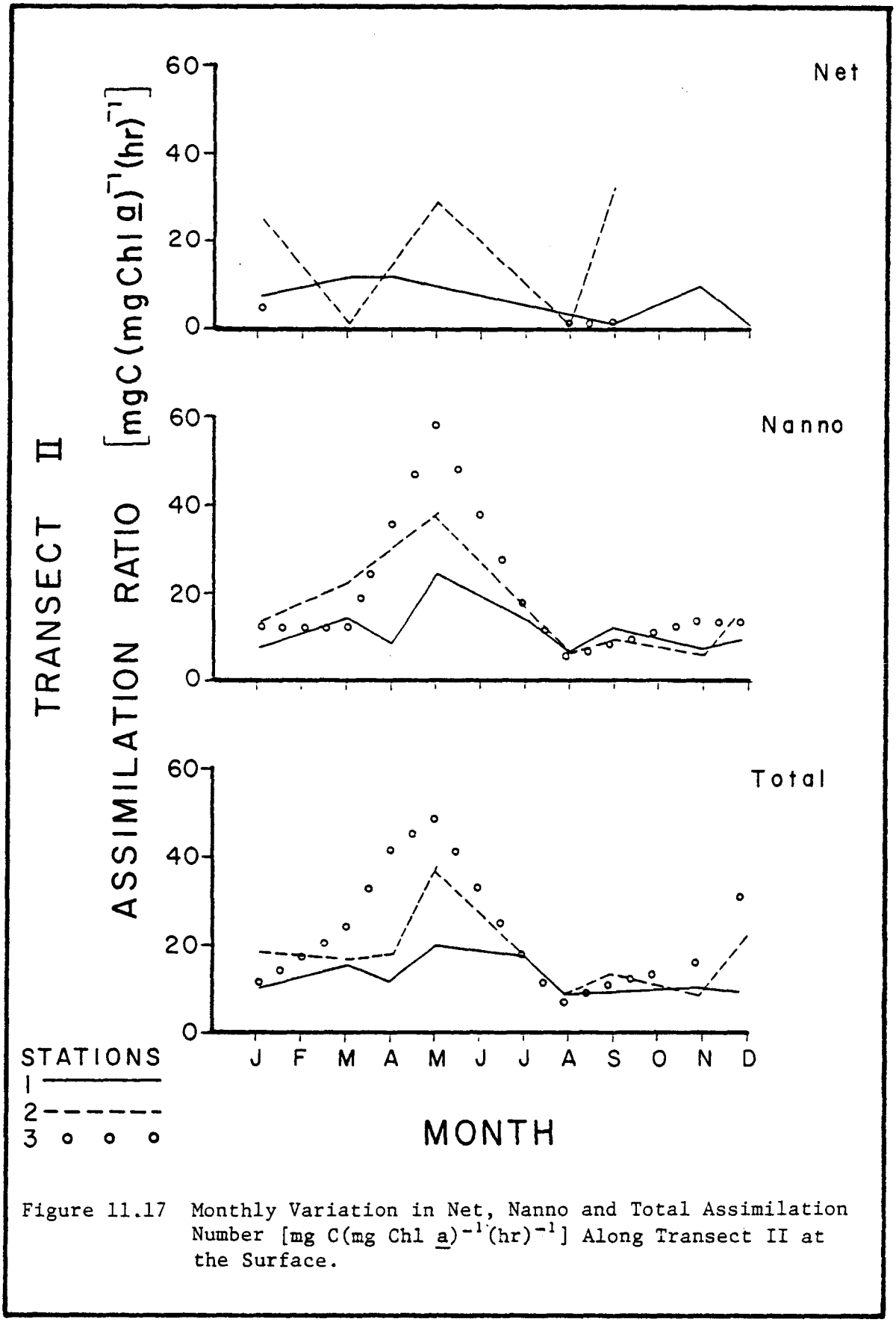


Figure 11.17 Monthly Variation in Net, Nanno and Total Assimilation Number [mg C(mg Chl a)$^{-1}$(hr)$^{-1}$] Along Transect II at the Surface.

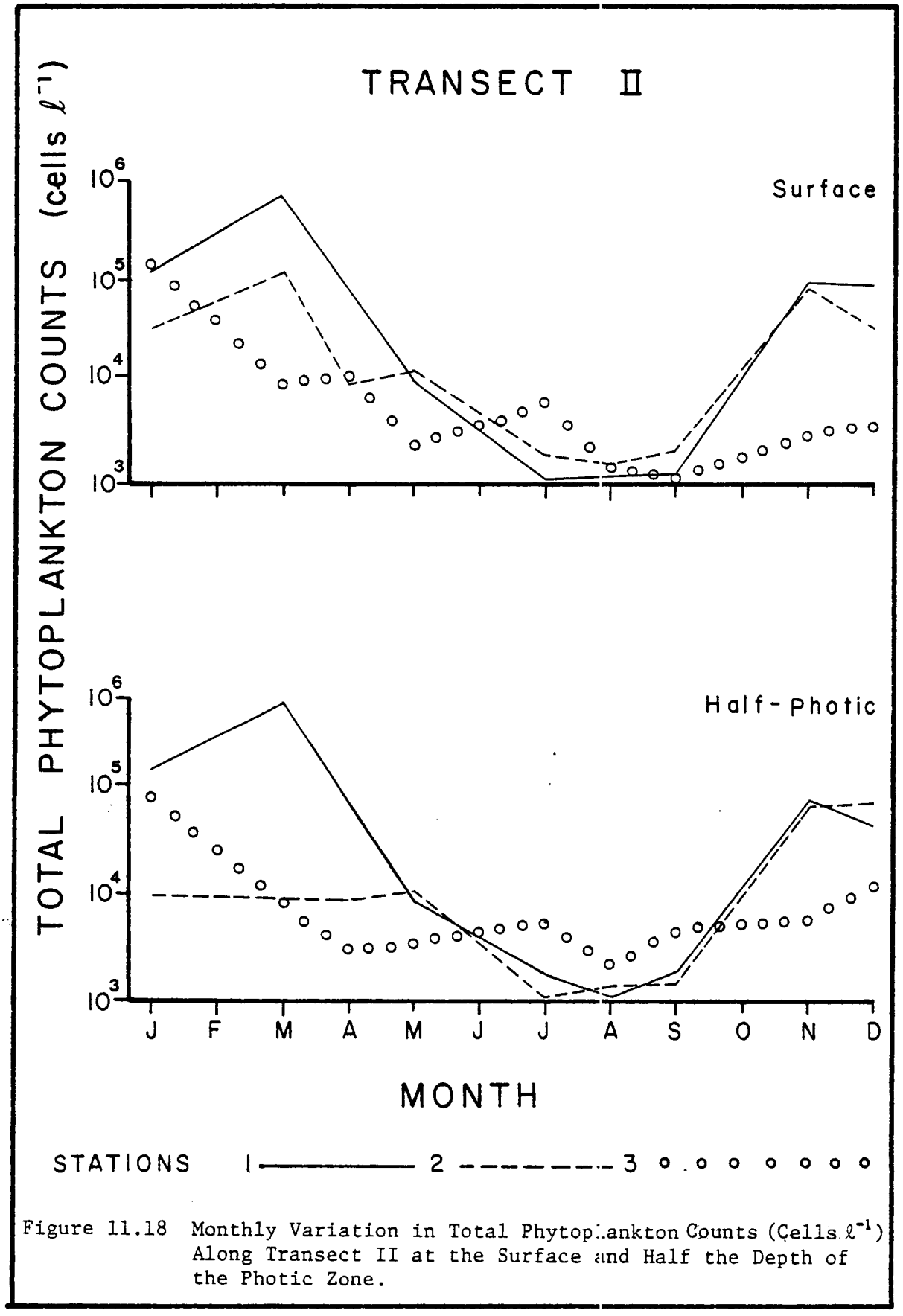


Figure 11.18 Monthly Variation in Total Phytoplankton Counts (Cells ℓ^{-1}) Along Transect II at the Surface and Half the Depth of the Photic Zone.

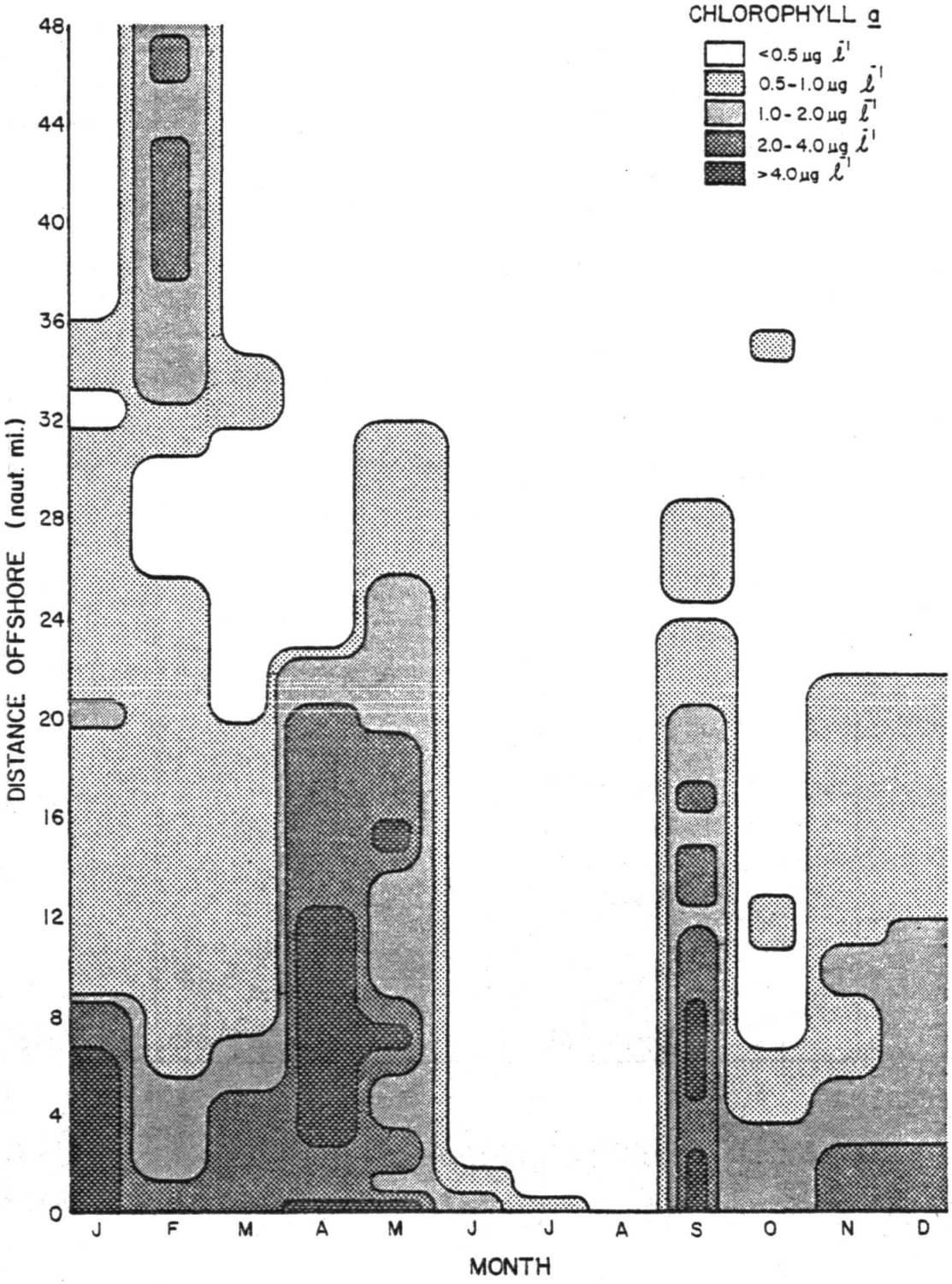
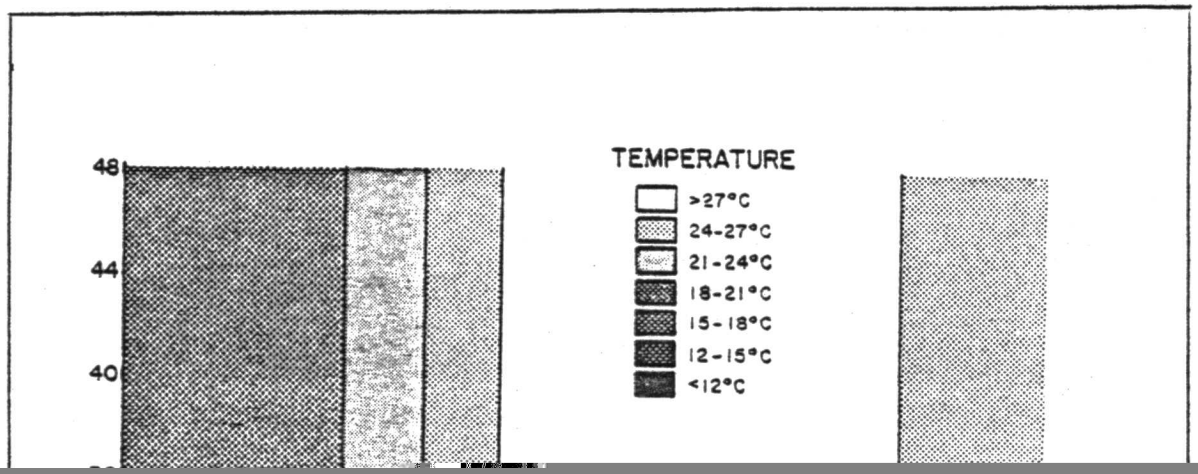


Figure 11.19 Monthly Variation of Chlorophyll a Along Transect II at 2 m Depth.


48
44
40
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>27°C
24-27°C
21-24°C
18-21°C
15-18°C
12-15°C
<12°C

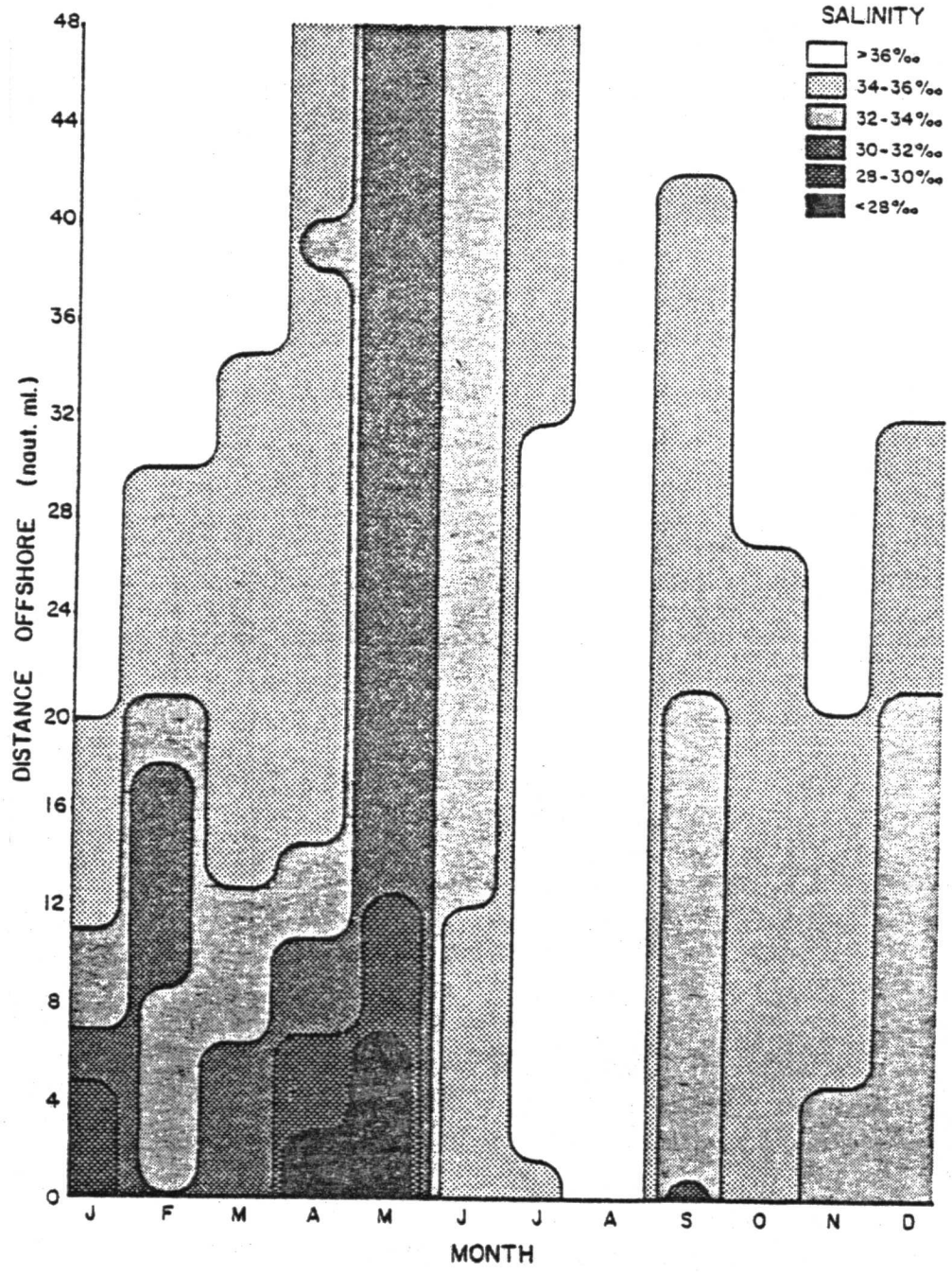

Figure 11.21 Monthly Variation in Salinity Along Transect II at 2 m Depth.

Figure 11.12 shows the monthly Secchi depth variation at Stations 1-6, Transect II throughout the year. The turbid inshore zone usually affected 1/II and reached out to 4/II for part of the year (September-January). Stations 2, 5, 6 and 3, Transect II, exhibited less turbidity and followed a parallel pattern throughout the year. Secchi depths were generally low between January-May, increased abruptly in July and August, decreased in September due to the influence of Hurricane Anita, increased somewhat in November and decreased in December. These patterns were related to water depth stratification strength, wind speed and fresh water inflow.

Figure 11.13 displays the monthly values of total chlorophyll a. A similar pattern occurred at the surface, and half the depth of the photic zone. At 1/II, values less than ~ 1 $\mu g\ \ell^{-1}$ occurred only in July-August. At Stations 2/II and 3/II, the highest concentrations were in January with concentrations less than 0.5 $\mu g\ \ell^{-1}$ through the remainder of the year. The bottom samples at Stations 1/II and 2/II exhibited higher summer concentrations than the shallower depths. In fact, the bottom water at 1/II always contained more than ~ 1 $\mu g\ \ell^{-1}$ of chlorophyll a. Station 3/II exhibited uniformly low concentrations throughout the year.

Figures 11.14 and 11.15 compare the relative contribution of the net and nanno-fractions to the monthly chlorophyll a patterns. Generally, the nanno-fraction biomass peaks followed the net-fraction biomass peaks in the spring and preceded the net-fraction peaks in the fall. This trend resulted from the successional response of phytoplankton life style to environmental quality. An anomalous peak in net-chlorophyll a occurred in the bottom waters of Station 2/II in July.

Figure 11.16 presents the total carbon uptake and the relative contributions of the net and nanno-fractions at the surface of 1/II, 2/II and 3/II. The total carbon uptake provided an impression similar to Figure

11.13 at the surface. It also appears, however, that the stations were more equal in carbon fixed, at least through August, than they were in standing crop. The nanno-fraction again followed the net-fraction in the spring and preceded it in the fall.

Figure 11.17 summarizes the monthly patterns of the assimilation number. The missed data points are due to undetected chlorophyll a. The assimilation numbers based on total phytoplankton showed the highest rates of carbon uptake per chlorophyll a during April-May and increased offshore. This was probably respectively due to the environmental conditions, including available nutrients, and the size of the dominant phytoplankton. High assimilation numbers that were not reflected in high biomass may be explained by samples taken at an early stage of community development or by active grazing by the zooplankton.

Figure 11.18 shows the monthly trend of total phytoplankton counts at the surface and half the depth of the photic zone. All stations exhibited a similar pattern with decreasing amounts through August-September followed by increasing amounts to the end of the year. Cell numbers generally decreased offshore during the productive times of the year and increased offshore during the times of low biomass. The September increase in the nanno-fraction of chlorophyll a (Figure 11.15) was not reflected in the cell counts.

The rank order of phytoplankton species abundance by sampling date, depth and station are presented in Appendix J. The monthly temporal pattern of dominant phytoplankton species composition for Stations 1/II, 2/II and 3/II are presented in Tables 11.2 - 11.4. Data from the surface and one-half the depth of the photic zone samples were lumped in compiling these tables. Using the data in Appendix J, Tables 11.2 - 11.4 were generated by listing approximately the 10 most abundant species at each sta-

tion during successive cruises in rank order of decreasing abundance. The numbers under each cruise heading give the rank order of abundance within that period. For example, at Station 1/II, March, *Skeletonema costatum* was the most abundant and *Gonyaulax minima* was the least abundant of the top 11 species.

The tables simply express the community changes observed at Stations 1/II, 2/II and 3/II during 1977. Some general observations applicable to all three tables are:

1) Successive monthly cruises unfailingly added new species to the overall list of most abundant species. This was especially true of Station 2/II between January and March and Station 3/II between January and April.

2) Each table can be divided into its own monthly groups;

Table 11.2 - November-July; August-October;
Table 11.3 - September-February; April-July; August;
Table 11.4 - January-February; March-December.

These groupings are much more complex than those offered in the 1976 report (Kamykowski, *In* Groover, 1977). This complexity is probably due to the differences in the STOCS processes in the two years.

The dominant species at each station during the periods defined in 2) above were:

1/II November-July: *Skeletonema costatum, Chaetoceros decipiens, Chaetoceros* spp., *Nitzschia seriata*

August-October: *Navicula* spp., *Thalassionema nitzschioides, Nitzschia*

2/II September-February; April-July: *Skeletonema costatum; Rhizosolenia stolterfothii, Chaetoceros* spp. *Chaetoceros decipiens*

March: Dinoflagellates

August: Barren

3/II January-February: *Skeletonema costatum, Nitzschia pacifica, Nitzschia seriata*

TABLE 11.2

MONTHLY CHANGES IN PHYTOPLANKTON SPECIES COMPOSITION AT STATION 1/II. NUMBERS UNDER EACH CRUISE HEADING GIVE RANK ORDER OF DECREASING ABUNDANCE

Species	Jan Feb	Mar	Apr	May June	July	Aug	Sept Oct	Nov	Dec
Skeletonema costatum	1	1	2	4					1
Ditylum brightwellii	2	2							
Nitzschia seriata	3		5	6				5	
Chaetoceros decipiens	4	10	6		2				
Chaetoceros spp.	5	5	10		7				4
Asterionella glacialis	6	4							
Rhizosolenia delicatula	7		7	9				2	
Rhizosolenia alata v. *alata*	8								
Hemiaulus hauckii	9								
Chaetoceros compressus	10								
Prorocentrum compressum		3		5		5			
Thalassiothrix frauenfeldii		6	4		8				
Coclodinium archimedes		7							
Chaetoceros atlanticus		8	3		5				
Thalassionema nitzschioides		9					1		2
Gonyaulax minima		11							
Chaetoceros curvisetus			1					1	
Rhizosolenia stolterfothii			8	1					
Chaetoceros affinis			9						
Leptocylindrus danicus				2				9	
Gymnodinium spp.				3					
Rhizosolenia alata				7		6			
Prorocentrum micans				8			5		
Bacteriastrum spp.				10					8
Hemiaulus membranaceous					1				
Hemiaulus sinensis					3	3		6	
Chaetoceros didymus					4		4		
Torodinium robustum					6				5
Gyrodinium spp.					9				
Navicula spp.						1			
Nitzschia spp.						2	2	4	3
Ceratium macroceros						4			
Ceratium trichoceros						7			
Nitzschia longissima						8			10
Coscinodiscus spp.							3		9
Diploneis spp.							6		
Pleurosigma spp.							7		6
Navicula membranacea								3	
Rhizosolenia fragillisima								8	
Eucampia zoodiacus								10	
Cerataulina pelagica								7	
Asteromphalus spp.									7

TABLE 11.3

MONTHLY CHANGES IN PHYTOPLANKTON SPECIES COMPOSITION AT STATION 2/II. NUMBERS UNDER EACH CRUISE HEADING GIVE RANK ORDER OF DECREASING ABUNDANCE

Species	Jan Feb	Mar	Apr	May June	July	Aug	Sept Oct	Nov	Dec
Skeletonema costatum	1	1							
Rhizosolenia alata v. *alata*	2								
Rhizosolenia delicatula	3								
Thalassionema nitzschioides	4						3		1
Rhizosolenia stolterfothii	5		7	2					7
Chaetoceros spp.	6		5				9	9	6
Chaetoceros decipiens	7		2	9	4			8	
Chaetoceros atlanticus	8				3			7	
Chaetoceros curvisetus	9								
Pleurosigma spp.	10						5		
Gymnodinium spp.		2		1					
Ditylum brightwellii		3							
Prorocentrum compressum		4	10						
Gonyaulax minima		5			6				
Gyrodinium spp.		6							
Oxytoxum gladiolus		7							
Rhizosolenia alata		8			5	3	1	3	
Nitzschia seriata		9							
Gyrodinium fusiforme		10							
Hemiaulus membranaceous			1		2				
Thalassiothrix frauenfeldii			3	6				4	
Chaetoceros peruvianus			4					5	
Chaetoceros coarcticus			6						
Torodinium robustum			8			4	10	6	5
Thalassiosira spp.			9						
Leptocylindrus danicus				3			7		3
Lauderia spp.				4					
Nitzschia spp.				5			2		2
Rhizosolenia fragillisima				7					
Eucampia zoodiacus				8					
Chaetoceros brevis				10					
Chaetoceros didymus					1				
Trichodesmium erythraeum					7		4	1	
Hemiaulus sinensis						1			
Navicula spp.						2			
Coscinodiscus excentricus						5			
Podolampus spinifera						6			
Dinophysis caudata							8		
Cerataulina pelagica							11		
Guinardia flaccida								2	
Hemiaulus hauckii								10	8
Navicula warwrikae								11	
Chaetoceros affinis									4
Coscinodiscus spp.									9

TABLE 11.4

MONTHLY CHANGES IN PHYTOPLANKTON SPECIES COMPOSITION AT STATION 3/II. NUMBERS UNDER EACH CRUISE HEADING GIVE RANK ORDER OF DECREASING ABUNDANCE

Species	Jan Feb	Mar	Apr	May June	July	Aug	Sept Oct	Nov	Dec
Skeletonema costatum	1								
Nitzschia pacifica	2								
Nitzschia seriata	3								
Chaetoceros curvisetus	4								
Nitzschia spp.	5	10			1		5		3
Chaetoceros spp.	6				7		10		
Leptocylindrus minimus	7								
Rhizosolenia fragillisima	8								
Hemiaulus hauckii	9								
Rhozosolenia stolterfothii	10			2					
Gymnodinium spp.		1	9	1					
Gyrodinium fusiforme		2							
Torodinium robustum		3	7	5		1	2	1	2
Chaetoceros coarcticus		4							
Gymnodinium wulffii		5							
Rhizosolenia alata		6					1		
Stauroneis quadripedes		7							
Prorocentrum compressum		8		10		4			
Trichodesmium erythrueum		9		3					
Thalassiothrix fraunfeldii			1	4	6		6		4
Chaetoceros decipiens			2		4				
Nitzschia seriata			3						
Calyptrosphaera oblongata			4						
Gyrodinium spp.			5					2	
Chaetoceros peruvianus			6						
Hemiaulus membranaceous			8						8
Lauderia borealis			10						
Streptotheca thamesis			11						
Eucampia zoodiacus				6					
Chaetoceros atlanticus				7	3				
Guinardia flaccida				8					
Rhizosolenia calcar avis				9					
Thalassionema nitzschioides					2		4		1
Leptocylindrus danicus					5		3		
Chaetoceros didymus					8				
Chaetoceros messanensis					9				
Bacteriastrum spp.					10				
Hemiaulus sinensis						2			
Ceratium macroceros						3			
Ceratium minutum						5			
Polykrikos schwartzii						6			
Chaetoceros diversus							7		
Navicula membranaceous							8		
Rhizosolenia delicatula							9		
Ceratium trichoceros								3	
Oxytoxum sceptrum								4	
Pleurosigma spp.									5
Coscinodiscus spp.									6
Navicula warwrikae									7

March-December: *Nitzschia* spp., *Torodinium robustum*, *Thalassiothrix frauenfeldii*

Table 11.5 summarizes the class dominance at each depth during each cruise at all stations sampled. A succession of phytoplankton types was evident. In January, diatoms dominated along Transects I and II while coccolithophorids were significant along Transects III and IV. Dinoflagellates became dominant at some stations in March. An onshore-offshore gradient developed in March with diatoms dominant inshore and either coccolithophorids or dinoflagellates dominant offshore. This pattern continued through August with the coccolithophorid dominance moving toward the coast The last four months of 1977 were characterized by mixed communities that gradually changed to dominance by very small forms (coccolithophorids and monods).

Table 11.6 considers the relative abundance of the blue-green algae at each depth of each cruise of all stations sampled. Since some blue-green algae may fix dissolved nitrogen gas into organic molecules, they contribute uniquely to the shelf ecosystem. Their presence suggests an alternate source of water column nitrogen either through leakage, grazing or bacterial decomposition. The pattern in Table 11.5 suggests that blue-greens first appeared in March and gradually increased in abundance through May when they occurred across the shelf both at the surface and at one half the depth of the photic zone. Their numbers and distribution declined in July and August but again increased from September to November. No blue-greens were observed in December.

Table 11.7 lists the monthly diversity indices for each sample collected during 1977. Replicated samples are represented by the mean of the three values available. Diversity index values less than 1.00 with more than one species observed in the sample occurred only during March at

TABLE 11.5

MONTHLY VARIATION IN PHYTOPLANKTON CLASS DOMINANCE AT ALL STATIONS

Station	Depth	Jan Feb	Mar	Apr	May June	July	Aug	Sept Oct	Nov	Dec
1/I	0	1			1			1		
	.5	1			1			2		
2/I	0	1			1			1		
	.5	3			1			2		
3/I	0	1			2			-		
	.5	1			3			4		
1/II	0	1	1	1	1	1	3	1	1	4
	.5	1	1	1	1	1	1	2	1	4
2/II	0	1	1	1	1	3	3	4	4	4
	.5	1	3	2	1	3	3	1	3	3
3/II	0	1	2	1	2	1	3	1	4	4
	.5	1	3	3	3	1	3	1	4	3
1/III	0	1			1			2		
	.5	1			1			2		
2/III	0	3			1			4		
	.5	3			1			3		
3/III	0	3			1			4		
	.5	3			1			1		
1/IV	0	1			1			1		
	.5	1			1			1		
2/IV	0	3			2			3		
	.5	1			1			1		
3/IV	0	3			2			2		
	.5	3			1			2		

1 - diatoms
2 - dinoflagellates
3 - coccolithophorids
4 - monods

TABLE 11.6

MONTHLY VARIATION OF BLUE-GREEN ALGAE ABUNDANCE (CELLS ℓ^{-1}) AT ALL STATIONS

Station	Depth	Jan Feb	Mar	Apr	May June	July	Aug	Sept Oct	Nov	Dec
1/I	0	0			60			0		
	.5	0			100			80		
2/I	0	0			140			40		
	.5	0			191			0		
3/I	0	0			60			0		
	.5	0			160			0		
1/II	0	0	0	0	60	0	20	0	382	0
	.5	0	0	0	0	0	0	0	764	0
2/II	0	0	0	40	40	0	0	320	0	0
	.5	0	0	0	0	40	0	0	840	0
3/II	0	0	100	40	380	0	0	0	0	0
	.5	0	0	40	0	0	0	0	0	0
1/III	0	0			300			20		
	.5	0			300			0		
2/III	0	0			0			60		
	.5	0			1200			0		
3/III	0	0			280			20		
	.5	0			20			0		
1/IV	0	0			0			360		
	.5	0			0			80		
2/IV	0	0			320			880		
	.5	0			0			0		
3/IV	0	0			100			0		
	.5	0			0			0		

TABLE 11.7

MONTHLY VARIATION OF SPECIES DIVERSITY (H)[1]

Station	Depth	Jan Feb	Mar	Apr	May June	July	Aug	Sept Oct	Nov	Dec
1/I	0	3.18			3.78			1.89		
	.5	3.03			3.74			2.72		
2/I	0	3.59			3.29			1.72		
	.5	3.73			2.88			0.00		
3/I	0	3.57			1.07			-		
	.5	3.91			2.91			2.37		
1/II	0	1.98	0.33	3.88	3.89	2.26	2.29	1.45	2.88	1.95
	.5	2.24	0.30	3.96	4.19	2.55	1.69	1.93	2.52	2.33
2/II	0	3.83	0.67	2.80	4.01	3.08	1.49	2.31	2.19	2.10
	.5	3.43	2.08	2.72	4.21	2.34	2.00	1.62	2.05	2.70
3/II	0	3.19	1.25	2.12	2.03	2.25	1.00	2.07	0.31	2.41
	.5	2.87	2.03	2.58	1.34	2.58	1.11	2.90	1.46	2.88
1/III	0	2.27			4.01			3.68		
	.5	3.02			4.23			2.94		
2/III	0	3.88			3.64			2.66		
	.5	3.30			3.32			3.12		
3/III	0	3.54			3.37			2.47		
	.5	3.79			3.45			2.32		
1/IV	0	3.01			3.38			3.63		
	.5	3.39			3.04			3.97		
2/IV	0	3.63			2.24			2.67		
	.5	4.25			1.22			1.78		
3/IV	0	3.51			2.01			2.25		
	.5	1.94			2.01			1.00		

[1] $H = \sum_{i} - Pi \log_2 Pi$

where $Pi = \frac{\text{abundance ith species}}{\text{total abundance}}$

[2] Replicate stations

[3] Single species observed

[4] No species observed

Station 1/II, surface; Station 1/II, one half the depth of the photic zone; and Station 2/II, surface. The overwhelmingly dominant species in these samples was *Skeletonema costatum*. This was the main bloom species in the STOCS area during 1977.

Figures 11.19, 11.20 and 11.21 consider the summarized results of the continuous near-surface measurements (chlorophyll a, temperature, salinity, respectively) obtained along Transect II during each month of 1977. The continuous data calibrated to discrete measurements are presented as monthly graphs in Appendix J. Figure 11.19 shows a complex pattern of chlorophyll a across the shelf. Using the 1 $\mu g\ \ell^{-1}$ contour as a break point for significant concentrations, chlorophyll a, extended about eight nautical miles from the coast in January, February and March. In February, a plume of chlorophyll a extended offshore from a point about 30 nautical miles offshore. The coastal plume extended to about 25 nautical miles offshore in April and May; the outer shelf cleared to concentrations less than 0.5 $\mu g\ \ell^{-1}$. The coastal plume quickly decayed in June and disappeared in July and August. Hurricane Anita provided the stimulus (water mass movement or wind mixing) for the September coastal plume that extended beyond 20 nautical miles offshore. This plume withdrew to about six nautical miles in October-November and moved out to 12 nautical miles in December.

Figures 11.20 and 11.21 provide temperature and salinity data to correlate with the chlorophyll a patterns. Figure 11.20 summarizes the temperature structure observed along Transect II. The coastal temperature range extended from 9°C in January to 30°C in August; the offshore temperature range extended from 17°C in January to 30°C in August. Intermediate sections of the shelf exhibited intermediate temperature ranges. The surface waters were horizontally isothermal between April-November. The sig-

nificant temperature information for interpreting Figure 11.19 occurred in January-February. The cold coastal plume in January was related to a coincident chlorophyll a plume; the coldest offshore temperature in January-February was related to a generally higher biomass outside the 25 nautical mile contour.

The significance of the offshore temperature is suggested in Figure 11.22, a plot of the temperature-nitrate relationship at Station 3/II during 1976. Temperatures below 21°C generally were coincident with increasing nitrate concentration.

Figure 11.21 further explains some of the chlorophyll a patterns in Figure 11.19. The January coastal plumes of chlorophyll a and temperature were coincident with a low salinity plume inshore. In fact, all major coastal chlorophyll a plumes coincided with low salinity plumes (see January, April-May, September and November-December). It was also significant that the offshore chlorophyll a plume in February was coincident with high salinity water; this relationship together with the data in Figures 11.20 and 11.22 suggests upwelling. Apparently, the upwelling occurred mid-shelf and curled back offshore in the surface layer.

DISCUSSION

Figure 11.23 compares the approximate depth of the 16% isolume as determined by Secchi disc and by submarine photometer. In turbid water, the two measurements generally agreed. With decreasing turbidity, however, the Secchi depth increasingly overestimated the depth of the 16% isolume of photosynthetically active radiation. These differences were related to the sensitivity spectrum of the human eye vs that of the submarine photometer. Since the submarine photometer treated a broader spectral band with equal weight, it provided a standard index of photic zone depth.

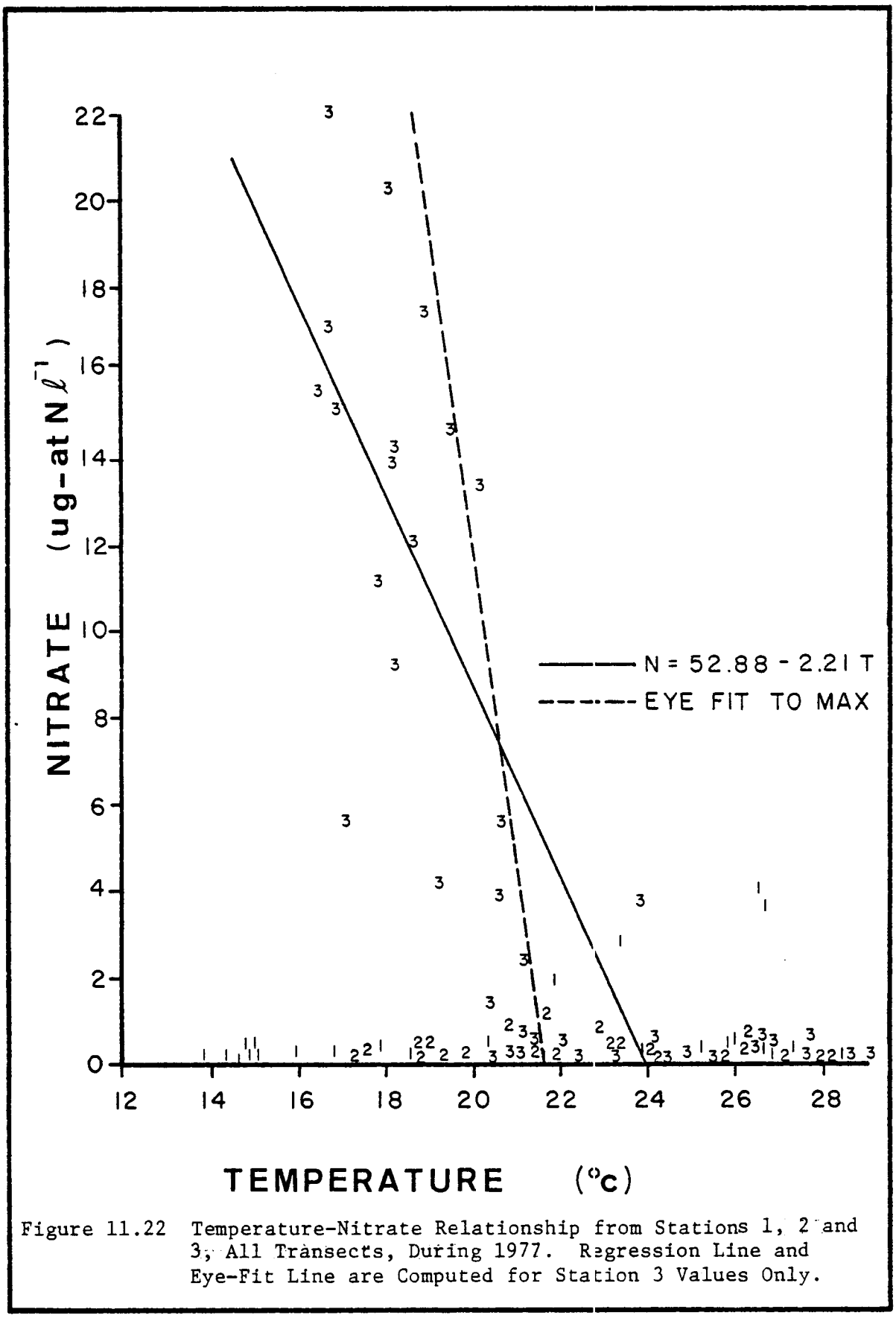

Figure 11.22 Temperature-Nitrate Relationship from Stations 1, 2 and 3, All Transects, During 1977. Regression Line and Eye-Fit Line are Computed for Station 3 Values Only.

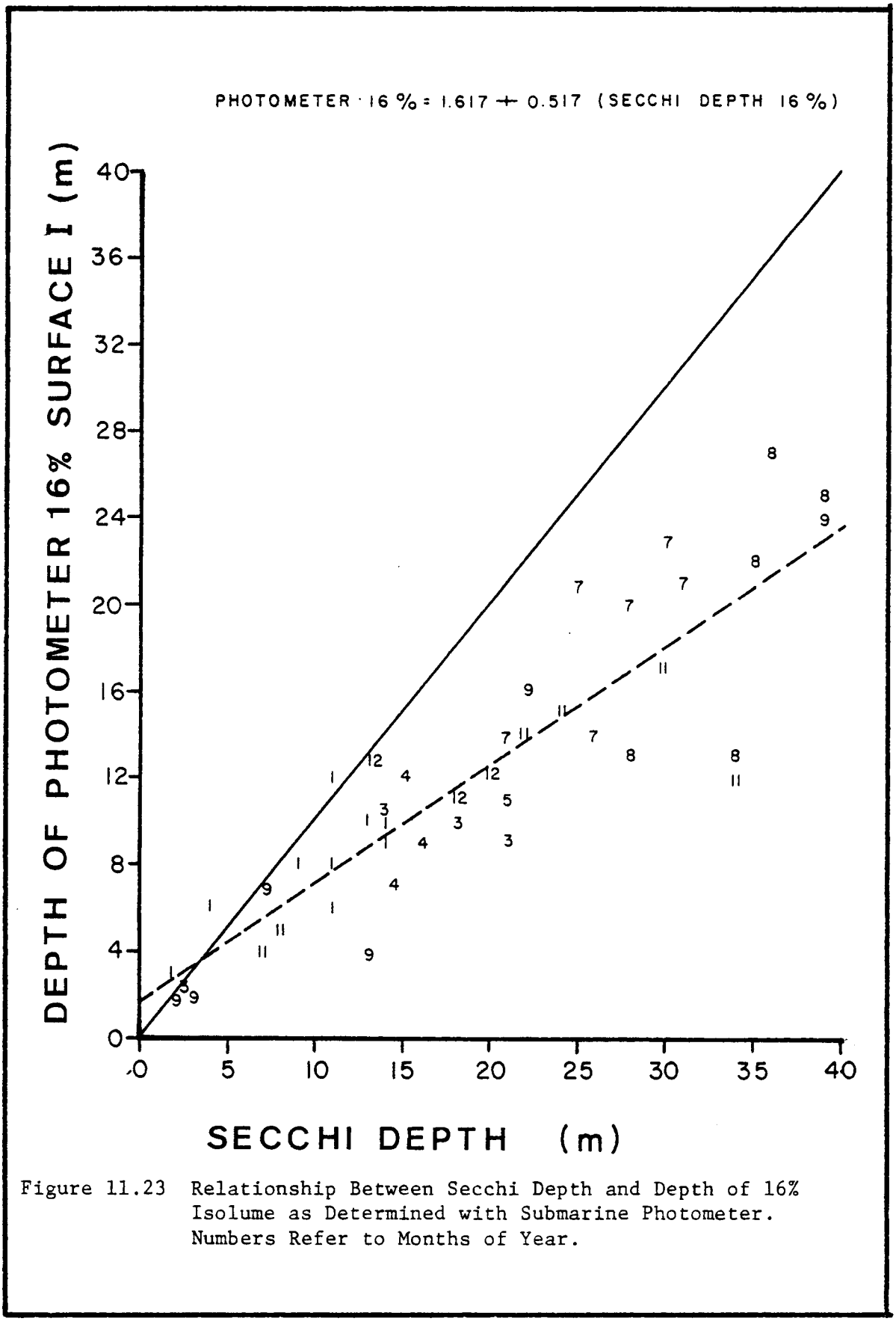

Figure 11.23 Relationship Between Secchi Depth and Depth of 16% Isolume as Determined with Submarine Photometer. Numbers Refer to Months of Year.

The actual relationship of either measure to an absolute photic zone depth depended on the characteristics of the specific phytoplankton community.

Figure 11.24 considers the relationship between surface salinity and Secchi depth. All data tended to fall within the solid line except for May. This clear low-salinity mass was probably related to the influence of Mississippi River water in the STOCS area. Trends within the solid line show that salinities less than 33 °/₀₀ were associated with Secchi depths less than 4 m. Salinities above 33 °/₀₀ showed increasing variability as oceanic salinities (≈ 37 °/₀₀) are approached.

Figure 11.25 presents the relationship between Secchi depth and surface chlorophyll a. The contribution of the phytoplankton to water column turbidity is evident: as Secchi depth decreased, surface chlorophyll a generally increased. The scatter in the plot can be attributed to suspended inorganic sediments and to layering of phytoplankton in subsurface layers.

Figure 11.26 presents the relationship between surface chlorophyll a and salinity. Three categories of data were considered: 1) January offshore; 2) May; 3) remaining months. January offshore was distinguished by relatively high chlorophyll a at high salinities. As stated previously, this phytoplankton biomass was caused by classical upwelling of nutrient-rich, high-salinity water at mid-shelf. The May values exhibited relatively low chlorophyll a at low salinities. There was a detectable increase in chlorophyll a with decreasing salinity. This pattern was attributed to Mississippi River influences. The remaining months followed a pattern of increasing chlorophyll a paralleling decreasing salinity. Compared to the May increase in chlorophyll a (from ~ 0.5 μg ℓ^{-1}) below 32 °/₀₀, the remaining months increased in chlorophyll a with any freshwater input (*i.e.*

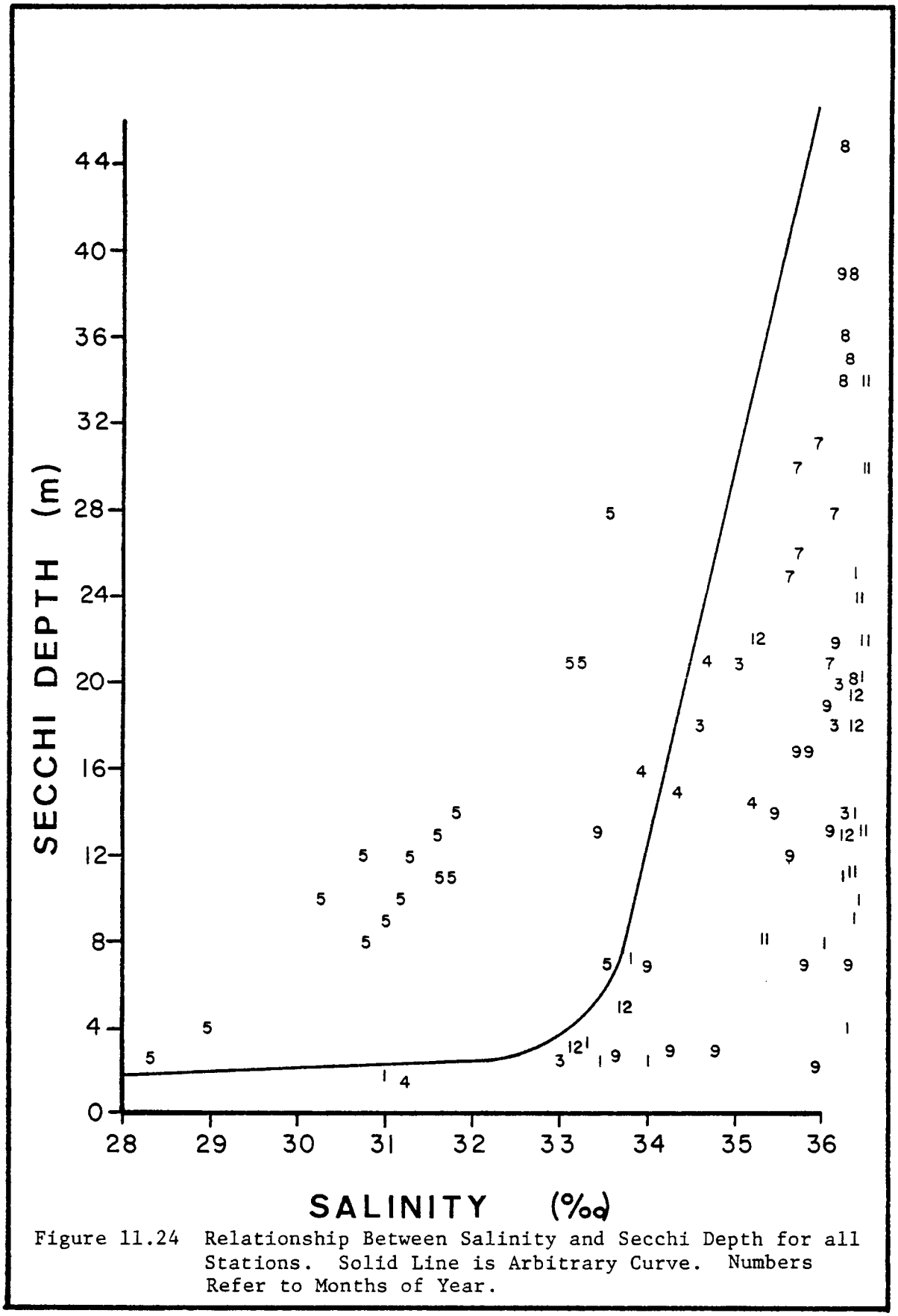

Figure 11.24 Relationship Between Salinity and Secchi Depth for all Stations. Solid Line is Arbitrary Curve. Numbers Refer to Months of Year.

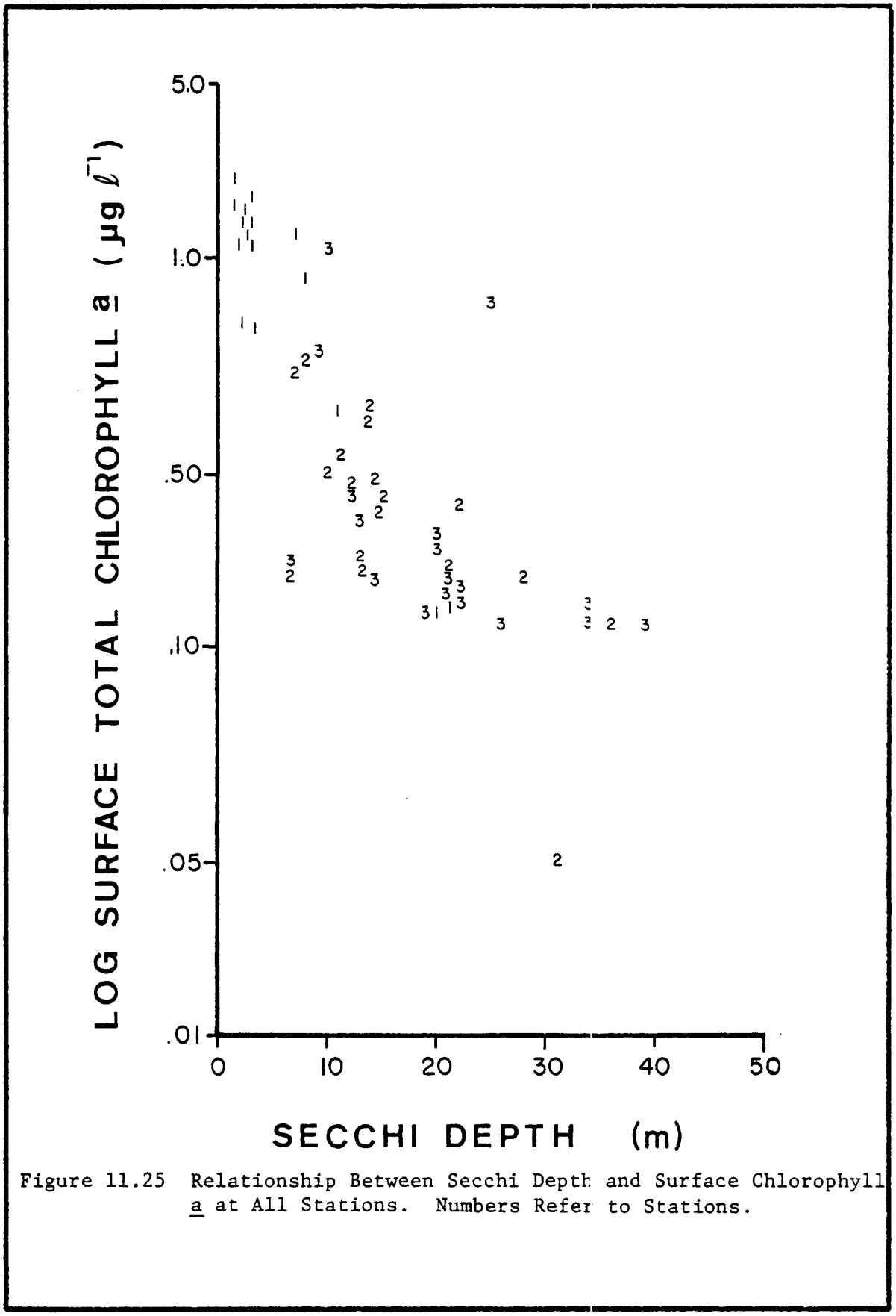

Figure 11.25 Relationship Between Secchi Depth and Surface Chlorophyll a at All Stations. Numbers Refer to Stations.

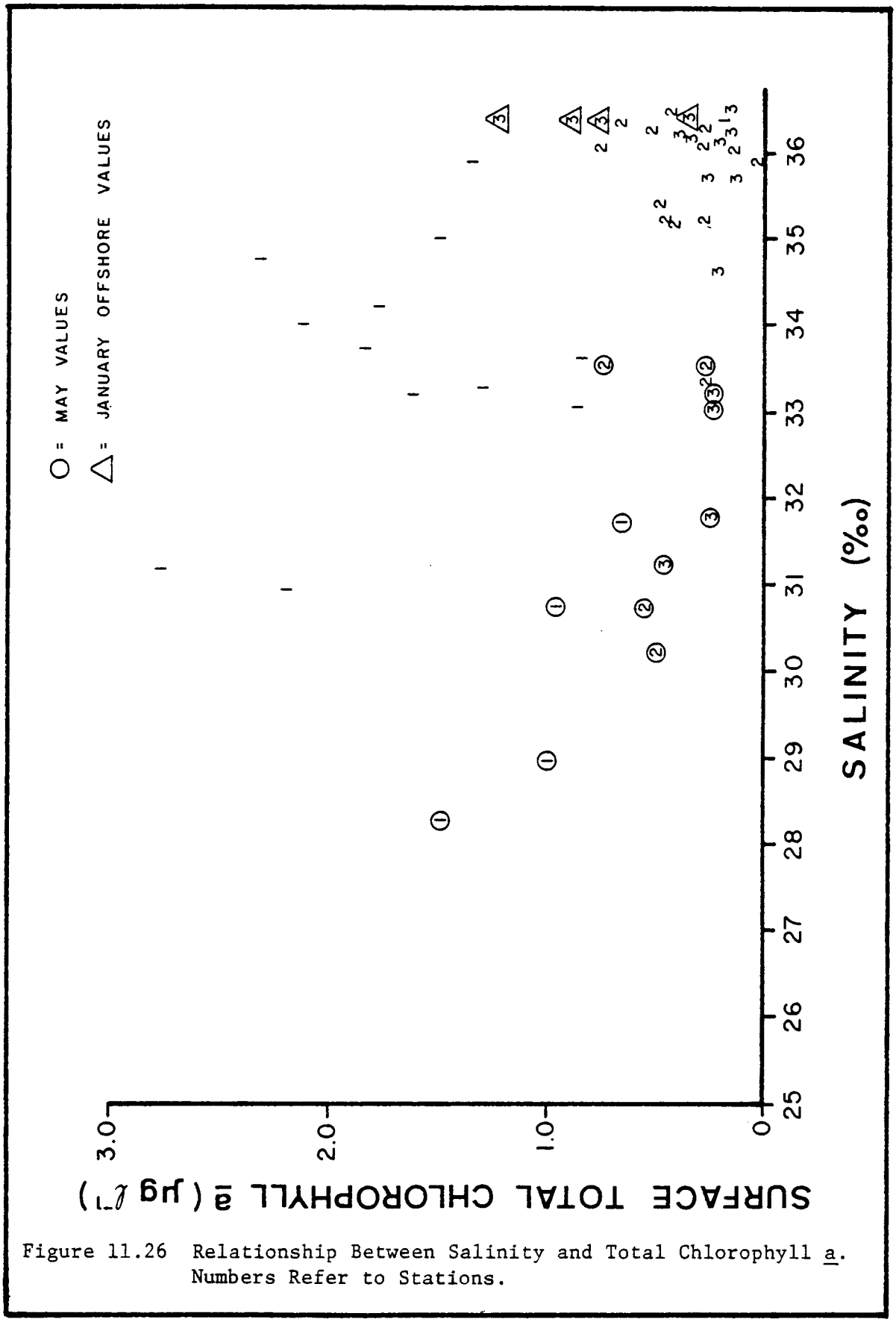

Figure 11.26 Relationship Between Salinity and Total Chlorophyll a. Numbers Refer to Stations.

chlorophyll a ≈ 2.5 μg ℓ^{-1} at 32 °/₀₀).

Figure 11.27 depicts the percent nanno-chlorophyll a as it changed with temperature and salinity. The nanno contribution increased with increasing temperature and with increasing salinity. The interpretation of the salinity trend was again improved by dividing the data into three categories.

Figure 11.28 compares the pattern in chlorophyll a and carbon uptake. Though the scatter was large, two linear trends emerged. The carbon uptake per unit chlorophyll a in May was significantly higher than that in the remaining months. The reason for this change was not clear. Neither analytical error in species counts nor substrate availability appeared to account for the greater May uptake of carbon. It is possible that the increased May efficiency was caused by the unique hydrographic conditions or by some factor associated with the Mississippi River water.

Table 11.8 lists the total community assimilation numbers for 1977. On a monthly basis, the efficiency of carbon uptake increased from January through May, declined through the summer months and increased again in December. On a station basis, assimilation numbers tended to increase offshore on all transects. These trends were related in a complex relationship with species composition, nutrient availability, temperature and salinity. The former dependence is suggested in Figure 11.29. The assimilation number increased both with percent nanno biomass and with percent nanno activity. Assuming that high assimilation number is an index of a healthy phytoplankton community, the times of lowest assimilation or growth stress occurred in two time intervals: January and August-November. The remaining months were dominated by relatively unstressed communities at a minimum of two stations along Transect II. The January period probably reflected temperature stress; the fall period probably reflected nutrient stress.

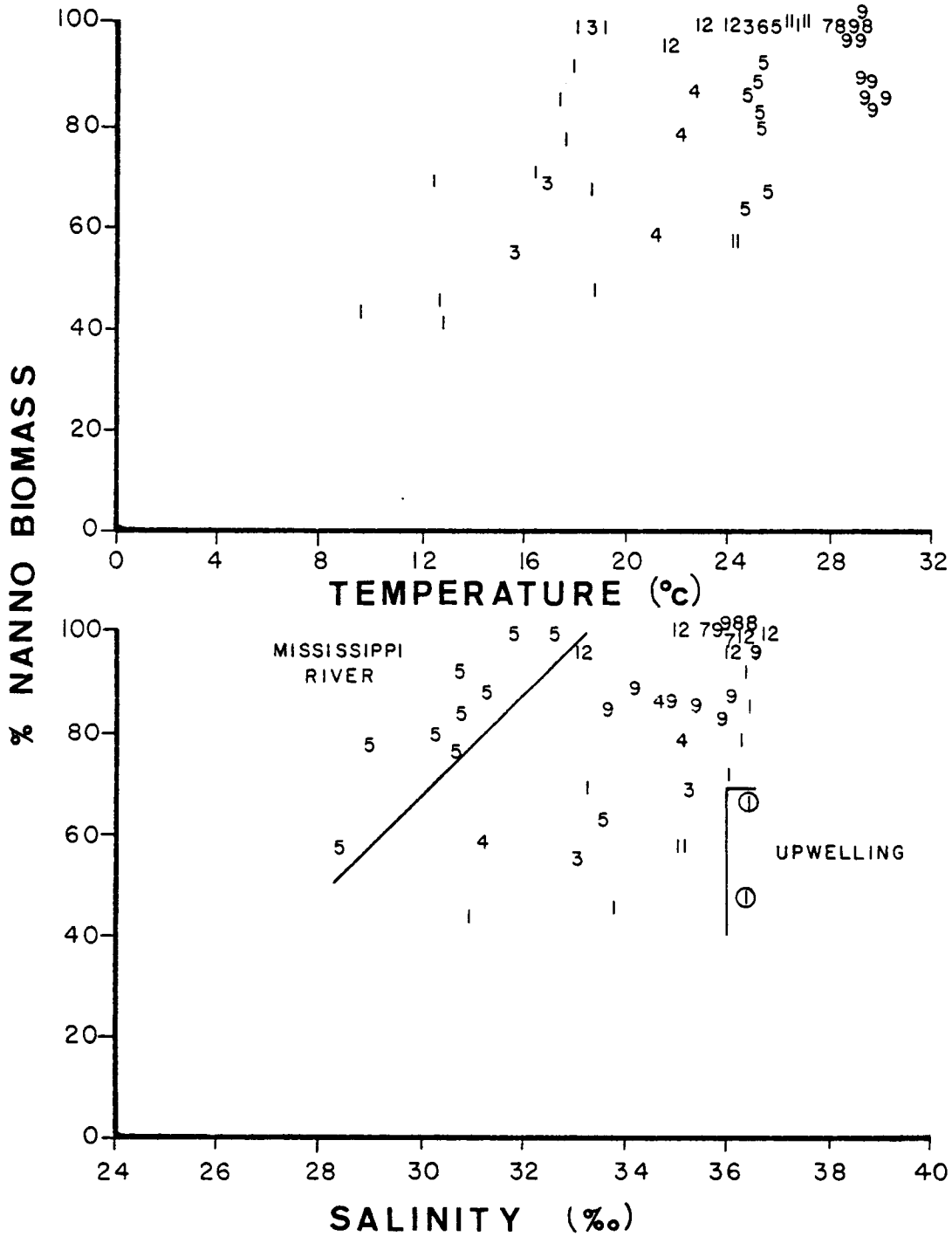

Figure 11.27 Relationship Between Temperature and % Nanno Biomass and Salinity and % Nanno Biomass at All Stations. Numbers Refer to Months of Year.

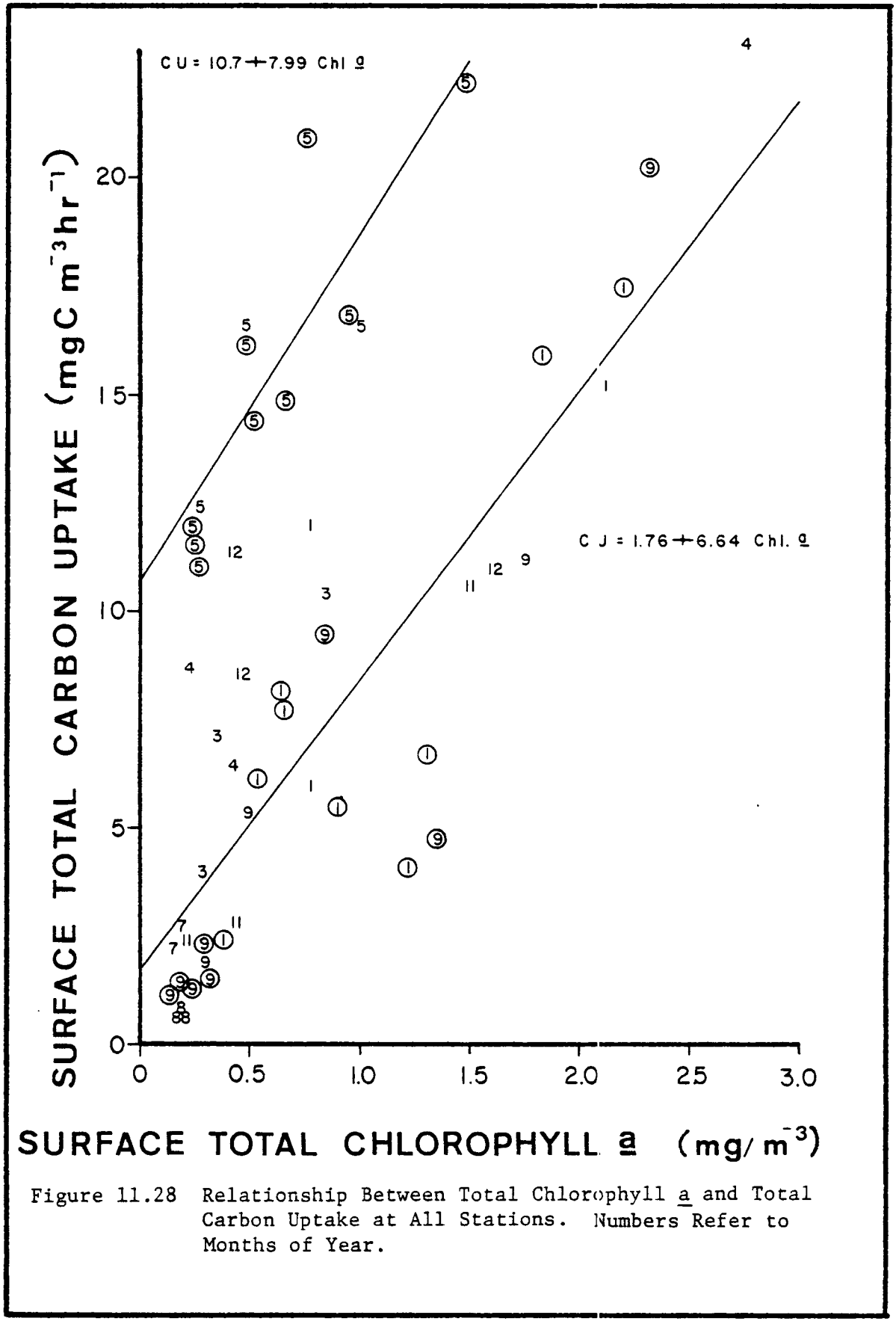

Figure 11.28 Relationship Between Total Chlorophyll a and Total Carbon Uptake at All Stations. Numbers Refer to Months of Year.

TABLE 11.8

MONTHLY VARIATION OF ASSIMILATION NUMBERS [mg C(mg Chl a)$^{-1}$(hr)$^{-1}$] AT ALL STATIONS

Station	Jan Feb	Mar	Apr	May June	July	Aug	Sept Oct	Nov	Dec	$\Sigma/\bar{X}$
1/I	7.93			15.20			11.31			34.44/11.48
2/I	11.88			27.88			8.26			45.02/16.01
3/I	3.26			49.08			7.89			60.23/20.08
1/II	7.16	12.29	8.38	16.78	14.21	5.65	6.32	7.05	6.81	84.65/9.41
2/II	15.76	13.90	15.68	34.75	-	5.53	10.96	6.30	19.02	121.90/15.24
3/II	7.62	21.23	39.55	47.27	15.27	4.44	7.36	13.00	28.63	184.37/20.49
1/III	5.15			17.71			8.83			31.69/10.56
2/III	12.91			28.33			5.57			46.81/15.60
3/III	6.09			34.72			6.67			47.48/15.83
1/IV	8.74			23.03			3.55			35.32/11.77
2/IV	11.65			42.58			6.39			60.62/20.21
3/IV	7.11			50.38			9.73			67.22/22.41
Σ	95.28	47.42	63.61	387.71	29.48	15.62	92.84	26.35	54.46	
$\bar{X}$	7.94	15.81	21.20	32.31	14.74	5.21	7.74	8.78	18.15	

Overall Σ - 812.77 Transect II 390.92 Station 1 186.1 Station 2 277.35 Station 3 359.39

Overall N - 53 Transect II 26 Station 1 18 Station 2 17 Station 3 18

Overall $\bar{X}$ - 15.33 Transect II 15.04 Station 1 10.34 Station 3 16.31 Station 3 19.97

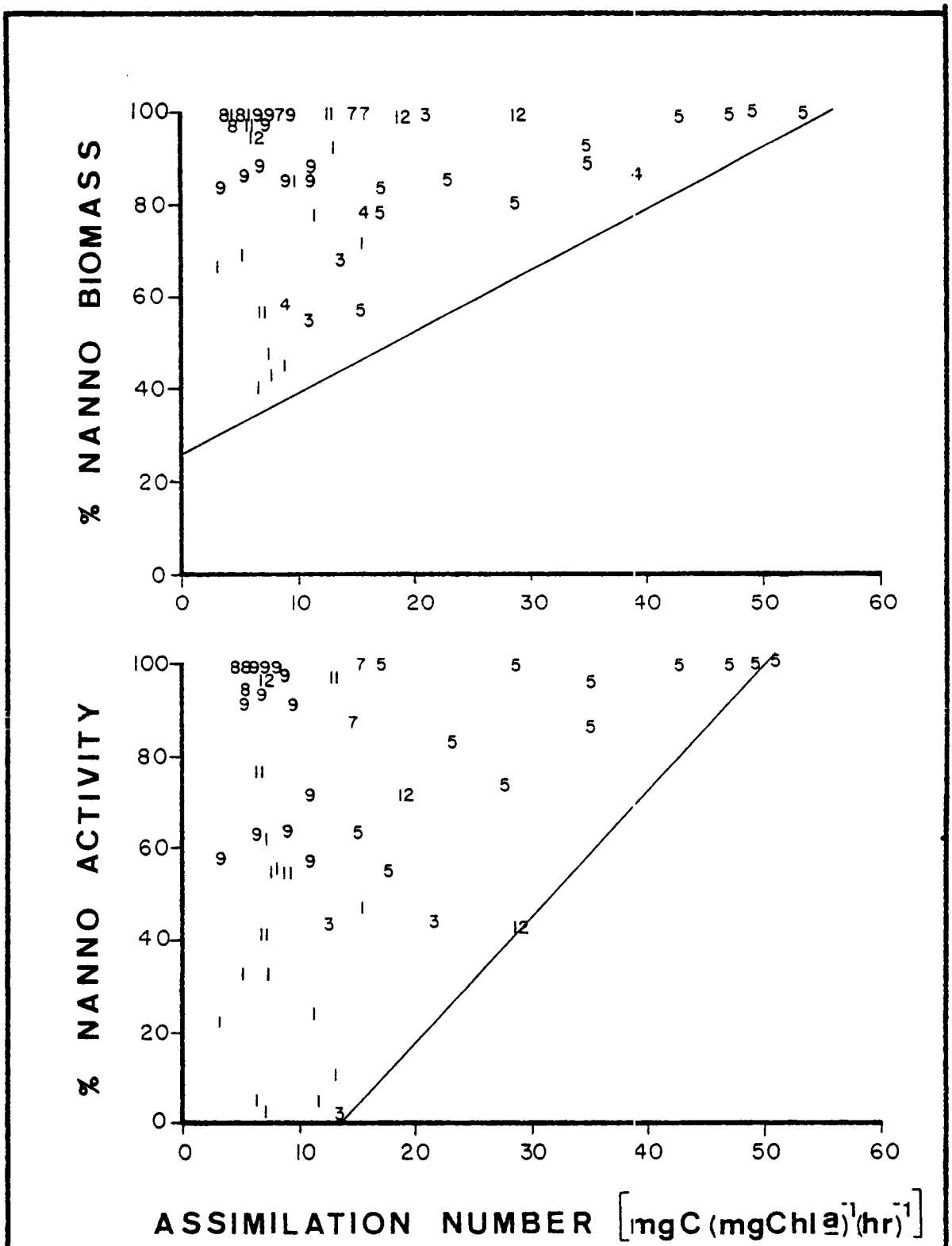

Figure 11.29 Relationship Between Assimilation Number and % Nanno Biomass and Assimilation Number and % Nanno Carbon Uptake at All Stations. Numbers Refer to Months of Year.

Figure 11.30 presents the mutual dependencies between total chlorophyll a and total phytoplankton cell counts. Despite high scatter, the two biomass parameters showed co-variation. The weakness of the plot was due to the inadequate estimation of the numbers of the nanno fraction and to the large variability of chlorophyll a per cell in different species.

CONCLUSIONS

1. Seasonal surface patterns of all measured parameters showed an offshore decrease in phytoplankton biomass and production and suggested decreasing activity from north to south.

2. The nannophytoplankton generally dominated STOCS biomass and activity during 1977.

3. Substantial near bottom concentrations of chlorophyll a occurred out to Station 2/II during the summer months.

4. The monthly temporal patterns of all parameters showed a bimodal cycle of biomass and activity in the nearshore stations. The net fraction preceded the nanno fraction in spring; the order of appearance reversed in fall.

5. The continuous measurement of chlorophyll a, temperature and salinity along Transect II identified the major incursions of freshwater into the STOCS area, an upwelling at mid-shelf in February and possible wind mixing in September due to Hurricane Anita. Nearshore chlorophyll a plumes may have extended up to 25 nautical miles offshore.

6. The phytoplankton species divided into complex monthly groupings reflecting the complex physical processes in the STOCS area during 1977. *Skeletonema costatum* was a universal dominant of net fraction abundance peaks.

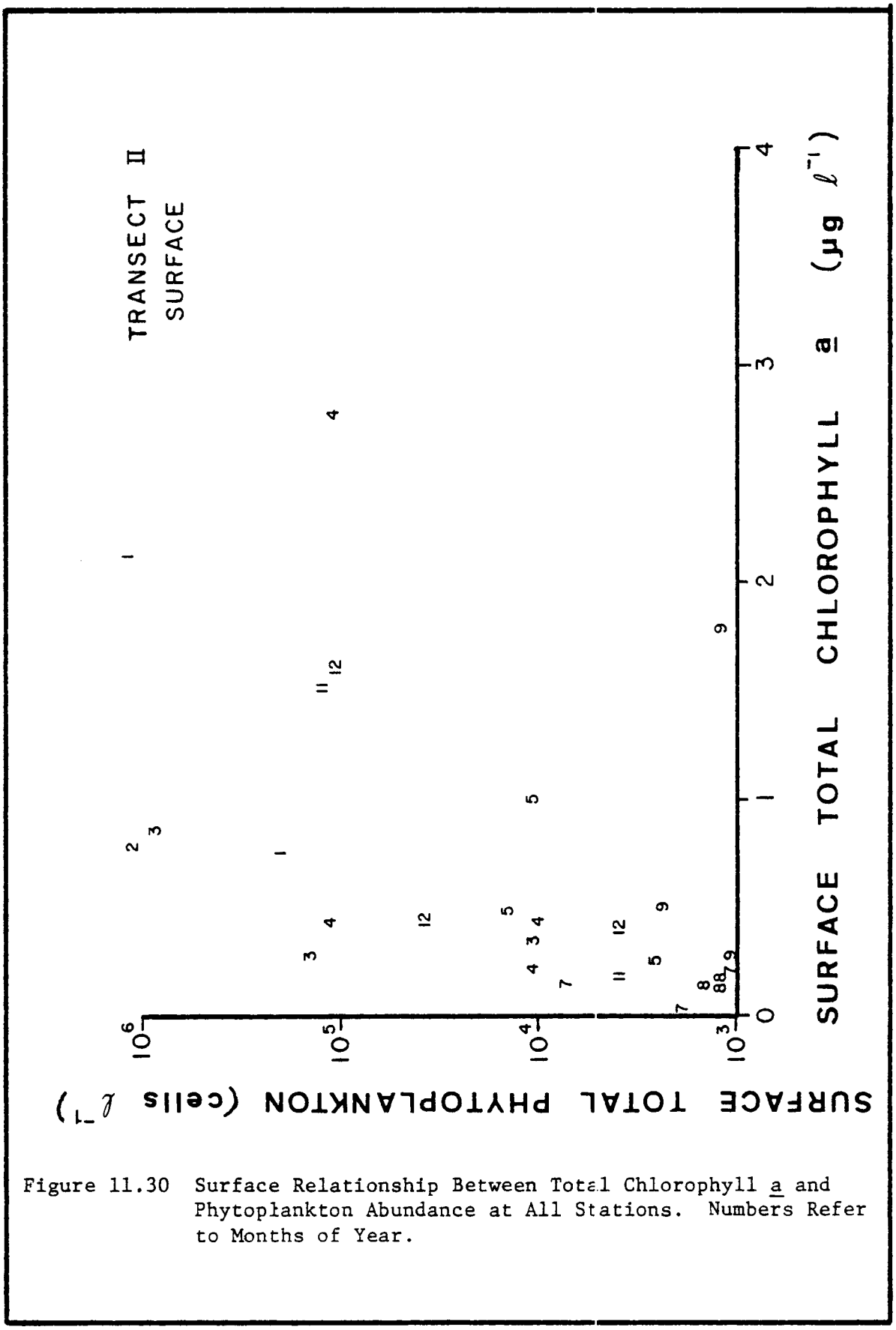

Figure 11.30 Surface Relationship Between Total Chlorophyll a and Phytoplankton Abundance at All Stations. Numbers Refer to Months of Year.

7) Good relationships were observed among the various measured parameters. The assimilation numbers were anomalously high in May, possibly reflecting the influence of Mississippi River water in the STOCS area. Possible phytoplankton stress was identified in January and between August and November.

8) Local run-off apparently contributes directly to high biomass in the nearshore areas. Mississippi River water is characterized by unusual clarity for its salinity range.

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CHAPTER TWELVE

SHELLED MICROZOOPLANKTON AND GENERAL MICROPLANKTON

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ABSTRACT

Depth stratified Nansen net tows and discrete depth Niskin bottle samples were collected in the BLM-STOCS study area seasonally and during July, August, November and December of 1977. Shelled microzooplankton and general microplankton were studied from the Nansen nets and Niskin bottles respectively.

The shelled microzooplankton and general microplankton data were compared to the physical oceanography of the study area by use of density, diversity and other plots of the data along with cluster analysis. These comparisons revealed: ponds of water moving onto the shelf at various depths during the winter; strong upwelling in the winter and into the spring; brackish water moving out toward the open Gulf of Mexico in the spring drawing deeper open Gulf water shoreward underneath it; and, a dramatic eutrophism of the STOCS during the winter and into the spring of 1977. These conclusions were suggested by certain observed species of shelled microzooplankton that indicated the above oceanographic conditions.

INTRODUCTION

Purpose

This component of the BLM-STOCS studies was directed toward monitoring the shelled microzooplankton and general microplankton with special emphasis on the use of shelled microzooplankton as indicators of oceanographic conditions to characterize the study area. The organisms collected were identified to lowest taxonomic unit, these data placed on computer cards, and R and Q mode cluster analyses performed for significant stations, species and species groups, resulting in dendrograms. This information was correlated to the other oceanographic components (biological, physical and chemical) of the STOCS study area. A survey of previous work on the microplankton from the STOCS is contained in the 1976 Final Report (Casey, *In* Groover, 1977).

Emphasis was placed on the use of the shelled microzooplankton (radiolarians, planktonic foraminiferans, benthonic foraminiferans and pteropods) as indices of oceanographic conditions. To this end, three tables are included in the text designating such indicators, and Table 1, Appendix K is constructed so that it may be used in conjunction with the tables and figures in the text.

METHODS AND MATERIALS

Collecting Procedures

Nansen Tows (Depth Stratified Samples)

Nansen tows were taken at Stations 1-3 of all transects during the seasonal sampling, and at Stations 1-3, Transect II during the July

through December monthly samplings (Figure 12.1). At Station 1 of all transects, the net was lowered to just off the bottom (usually about 25 m) and slowly (about 20 m/minute) towed to the surface. At Station 2 of all transects, two separate tows were taken. In the first tow, the net was lowered to just off the bottom (usually about 50 m) and slowly towed toward the surface. While the net was still fishing (towing) a messenger was dropped so that the net closed at 25 m; the second tow at this station was taken by lowering the net to 25 m and slowly towing it to the surface. At Station 3 of all transects, three separate tows were taken. In the first tow, the net was lowered to just off the bottom (usually about 100 m) and slowly towed toward the surface and closed at 50 m; the second tow was lowered to 50 m and closed at 25 m; and the third tow was from 25 m to the surface. The net was then washed with seawater from the outside of the mesh and the material in the cod end was preserved in a 500-ml Nalgene bottle with a 5% formalin solution containing sodium borate, strontium chloride and rose Bengal. This preservative solution was prepared in the following manner: 1 gal. of 37% (stock) formaldehyde + 80 gm $Na_2B_4O_7 \cdot 10H_2O$ (sodium borate) + 18.2 gm $SrCl_x \cdot 6H_2O$ (strontium chloride) + 2 gm rose Bengal. Each bottle was then labeled and a shipboard data sheet completed. A total of 96 samples were collected and are reported on herein.

Niskin Bottle Samples (Discrete Samples)

Niskin samples during the winter seasonal sampling were taken at 10 m depth and at one-half the depth of the photic zone (as determined with either a Secchi disk or photometer) at Stations 1 and 2, all transects; and at 10 m depth, one-half the depth of the photic zone, the photic zone, and just off the sea floor at Station 3, all transects. Niskin samples during the remaining two seasonal samplings were taken at one-half the

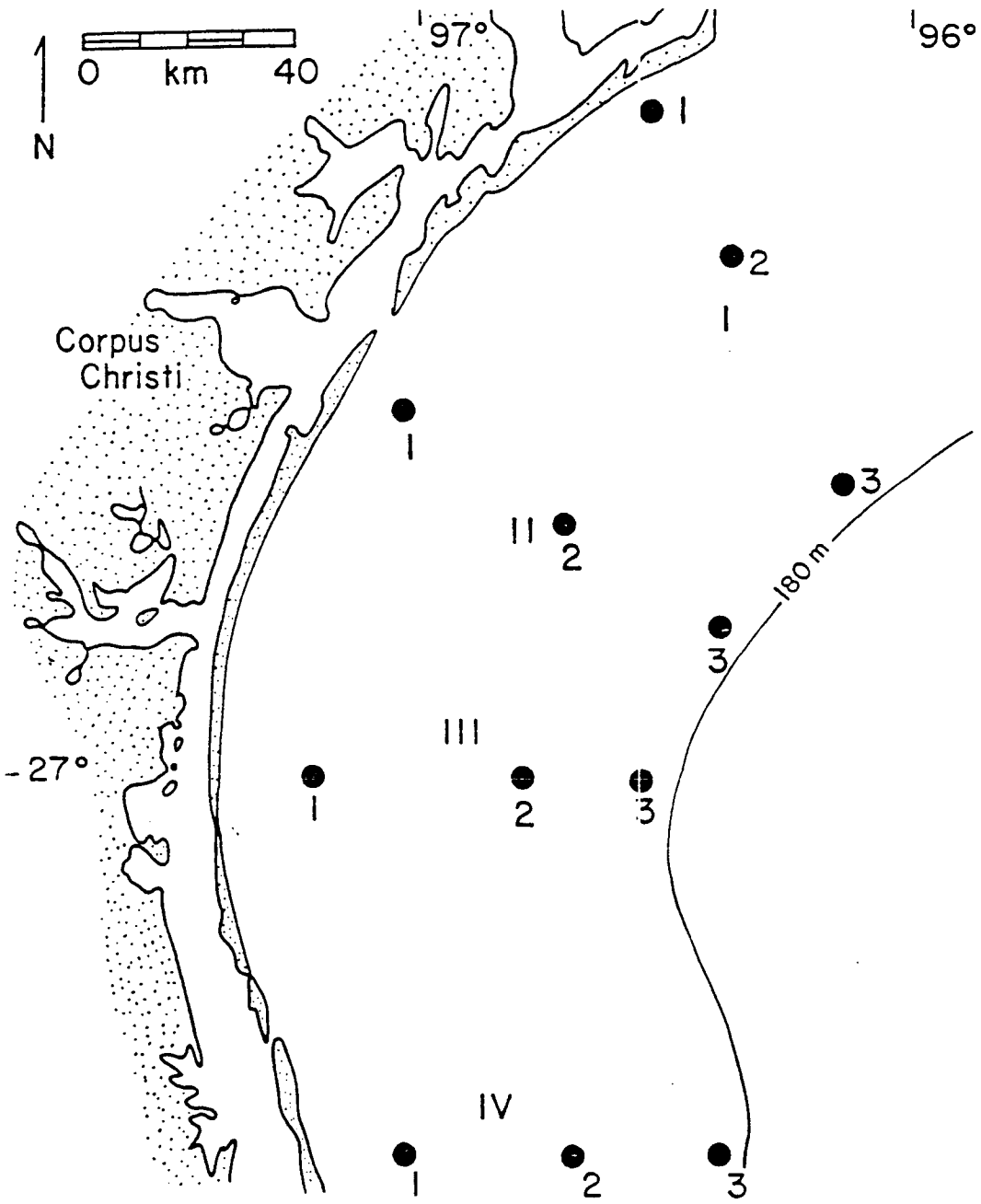


Figure 12.1 Stations Where Nansen Net and Niskin Bottle Samples were Taken During 1977. Seasonal Samplings were From Stations 1-3, All Transects, and Monthly Samplings were from Stations 1-3, Transect II.

depth of the photic zone and the depth of the photic zone at Stations 1, all transects; and at one-half the depth of the photic zone, the photic zone, and just off the sea floor at Stations 2 and 3, all transects. Transect II was sampled in the same manner monthly during the July, August, November and December cruises. From each 30-ℓ Niskin bottle, 29 ℓ were filtered through a 38-μm mesh stainless steel screen. The filtrate was washed into a 500-ml Nalgene bottle and preserved in a 2 to 3% preservative solution as described for the Nansen tows, except that no rose Bengal was used. Each bottle was then labeled and the shipboard data sheet completed. A total of 126 samples were collected and are reported on herein.

Post Collecting Procedures

Nansen Samples

In the laboratory, the samples were split into two aliquots with a plankton splitter. One aliquot was archived and the second was sorted for microplankton. The seasonal samples were either hand-picked using a breaking pipette and a plankton microscope and then placed on slides, or identified and counted directly with the plankton microscope. The monthly samples (and a few seasonal samples that did not contain stain) were handled by taking an aliquot and identifying and counting organisms using the plankton microscope. All samples and slides were saved.

Data from the seasonal samples were placed on computer cards and cluster analyses performed that resulted in dendrograms (Sneath and Sokal, 1973; Kruskal, 1956). The dendrograms, radiolarian density and richness, planktonic foraminiferan density and the density of *Bolivina lowmani* were compared with other oceanographic phenomena and used as aids to interpret these phenomena.

Niskin Samples

An aliquot of either 5 or 10 ml was removed from a well agitated Niskin sample using a Hensen-Stemple pipette. This aliquot was placed in a Zeiss plankton counting chamber and the microplankton were allowed to settle. After the microplankton had settled to the chamber floor, the first 100 organisms (including fecal pellets) were identified and counted using an inverted microscope. Due to very high density, 300 individuals were counted from five winter samples. The surface area of the chamber traversed during winter samples. The surface area of the chamber traversed during counting was recorded. The residue and supernatant of each sample were then combined and archived.

The data were placed on computer cards, cluster analyses performed and dendrograms and maps of relative abundance (percent of total) of major groups and total density were prepared on the data from the 12 seasonal stations. These were compared with other oceanographic phenomena. Tables of what appeared to be some of the important indicators were also prepared.

RESULTS AND DISCUSSION

Physical and Chemical Oceanographic Setting

Water masses of the STOCS in 1977 were plotted on a Temperature-Salinity (T-S) diagram (Figures 12.2). The T-S diagram for 1977 was very similar to those prepared from the 1975 and 1976 data (Casey, 1977; Casey, *In* Groover, 1977) with a core of Western Gulf Surface Water (WGSW) always present during the three seasons. The main differences between 1977 and previous years were the colder temperatures during the winter 1977 samplings and the slight suggestion of an incursion of Subtropical Underwater in the spring of 1977 (during the summer of 1976 this incursion was very evident).

Smith in Chapter 2 of this report, has done an excellent job of

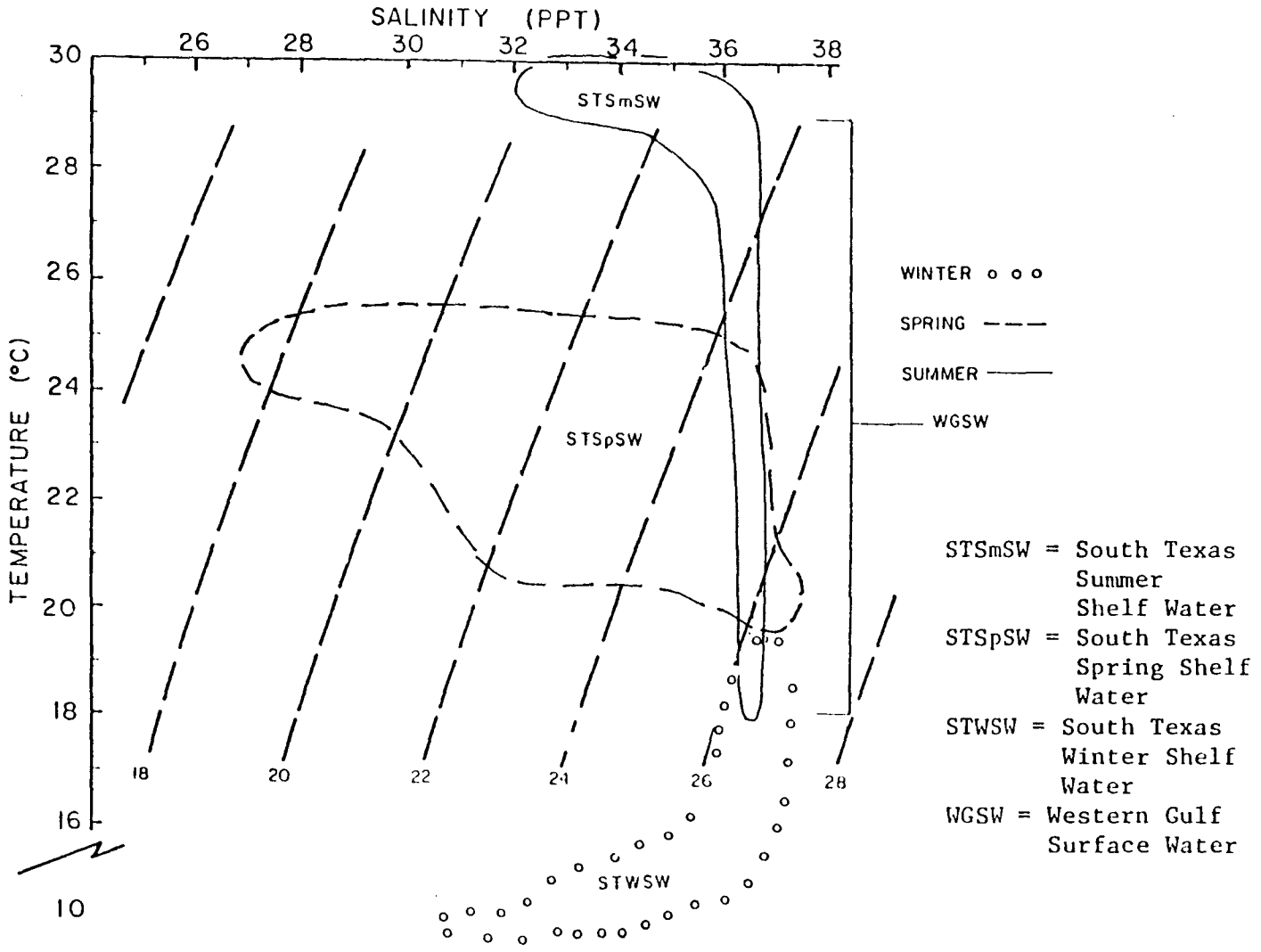


Figure 12.2 Water Mass Characterization of the STOCS 1977, from Seasonal Data.

describing the physical oceanography of the 1977 STOCS and the following is but a review of the physical oceanography of the STOCS in 1977, important in interpreting the shelled microzooplankton distributions. Winter 1977 was dominated by strong cold fronts that cooled the waters to a greater degree than in the previous two years and mixed the water column. The general circulation pattern was wind driven parallel to the coast from north to south. Smith's Figure 2.3 (Chapter 2) shows an upwelling at mid-shelf in winter. This probably was due to an "early" switch in the wind systems from a northerly to a southerly direction (Kamykowski, personel communication). These conditions created the most obvious upwelling seen on the STOCS; this upwelling apparently continued into the spring.

Spring run-off (both local and from the Mississippi) produced a lens of brackish water that flowed from the north to south across the STOCS with a slight offshore component. This offshore component "caused" an open ocean estuarine type of upwelling within the STOCS. Smith suggested that Subtropical Underwater might have moved onto the shelf along Transect I at this time.

Summer conditions developed with the establishment and subsequent thickening of the thermocline and the north-south alternating wind patterns. This resulted in waters having a greater residence time on the shelf during the summer than in either winter or spring (months as opposed to days of weeks). Unlike the summer of 1976, there did not appear to be an incursion of Subtropical Underwater or the grounding of an anticyclonic gyre from the Loop Current in 1977. However, a wedge of somewhat higher salinity water did extend shoreward at mid depths over the outer shelf (Smith, Chapter 2, Figure 2.30).

Nansen Depth Stratified Tow Data Related to Physical Oceanography

The data from the Nansen tows may be seen in Table 1, Appendix K.

These raw data were converted into maps showing the densities of polycystin radiolarians (in number of individuals/m^3), planktonic foraminiferans and the benthic foraminiferan *Bolivina lowmani*; and, polycystin radiolarian richness (number of species/tow) for each season at depths of 0-25 m, 25-50 m and greater than 50 m (Figures 12.3 - 12.6).

During the winter, ponds of shallow and deeper open-ocean Gulf water moved onto the STOCS probably due to eddies breaking off from the general southerly movement of the offshore wind driven current. In winter, deep open-ocean Gulf water occurred all along the STOCS at mid-shelf with a return seaward at the surface. In spring, a lens of brackish water, from local sources and the Mississippi River, moved south across the STOCS. The offshore component of this surface flow dragged surface and deeper open Gulf water shoreward under the pycnocline. Mixing occurred through the pycnocline resulting in an "open-ocean type" of estuarine upwelling on the STOCS during spring. In the fall there appeared to be a general encroachment of open-ocean Gulf water throughout the water column. The nearshore surface currents in the fall alternated north and south with a general deep bottom current directed toward the north on the outer shelf. These general trends appear to be similar to what was found in the 1975 and 1976 years of the BLM-STOCS program (Casey, 1977; Casey, *In* Groover, 1977) with the exception of the dramatic upwelling (upwelled water to the surface, not just an upbowing of water) in the spring of 1977.

Radiolarian Density Maps from Depth Stratified Nansen Tows

Radiolarian density maps from depth stratified Nansen tows for winter, spring and fall of 1977 are shown in Figure 12.3. The radiolarian densities for winter showed a general encroachment (high radiolarian densities) of Gulf surface waters (0-25 m) along Transect III and a pond

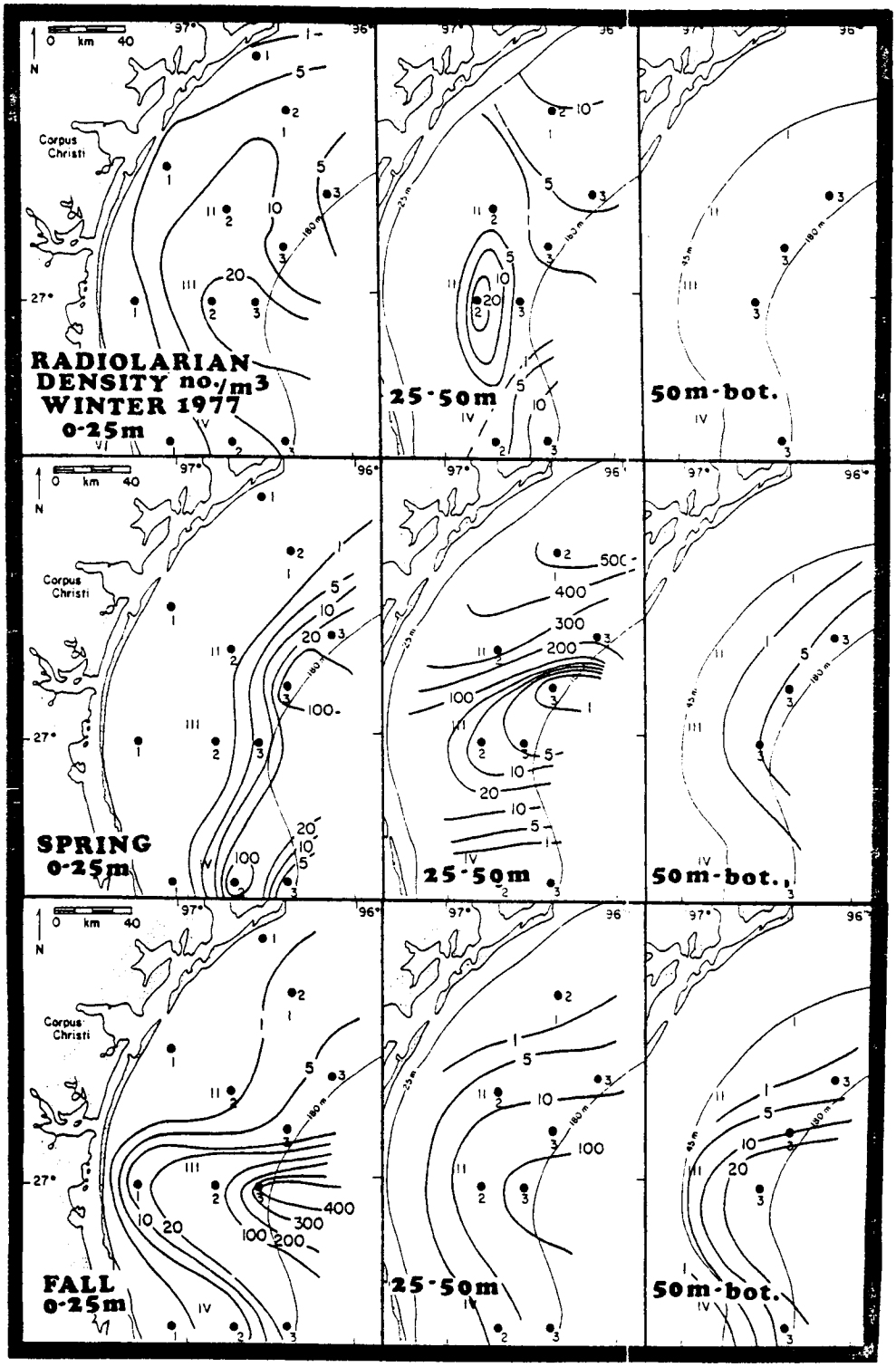


Figure 12.3 Radiolarian Density Maps for Winter, Spring, and Fall at Surface (0-25 m), Shelf Intermediate (25-50 m) and Deep (50 m) Depths.

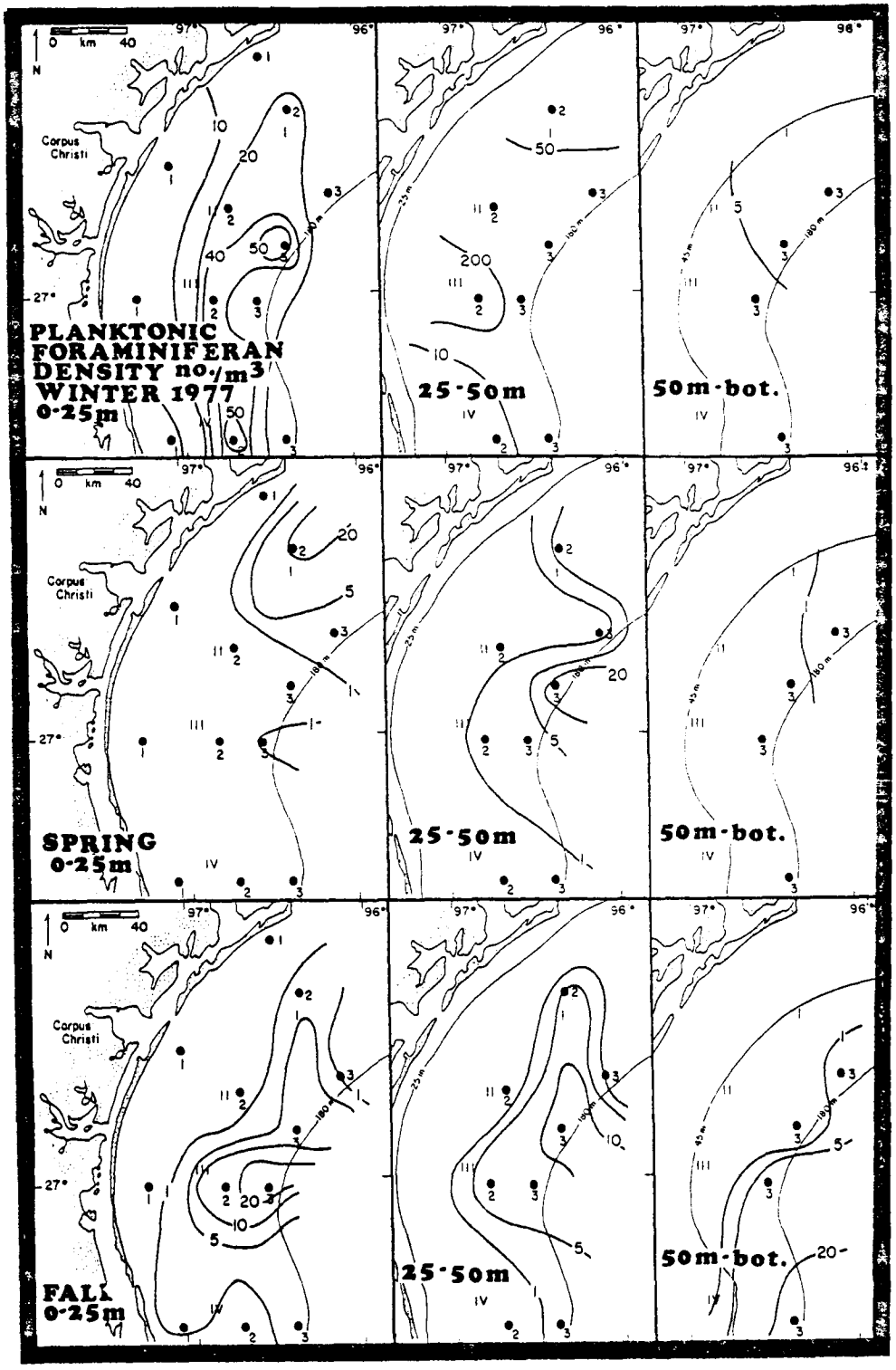


Figure 12.4 Planktonic Foraminiferan Density Maps for Winter, Spring and Fall at Surface (0-25 m), Shelf Intermediate (25-50 m) and Deep (50 m) Depths.

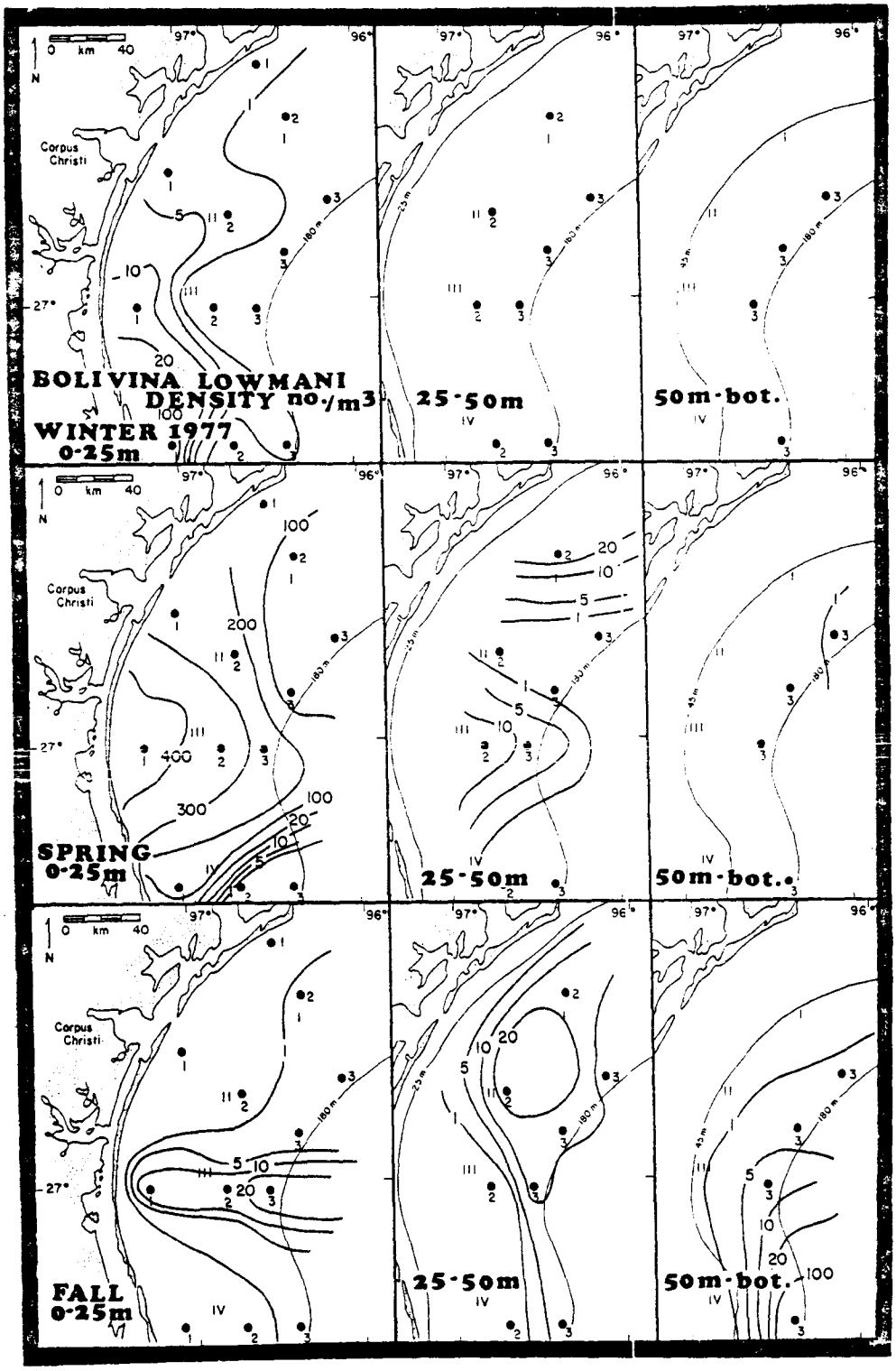


Figure 12.5 *Bolivina lowmani* Density Maps for Winter, Spring and Fall at Surface (0-25 m), Shelf Intermediate (25-50 m) and Deep (50 m) Depths.

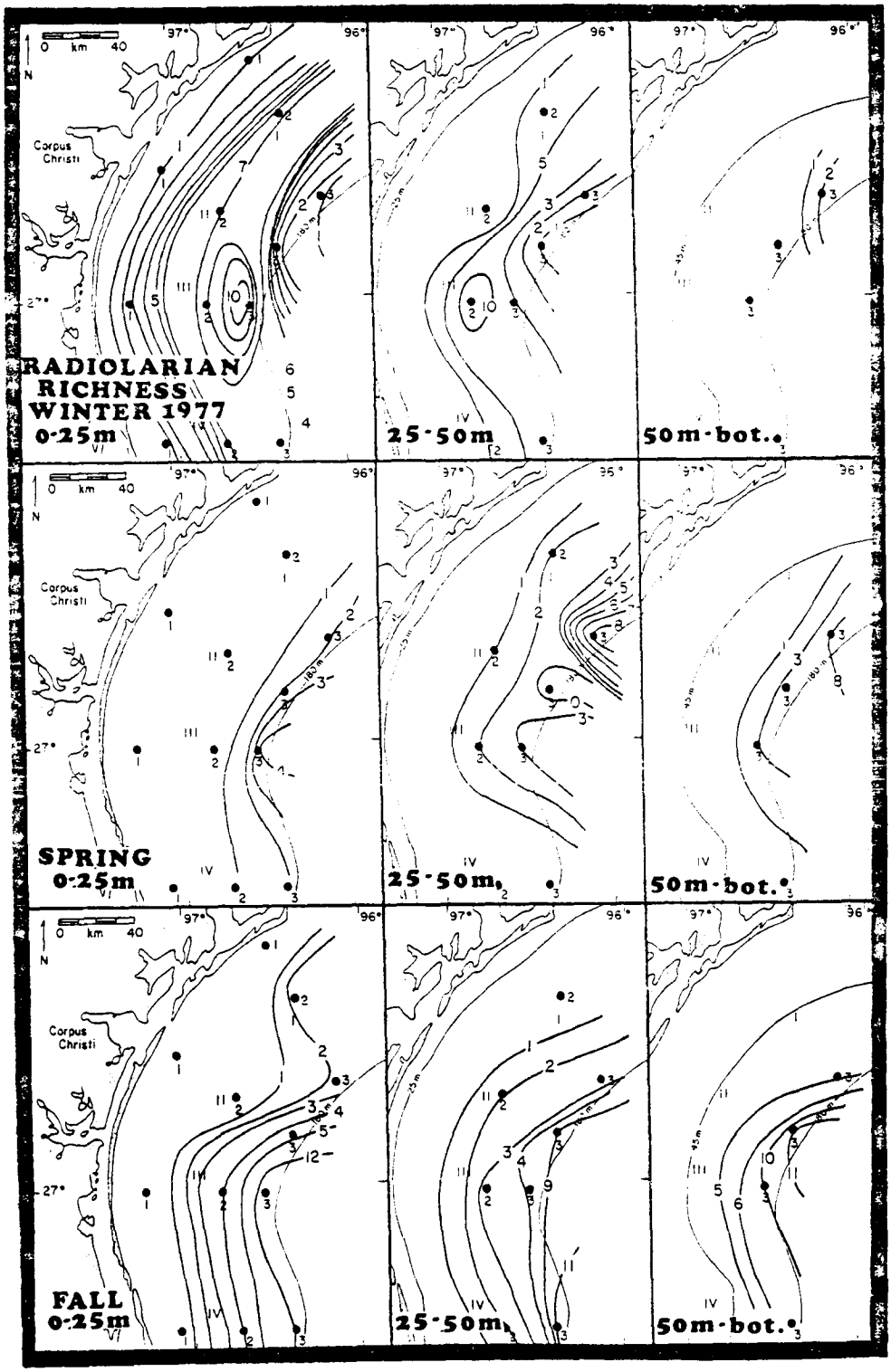


Figure 12.6 Radiolarian Richness Maps for Winter, Spring and Fall at Surface (0-25 m), Shelf Intermediate (25-50 m) and Deep (50 m) Depths.

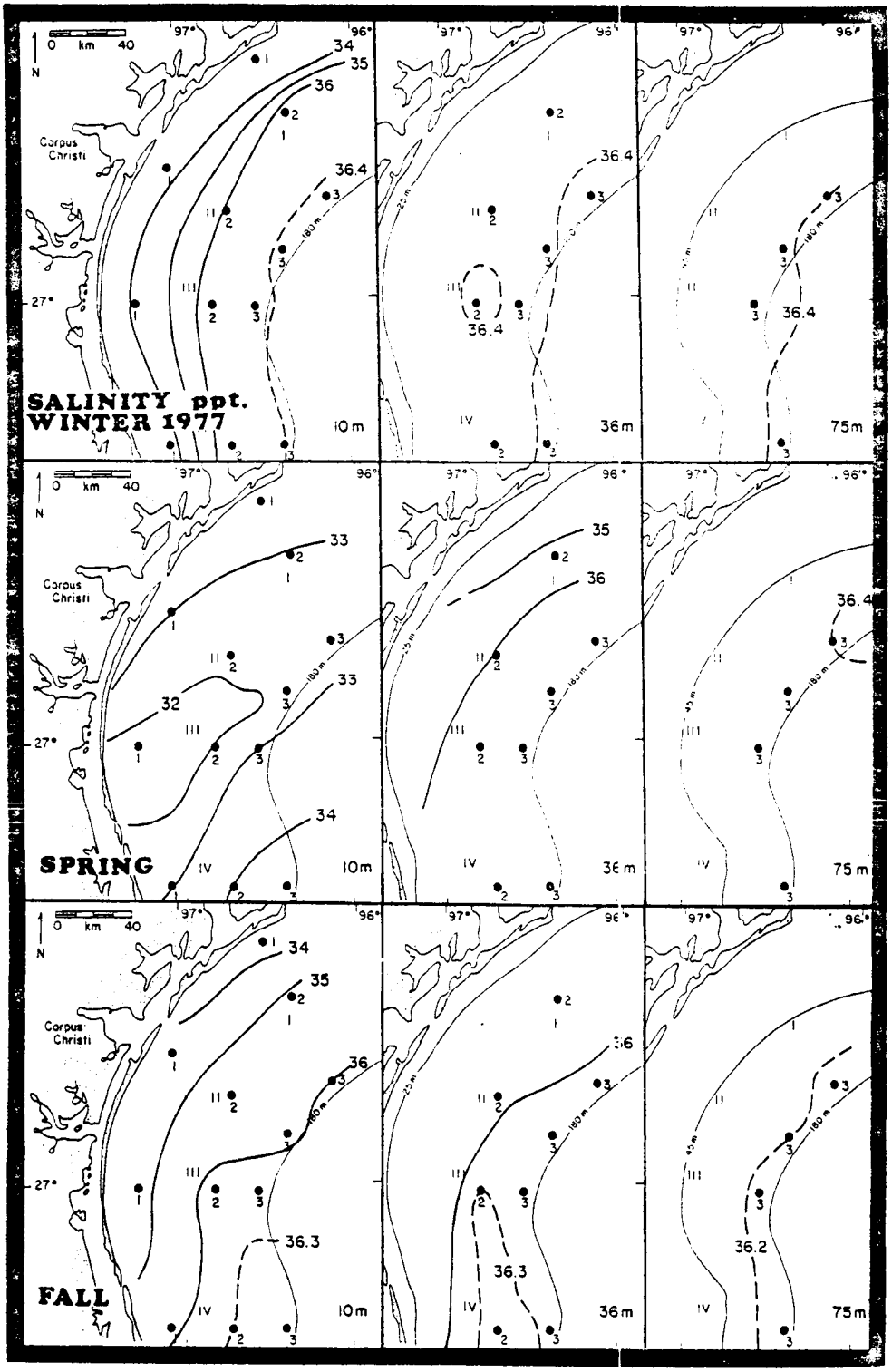


Figure 12.7 Salinity Maps for Winter, Spring and Fall at 10, 36 and 75 m Depths.

of shallow water (high radiolarian densities) at Station 2/III. The winter salinities (Figure 12.7) showed normal marine waters (36 ppt) shoreward to Station 2 and high salinity (36.4 ppt) water around Station 2/III agreeing with our interpretation that a pond of shelf intermediate (25-50 m) water occurred at that station.

Radiolarian density maps from Nansen tows for spring (Figure 12.3) showed an absence of radiolarians in surface waters at most inner and mid-stations and open Gulf water was present at the surface at the outer stations. The greatest radiolarian density was at Station 3/II for this surface (0-25 m) water. Under this surface water and above deeper water (greater than 50 m), the shelf-intermediate water (25-50 m) contained high radiolarian densities especially in the northern section of the study area. Spring salinities (Figure 12.7) suggested a lens of brackish water was over the shelf in the shallow waters and there was an encroachment of shelf-intermediate and shelf deeper waters. This agreed with the high radiolarian densities recorded.

Radiolarian density maps of Nansen tows for fall (Figure 12.3) showed there was an encroachment of open Gulf water (high density) into Station 1 along Transect III at all depths. The salinity maps for fall (Figure 12.7) also suggested such an encroachment of open marine waters, but that this encroachment was from the south to the north at surface and shelf-intermediate depths (note 36.3 ppt contours on the fall maps of Figure 12.7).

Planktonic foraminiferan density maps from Nansen tows for winter (Figure 12.4) showed there were two ponds of open Gulf surface water (high densities) at Stations 3/II and 2/IV. The maps also indicated there was another pond of Gulf surface water at shelf-intermediate depth at Station 2/III, where the radiolarian densities also suggested a pond. The

density maps for spring (Figure 12.4) showed there was an encroachment of open ocean water at the surface from the north and perhaps at shelf-intermediate depths from the east along Transects II and III. Planktonic foraminiferan density maps for fall (Figure 12.4) showed there was an encroachment of open Gulf water onto the shelf at the surface along Transect III with what appeared to be a branching to the north and south. At shelf-intermediate depths the general circulation of open Gulf water appeared to be to the north which was in good agreement with the salinity maps (Figure 12.7).

B. lowmani density maps from Nansen tows for winter (Figure 12.5) showed a high density in the surface waters of the southern STOCS moving offshore and northward, with no occurrences in shelf-intermediate or deeper tows. *B. lowmani* density maps for spring (Figure 12.5) showed a high density nearshore moving out along Transect III at the surface and at shelf-intermediate depths. This pattern agreed well with the pattern of low salinity water (32 ppt) moving offshore at the surface (Figure 12.7).

Density maps for fall illustrated that densities of *B. lowmani* were very low over the inner shelf, suggesting a pond of nearshore water (*B. lowmani* rich) had moved offshore at Station 3/III, and another pond of nearshore water was at shelf-intermediate depths at about Station 2/II. The highest densities of *B. lowmani* during the fall occurred at depth on the outer shelf, especially in the southern part of the STOCS. This high density suggested a northerly transport of water as was also suggested by the 36.3 ppt shelf-intermediate depth (36 m) salinity contour (Figure 12.7).

Radiolarian richness maps (Figure 12.6) for winter illustrated there was a pond of water at surface and shelf-intermediate depths on the outer (Station 3) and mid-shelf (Station 2) along Transect III. Spring radiolarian richness (Figure 12.6) illustrated that the radiolarians were mainly

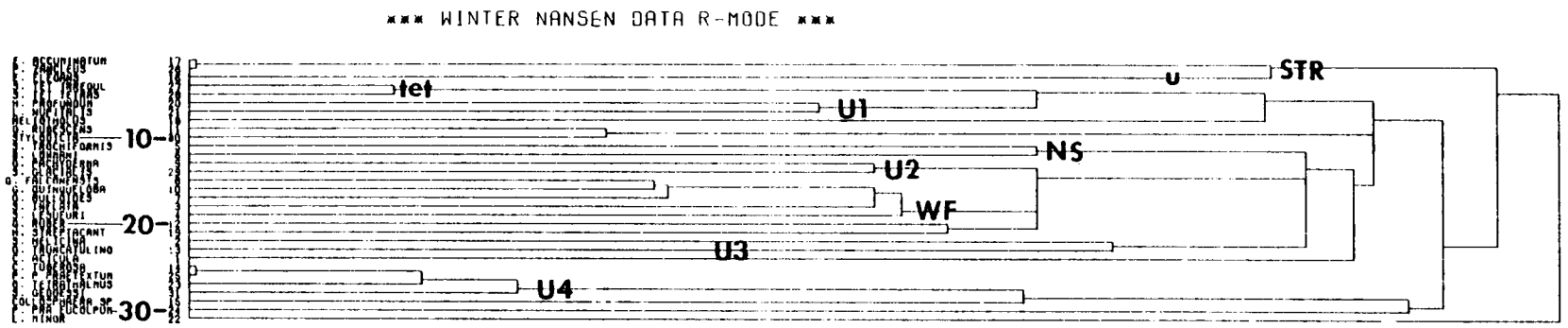
confined to the outer shelf with an encroachment onto the shelf at shelf-intermediate depths. The fall maps (Figure 12.6) showed a general encroachment onto the shelf at all depths.

Monthly Samples

The data for the monthly samples on Transect II are found in Table 1, Appendix K. The July and August monthly samples appeared to be very similar to the fall seasonal samples except that there was an absence of *Globigerina quinqueloba* in the monthly samples suggesting that the fall seasonal sampling period was the start of winter (presence of *G. quinqueloba*). The November and December monthly samples illustrated that winter conditions had developed by the common occurrences of the winter STOCS indicators *G. falconensis* and *G. quinqueloba* and the general decline in polycystin radiolarian abundance.

R-Mode Cluster Analysis

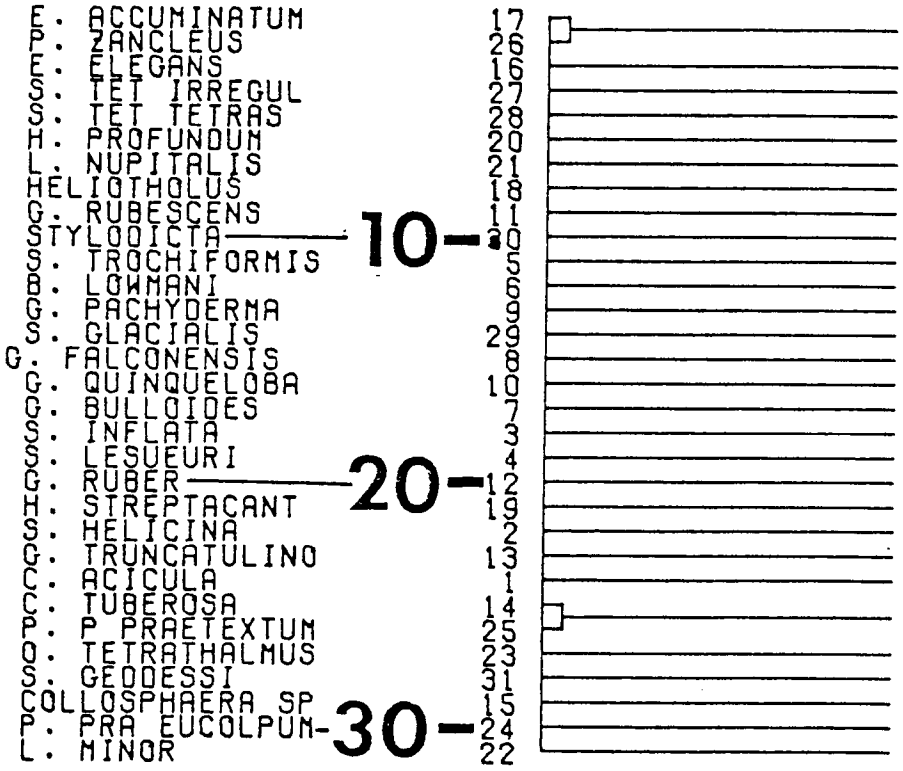
The R-mode cluster analysis dendrogram for winter 1977 was divided into main cluster groups (Figure 12.8). The group labeled STR (summer thermocline related), consisting of the radiolarian species *Eucyrtidium accuminatum*, *Pterocorys zancleus* and *Euchitonia elegans*, separated in abundance either above or below the thermocline in summer. During winter these three forms all occurred between 25 and 50 m at Station 2/III. *E. elegans* also occurred at Station 2/II in the surface sample (0-25 m) representing an upwelling of waters onto mid-shelf. This species was designated by the u (upwelling) on the dendrogram. This upwelling was substantiated by the outcropping of isotherms in Figure 2.5 of Chapter 2. The group labeled "tet" (*Spongaster tetras* subspecies) consisted of the two morphotypes of *S. tetras*, *S. tetras irregularis* and *S. tetras tetras*.



STR = summer thermocline related
u = upwelling
tet = Spongaster tetras subspecies
U1 = upwelling 1
NS = nearshore
U2 = upwelling 2
WF = winter fauna
U3 = upwelling 3
U4 = upwelling 4

Figure 12.8 Winter Nansen Data R-Mode Dendrogram.

Figure 12.8 Cont.'d. Key to R-Mode Shelled Microzooplankton Dendrogram, Winter Nansen 1977. Species and Group Names in Left Hand Column Can Be Found in Complete Form in Table 1, Appendix K.



S. tetras irregularis is a cold morphotype and *S. tetras tetras* is a warm morphotype (Table 12.1). *S. tetras irregularis* only occurred during the winter whereas *S. tetras tetras* was present in all seasons. *S. tetras irregularis* was therefore a winter indicator for the STOCS. The group labeled U1 (upwelling 1) consisting of *Hymeniastrum profundum* and *Lamprocyclas nupitalis*, occurred at shelf-intermediate depths in the southern STOCS and upwelled in the northern STOCS, suggesting at least some of the upwelled water came in from the south. The group labeled NS (nearshore), consisting of the pteropod *Spiratella trochiformis* and the benthonic foraminiferan *B. lowmani*, was restricted in abundance to nearshore waters and was a winter indicator. The group labeled U2 (upwelling 2), consisting of the planktonic foraminiferan species *Globigerina pachyderma* and the radiolarian species *Spongotrochus glacialis*, indicated the same upwelling pattern as did group U1. The group labeled WF (winter fauna) consisted of the winter shelled microplankton forms, including the planktonic foraminiferans *Globigerina falconensis, G. bulloides* and *G. quinqueloba* (Table 12.2), and pteropod species *Spiratella inflata* and *S. lesueuri*. The species labeled U3 (upwelling 3), the planktonic foraminiferan *Globorotalia truncatulinoides*, appeared at depth over the shelf but upwelled at Station 1/II. The group labeled U4 (upwelling 4), consisting of the radiolarians *Collosphaera tuberosa, Pterocanium praetextum praetextum, Ommatartus tetrathalamus* and *Stylotrochus geddesi*, upwelled at mid-shelf then moved offshore at the surface. The winter dendrogram (Figure 12.8) suggested that upwelling to the surface was prevalent over the STOCS in the winter of 1977 and this upwelled water moved offshore at the surface.

The R-mode cluster analysis dendrogram for spring 1977 was divided into four cluster groups (Figure 12.9). The group labeled OGSW (open Gulf surface water), composed of the radiolarians *Collosphera* spp. and

TABLE 12.1

AVERAGE NUMBER OF RADIOLARIANS/m^3 FOR EACH DEPTH INTERVAL FOR THE TWELVE PRIMARY SEASONAL STATIONS, 1977. SPECIES ARE DIVIDED INTO INDICATOR GROUPS*

	WINTER			SPRING			FALL		
	0-25 m	25-50 m	50 m+	0-25 m	25-50 m	50 m+	0-25 m	25-50 m	50 m+
WINTER/DEEP/UPWELLING									
Lithelius minor	.2	.1	0	0	0	0	0	.1	0
Spongotrochus glacialis	1.8	2.0	0	.1	0	.1	.2	0	.3
Heliotholus sp.	.2	.6	0	0	0	0	0	0	0
DEEP AND UPWELLING									
Challengerids	0	0	0	0	0	0	0	0	.4
SUMMER ABOVE THERMOCLINE									
Euchitonia elegans	.1	.3	0	0	0	0	.9	.7	.3
Ommatartus tetrathalmus	.1	.3	0	0	0	0	.4	.1	0
Eucyrtidium acuminatum	0	.1	0	0	0	0	.3	0	.1
Lamprocyclas maritalis	0	0	0	0	0	0	0	.1	0
SUMMER BELOW THERMOCLINE									
Anthocyrtidium cineraria	0	0	0	0	0	0	0	0	.7
Pterocorys zancleus	0	.1	0	0	0	0	.4	.3	1.0
Lamprocyclas nupitalis	0	0	0	0	0	0	.2	.1	.4
WARM AND COLD MORPHOTYPES									
Spongaster tetras irregularis (cold)	.1	0	0	0	0	0	0	0	0
Spongaster tetras tetras (warm)	.2	.1	0	0	0	0	.1	.3	.1
Pterocanium praetextum eucolpum (cold)	.1	0	0	0	.1	0	0	0	0
Pterocanium praetextum praetextum (warm)	.1	0	0	.1	.1	0	.2	0	.2
OPEN GULF SURFACE OR SHALLOW									
Polysolenia lappacea	0	0	0	0	8.4	0	0	0	0
Disolenia sanquebarica	0	0	0	0	17.0	0	0	0	.4
OTHER									
Hymeniastrum profundum	.6	.1	0	0	0	0	1.7	3.1	1.6
Hexadoridium streptacanthum	1.7	1.0	.1	2.5	.1	.2	.1	.3	.1

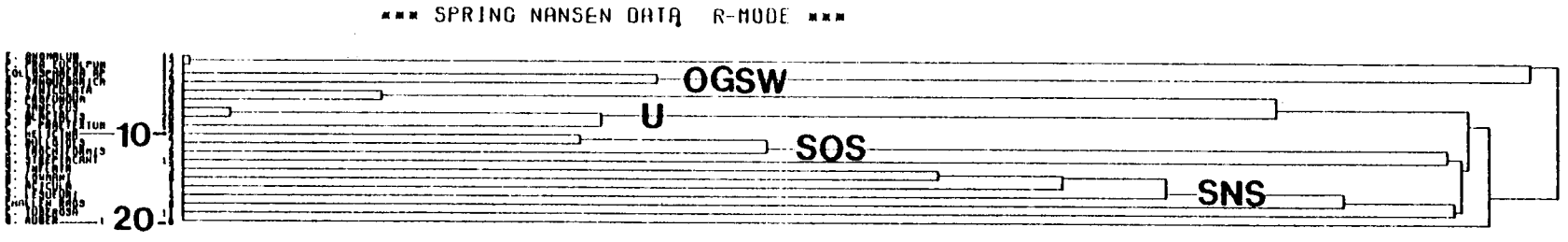
*These indicator groups are essentially the groups that have been developed during the three years of BLM-STOCS and are not solely from this year's data (1977).

TABLE 12.2

AVERAGE NUMBER OF PLANKTONIC FORAMINIFERA/m^3 FOR EACH DEPTH INTERVAL FOR THE TWELVE PRIMARY SEASONAL STATIONS, 1977. SPECIES ARE DIVIDED INTO INDICATOR GROUPS*

	WINTER			SPRING			FALL		
	0-25 m	25-50 m	50 m+	0-25 m	25-50 m	50 m+	0-25 m	25-50 m	50 m+
WINTER ASSEMBLAGE									
Globigerina falconensis	6.2	10.8	1.4	0	0	0	0	0	0
Globigerina pachyderma	1.0	2.5	.5	0	0	0	0	0	0
Globigerina quinqueloba	8.0	14.8	1.2	0	0	0	.2	.6	.1
SUMMER ASSEMBLAGE									
Globigerina bulloides	3.7	8.0	1.3	.1	.1	0	2.7	2.0	2.7
Globigerinoides ruber	2.0	6.1	.6	1.3	5.1	.2	4.0	.9	5.1
OTHER									
Globorotalia truncatulinoides	.1	1.5	0	0	0	0	0	0	0
Orbulina universa	0	.2	0	0	0	0	0	0	0
Globigerinoides sacculifer	.1	0	0	.2	0	0	0	0	0

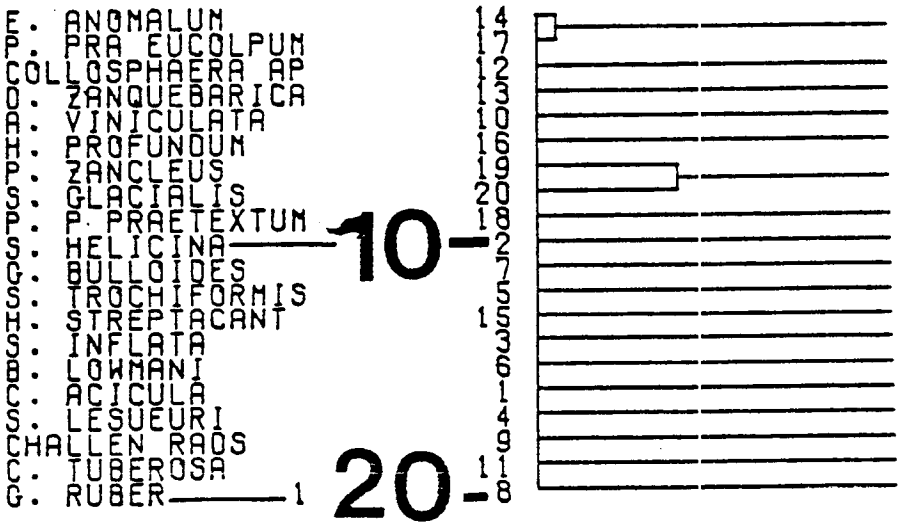
*These indicator groups are essentially the groups that have been developed during the three years of BLM-STOCS and are not solely from this year's data (1977).



OGSW = open Gulf surface water
U = upwelling
SOS = shallow outer shelf
SNS = shallow nearshore

Figure 12.9 Spring Nansen Data, R-Mode Dendrogram.

Figure 12.9 Cont.'d. Key to R-Mode Shelled Microzooplankton Dendrogram, Spring Nansen 1977. Species and Group Names in Left Hand Column can be Found in Complete Form in Table 1, Appendix K.



Disolenia zanquebraica, occurred in high abundances between 25 and 50 m at Station 3/I. This group appeared to be brought in with the "salt water wedge" of the estuarine type upwelling that occurred in the spring. The group labeled U (upwelling) composed of the radiolarian species, *Pterocorys zancleus*, *Spongotrochus glacialis* and *Pterocanium praetextum praetextum*, clustered together because they occurred at the various depths sampled at Stations 3 during the spring. The group labeled SOS (shallow outer shelf), composed of the planktonic foraminiferan *Globigerina bulloides* and the pteropod species *Spiratella helicina* and *S. trochiformis*, occurred together in the shallow (0-50 m) waters of the mid and outer stations on Transect III. The group labeled SNS (shallow nearshore), composed of the benthonic foraminiferan *B. lowmani* and the pteropod species *Spiratella inflata*, *Spiratella lesueuri* and *Creseis acicula*, were most abundant in shallow (0-50 m) nearshore (Stations 1 and 2) waters and were indicative of the spring low salinity lens (Table 12.3).

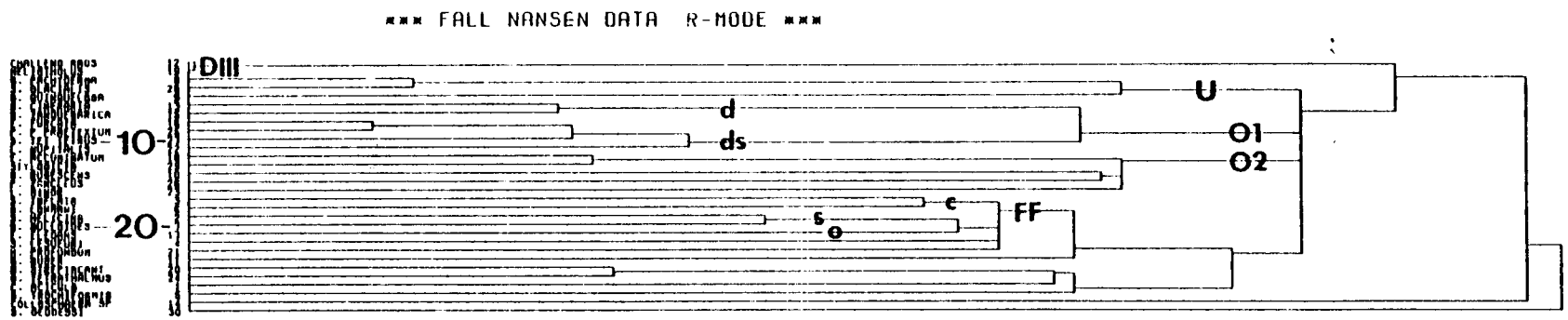
The R-mode cluster analysis dendrogram for fall 1977 was divided into five major cluster groups (Figure 12.10). The group labeled DIII (deep Transect III), composed of the radiolarians challengeriids and *Heliotholus* sp., occurred at depth (below 50 m) on Transect III. The group labeled U (upwelling), composed of the radiolarian species *G. pachyderma* and *G. quinqueloba*, occurred at depth on the outer shelf and in shallow waters on the mid-shelf, illustrating upwelling. *G. pachyderma* and *G. quinqueloba* have usually been considered winter assemblage members (Table 12.2). During the spring they occurred at depth under the thermocline along with *Spongotrochus glacialis*, which was considered to be a winter-deep-upwelling form (Table 12.1). The group labeled 01 (offshore 1) was composed of two subgroups labeled d and ds. The

TABLE 12.3

AVERAGE NUMBER OF PTEROPODS AND *Bolivina lowmani* FOR EACH DEPTH INVERVAL FOR THE TWELVE PRIMARY SEASONAL STATIONS, 1977. SPECIES ARE DIVIDED INTO INDICATOR GROUPS*

	WINTER			SPRING			FALL		
	0-25 m	25-50 m	50 m+	0-25 m	25-50 m	50 m+	0-25 m	25-50 m	50 m+
SPRING ASSEMBLAGE									
Creseis acicula	.5	.4	0	40.7	5.0	1.4	1.1	4.3	1.3
SUMMER ASSEMBLAGE									
Spiratella inflata	11.9	5.3	.7	84.8	31.1	0	12.3	22.2	4.3
OTHER									
Spiratella lesueuri	6.1	4.7	.2	10.3	2.3	.2	1.9	8.5	.6
SPRING LOW SALINITY LENS									
Bolivina lowmani	12.0	0	0	167.2	6.7	.7	5.7	12.0	36.3

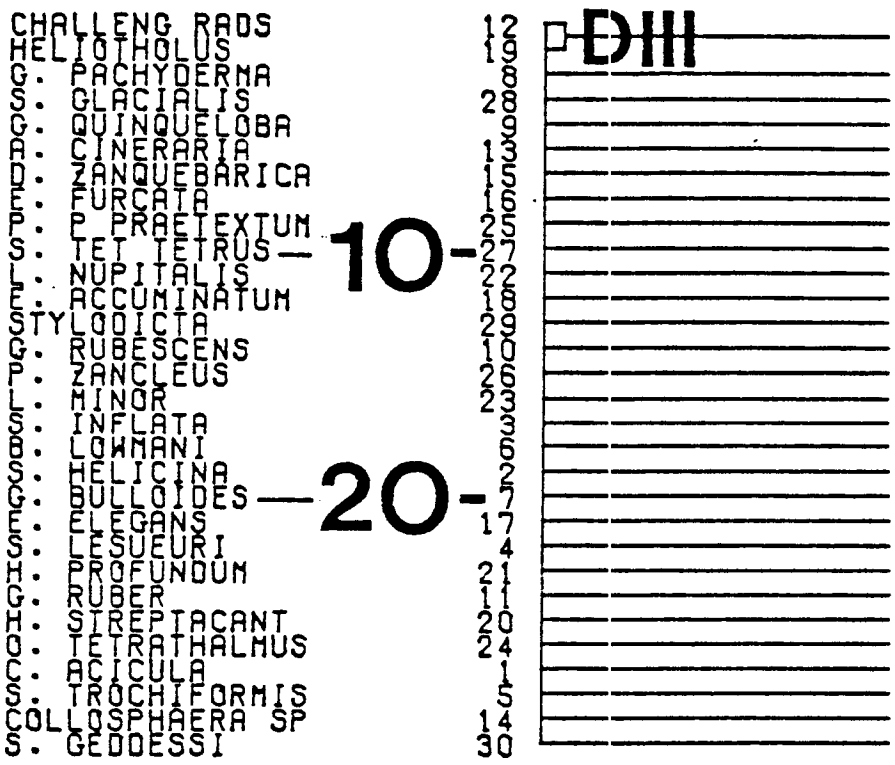
*These indicator groups are essentially the groups that have been developed during the three years of BLM-STOCS and are not solely from this year's data (1977).



DIII = deep Transect III
U = upwelling
O1 = offshore 1
d = deep
ds = deep and shallow
O2 = offshore 2
FF = fall fauna
c = cosmopolitan
s = shallow
o = outer shelf

Figure 12.10 Fall Nansen Data, R-Mode Dendrogram.

Figure 12.10 Cont.'d. Key to R-Mode Shelled Microzooplankton Dendrogram, Fall Nansen 1977. Species and Group Names in Left Hand Column can be Found in Complete Form in Table 1, Appendix K.



*

subgroup d (deep), composed of the radiolarian species *Anthocyrtidium cineraria* and *Disolenia zanquebarica*, occurred below 50 m on Transect III and was considered summer and open Gulf surface or shallow forms that were "pulled in" under the thermocline during this time (Table 12.1 and McMillen and Casey, in press). The subgroup ds, composed of the radiolarian species *Euchitonia furcata, Pterocanium praetextum praetextum, S. tetras tetras* and *Lamprocyclas nupitalis*, occurred throughout the water column at the outer stations. The group labeled 02 (offshore 2), composed of the planktonic foraminiferan species *Globigerina rubescens* and the radiolarian species *Eucyrtidium accuminatum, Stylodicta* sp., *Pterocorys zancleus* and *Lithelius minor* generally occurred throughout the water column at Stations 3 of all transects. The group labeled FF (fall fauna) was subdivided into three subgroups labeled c (cosmopolitan), s (shallow) and o (outer shelf). The subgroup c, composed of the pteropod *Spiratella inflata* (summer assemblage, Table 12.3) and the benthonic foraminiferan *B. lowmani* (the most common species on the dendrogram), occurred throughout the entire water column on the STOCS during the fall. The subgroup s, composed of the pteropod *S. helicina* and the planktonic foraminiferan *G. bulloides* (summer assemblage, Table 12.2), occurred in shallow water (upper 50 m) throughout the area. The species labeled o, *Euchitonia elegans*, occurred at Station 3 of all transects through the entire water column.

Q-Mode Cluster Analysis

The Q-mode cluster analysis dendrogram for winter 1977 (Figure 12.11) was divided into two cluster groups. The group labeled WF (winter fauna), composed of samples containing the planktonic foraminiferans *G. bulloides, G. falconensis* and *G. pachyderma*, was mainly restricted to the winter of

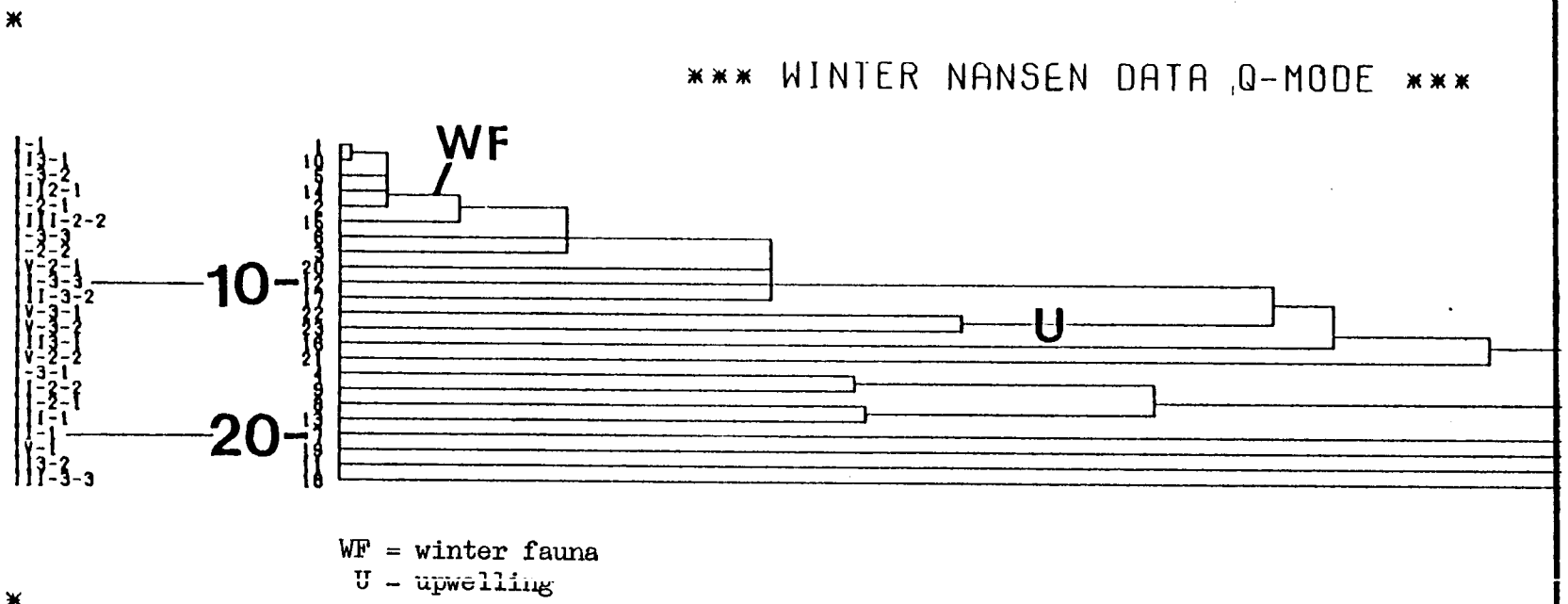


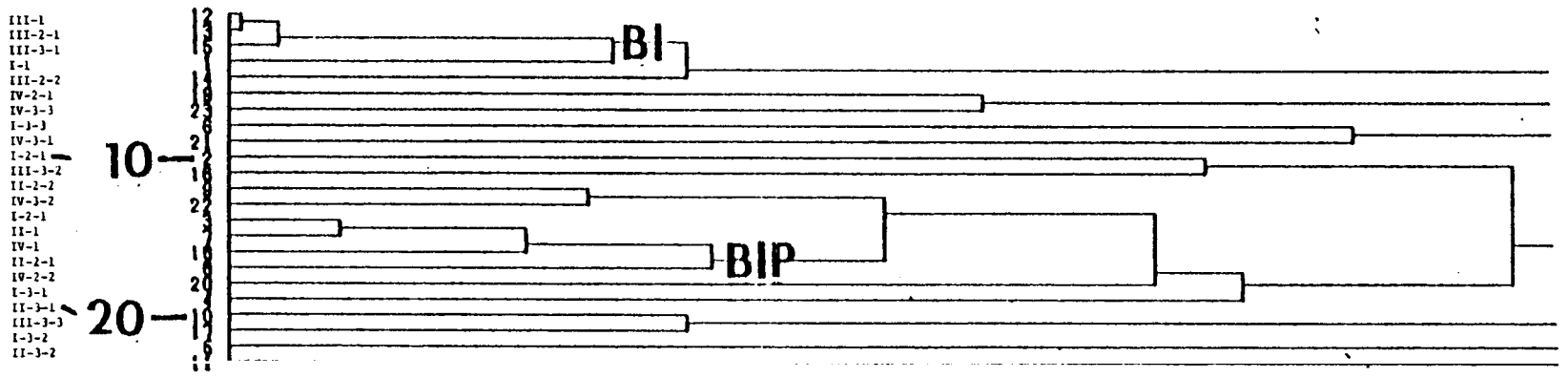
Figure 12.11 Winter Nansen Data, Q-Mode Dendrogram for 1977 Shelled Microzooplankton. Numbers in the Left Hand Column Represent the Station and Depth of Tow [Example: III-1 = Transect III, Station 1; III-2-2 = Transect III, Station 2 from 25-50 m (second depth from surface tow)].

1977. There were a few occurrences of *G. quinqueloba* in the fall while *G. bulloides* occurred all year round (Table 12.2). The occurrences of *G. quinqueloba* in the fall suggested that during the fall sampling period conditions were getting close to those of winter. The group labeled U (upwelling) was composed of samples containing the planktonic foraminiferan species *Globigerinella aequilateralis* (abundant in upwelling regions according to Tolderlund and Bé, 1971) and *Spongotrochus glacialis*, a radiolarian species indicative of upwelling (Table 12.1).

The Q-mode cluster analyses dendrogram for spring 1977 (Figure 12.12) was divided into two cluster groups. The group labeled B1, composed of stations that contained high concentrations of the benthonic foraminiferan *B. loumani* (> 100/m^3), was present only in surface (0-25 m) samples collected along Transect III. The group labeled BIP, composed of samples that contain high concentrations of *B. loumani* and pteropods, was present only in surface (0-25 m) samples. These groups appeared to correlate with the brackish water spring lens (Figure 12.7) and may be used as an indicator of that water. Table 12.3 illustrates that *B. loumani* was an indicator of this spring low salinity lens.

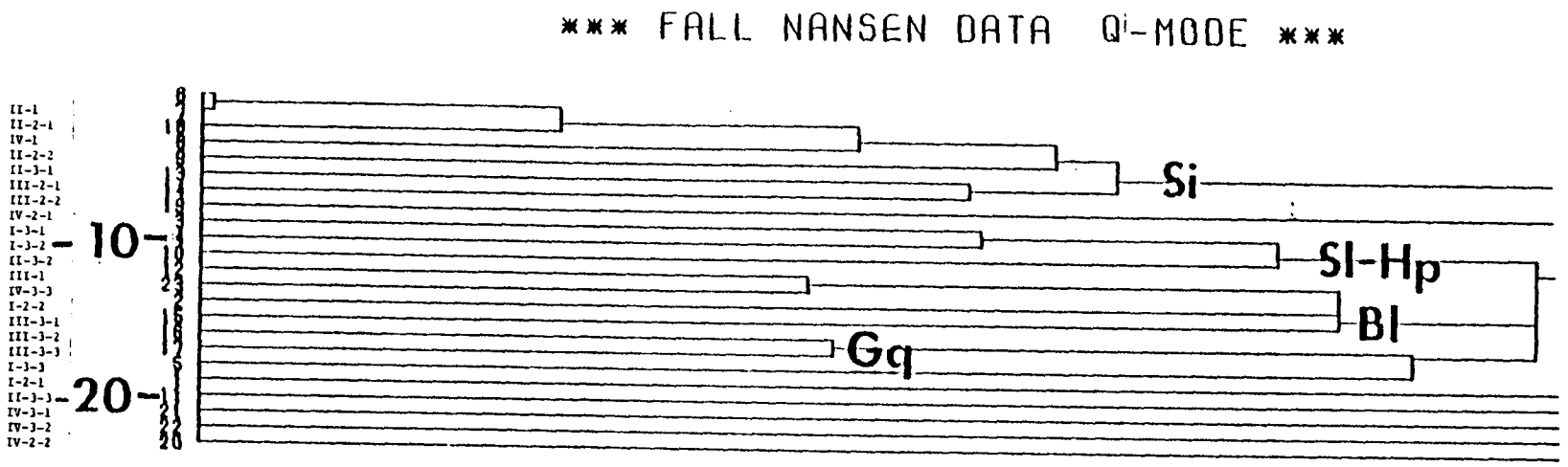
The Q-mode cluster analysis dendrogram for fall 1977 (Figure 12.13) was divided into four cluster groups. The group labeled Si was composed of samples that contained the pteropod *Spiratella inflata*. These samples were mainly nearshore (Station 1), surface (0-25 m) collections. The group S1-Hp, composed of samples that contained the pteropod *Spiratella lesueuri* and the radiolarian *Hymeniastrum profundum* along with some other radiolarians, occurred in collections from outer shelf shallow (0-50 m) waters. The group labeled B1, composed of samples containing common and abundant occurrences of *B. loumani*, was collected throughout

FIGURE 12 *** SPRING NANSEN DATA Q-MODE ***



Bl = Bolivina lowmani
BlP = Bolivina lowmani-pteropods

Figure 12.12 Spring Nansen Data, Q-Mode Dendrogram, Shelled Microzooplankton, 1977. Numbers in Left Hand Column Represent the Station and Depth of Tow [Example: III-1 = Transect III, Station 1; III-2-2 = Transect III, Station 2 from 25-50 m (second depth from surface tow].



Si = Spiratella inflata
Sl-Hp = Spiratella lesueuri-Hymeniastrum profundum
Bl = Bolivina lowmani
Gq = Globigerina quinqueloba

Figure 12.13 Fall Nansen Data, Q-Mode Dendrogram, 1977 for Shelled Microzooplankton. Number in Left Hand Column Represents the Station and Depth of Tow [Example: III-1= Transect III, Station 1; III-2-2 = Transect III, Station 2 from 25-50 m (second depth from surface tow].

the study area at various depths. The group labeled Gq, composed of samples that contained the planktonic foraminiferan species *G. quinqueloba* was found in the outer shelf Transect III samples from 25 to 50 m. As *G. quinqueloba* was considered a member of the winter assemblage it was reasonable to expect it to be found at depth (Table 12.2). The S1-Hp group appeared to correlate with a wedge of higher salinity water (see Figure 2.30, Chapter 2). There appeared to be a tendency for some radiolarians to occur either mainly above or below the thermocline in the fall (Table 12.1).

Niskin Sample (Discrete Depth) Data for General Microplankton Related to Physical Oceanography

Trends of the General Microplankton Data

The data from the Niskin samples may be seen in Table 2, Appendix K. Diatoms were dominant in all the samples taken from half the depth of the photic zone collected from the seasonal stations during 1977 except those from Station 1/III in the spring and Stations 1/III, 1/IV and 3/IV in the fall. At Stations 1/III for spring and 1/III and 1/IV for the fall, blue-green algae were dominant (with *Trichodesmium* being the dominant genus at Station 1/III during the spring). At Station 3/IV in the fall, dinoflagellates were the dominant phytoplankter but this sample contained the lowest density of general microplankton recorded during the half-photic zone sampling for this year (Figures 12.14 - 12.16). Comparing 1977 data to that of the previous two years, it appeared that there was an order of magnitude increase in general microplankton standing crop during the first two seasons of 1977.

R-Mode Cluster Analysis

The R-mode cluster analysis dendrogram for 1977 Niskin seasonal data (Figure 12.17) illustrated a cluster labeled FCC (food chain cluster) that

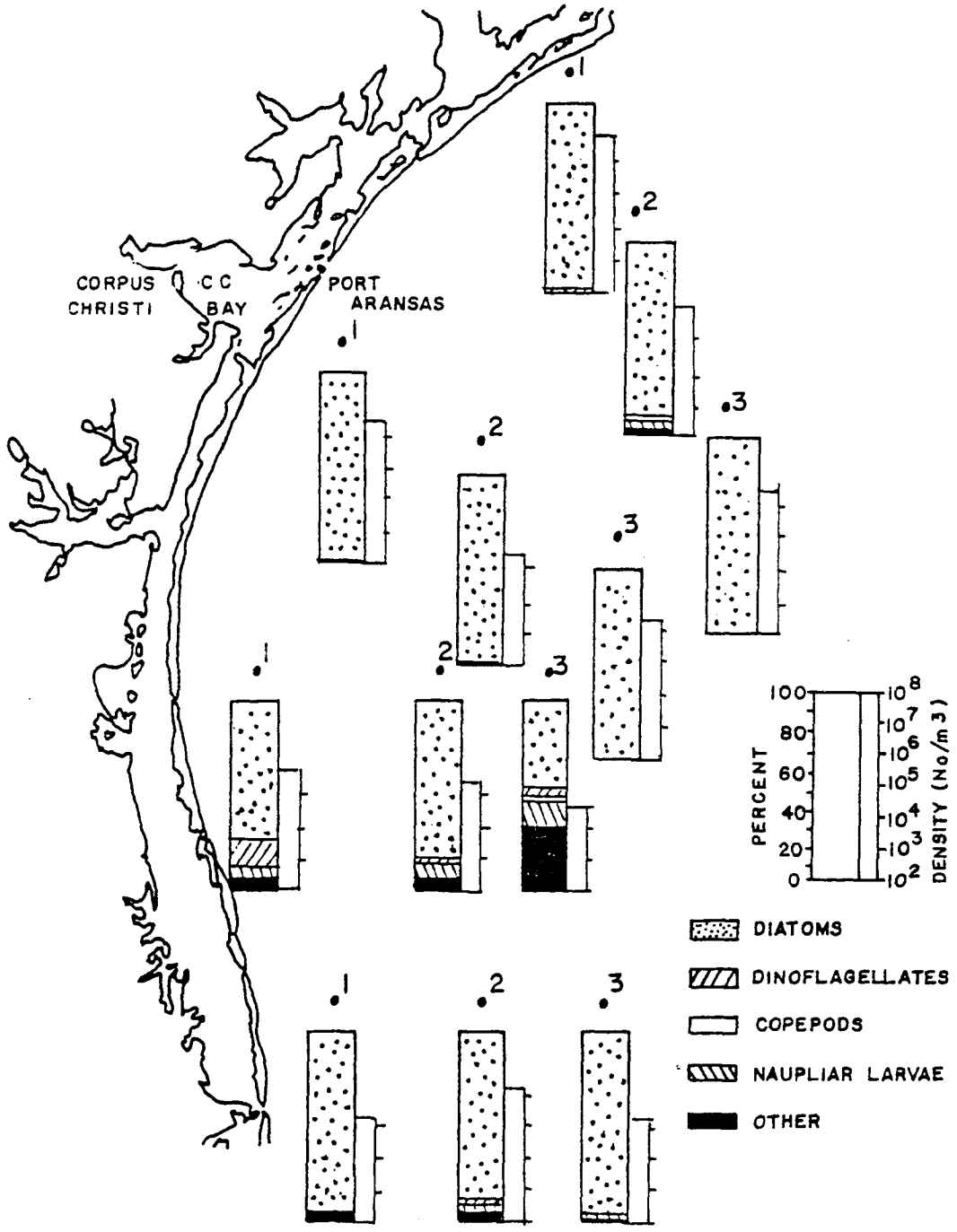


Figure 12.14 Relative Abundance (percent of total) of Major Groups and Total Density in Niskin Samples, Winter 1977 for half photic zone,

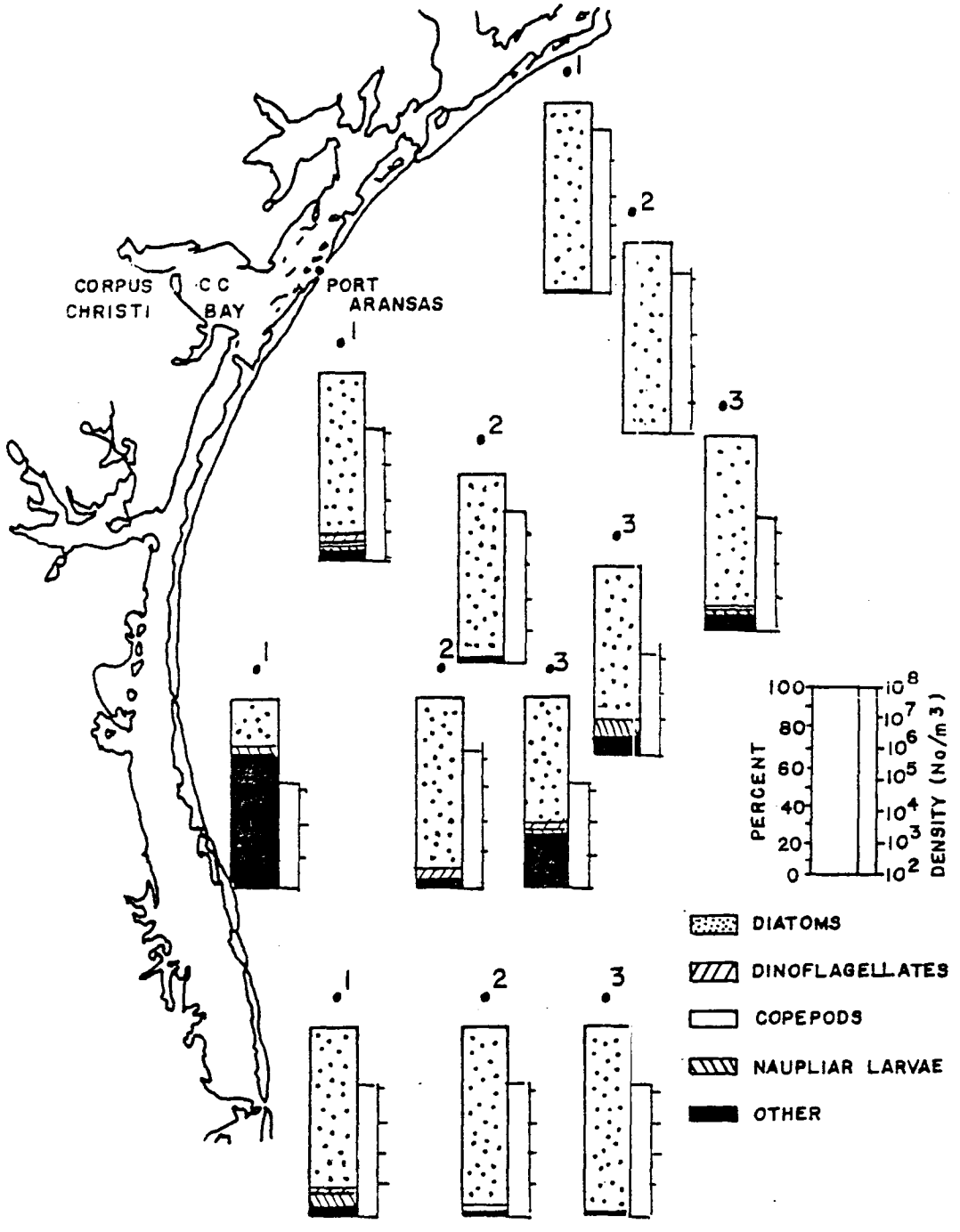


Figure 12.15 Relative Abundance (percent of total) of Major Groups and Total Density in Niskin Samples, Spring 1977 for half photic zone.

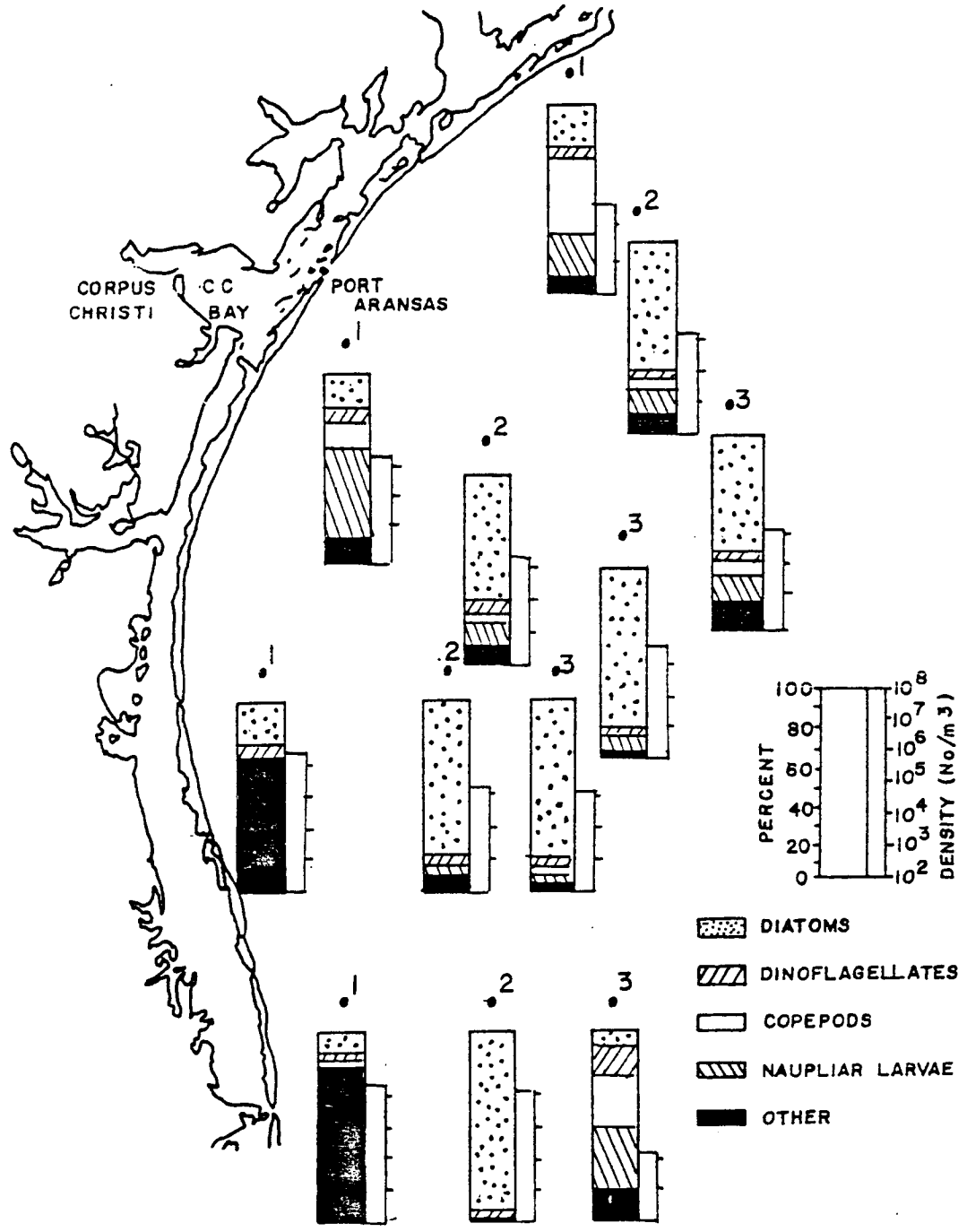


Figure 12.16 Relative Abundance (percent of total) of Major Groups and Total Density in Niskin Samples, Fall 1977 for half photic zone.

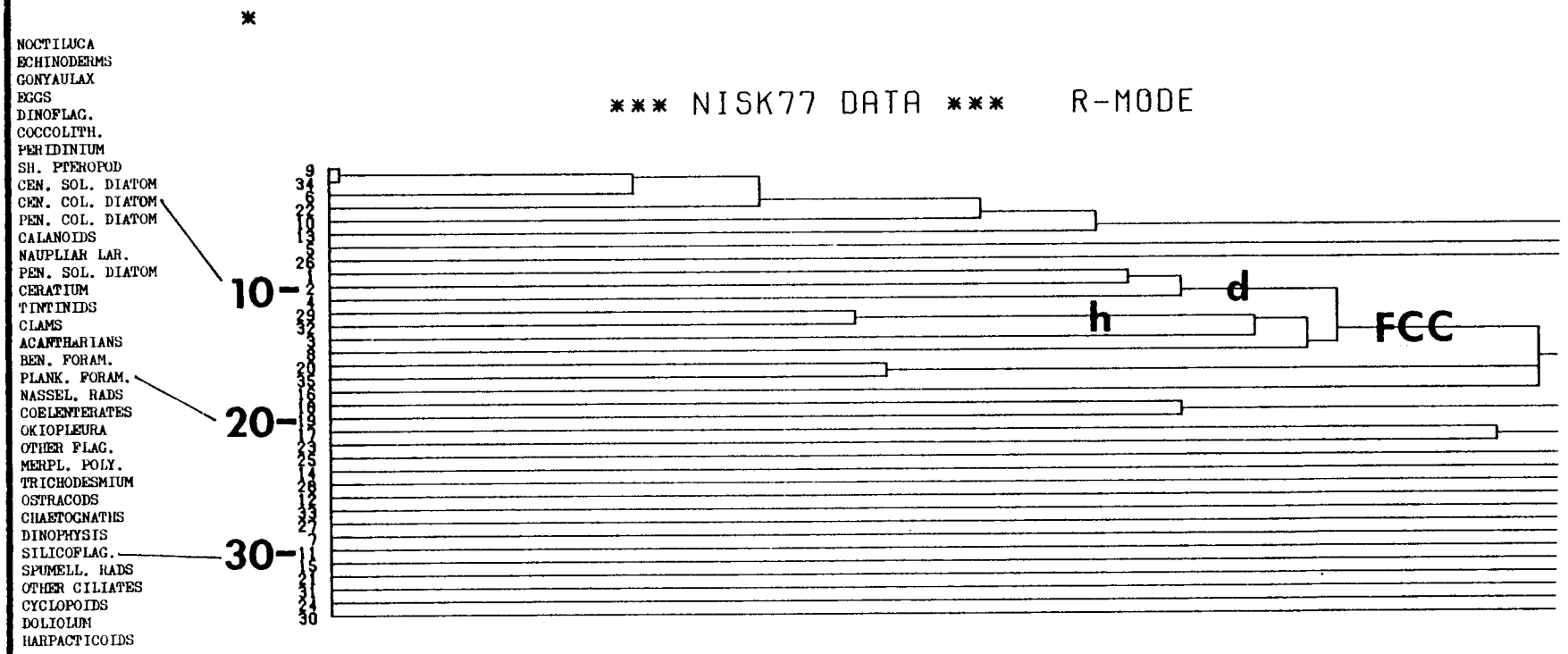
separated the most abundant forms into a rough food chain. The centric solitary diatoms, centric colonial diatoms and pennate colonial diatoms form the primary producer group labeled d (diatoms) on the dendrogram (Figure 12.17). Directly below and associated with the diatom cluster were the primary herbivores labeled h (herbivores) including the calanoid copepods and naupliar larvae.

Q-Mode Cluster Analysis

Two large groups appeared on the Q-mode cluster analysis dendrogram for 1977 Niskin seasonal data labeled HD (high density) and LD (low density) (Figure 12.18). The samples in the high density (HD) group exhibited high densities of general microplankton (usually higher than 400,000 individuals/m^3), and fewer than seven taxonomic units (indicating low diversity). These high density samples were mainly winter and spring samples. The samples in the low density (LD) group exhibited low density of general microplankton (usually lower than 400,000 individuals/m^3), and a high number of taxonomic units (about 12), suggesting higher diversity. These low density samples were collected during all seasons. General observations suggested that diversity of general microplankton at the half-photic zone depth showed a drastic drop during the first two seasons of 1977 when compared to the previous two years. Considering the apparent drastic increase in density and the apparent drastic decline in diversity, it appears that the first two seasons of 1977 were periods of eutrophism on the STOCS. This is considered to be one of the most important aspects that should be dealt with in the future synthesis of these data.

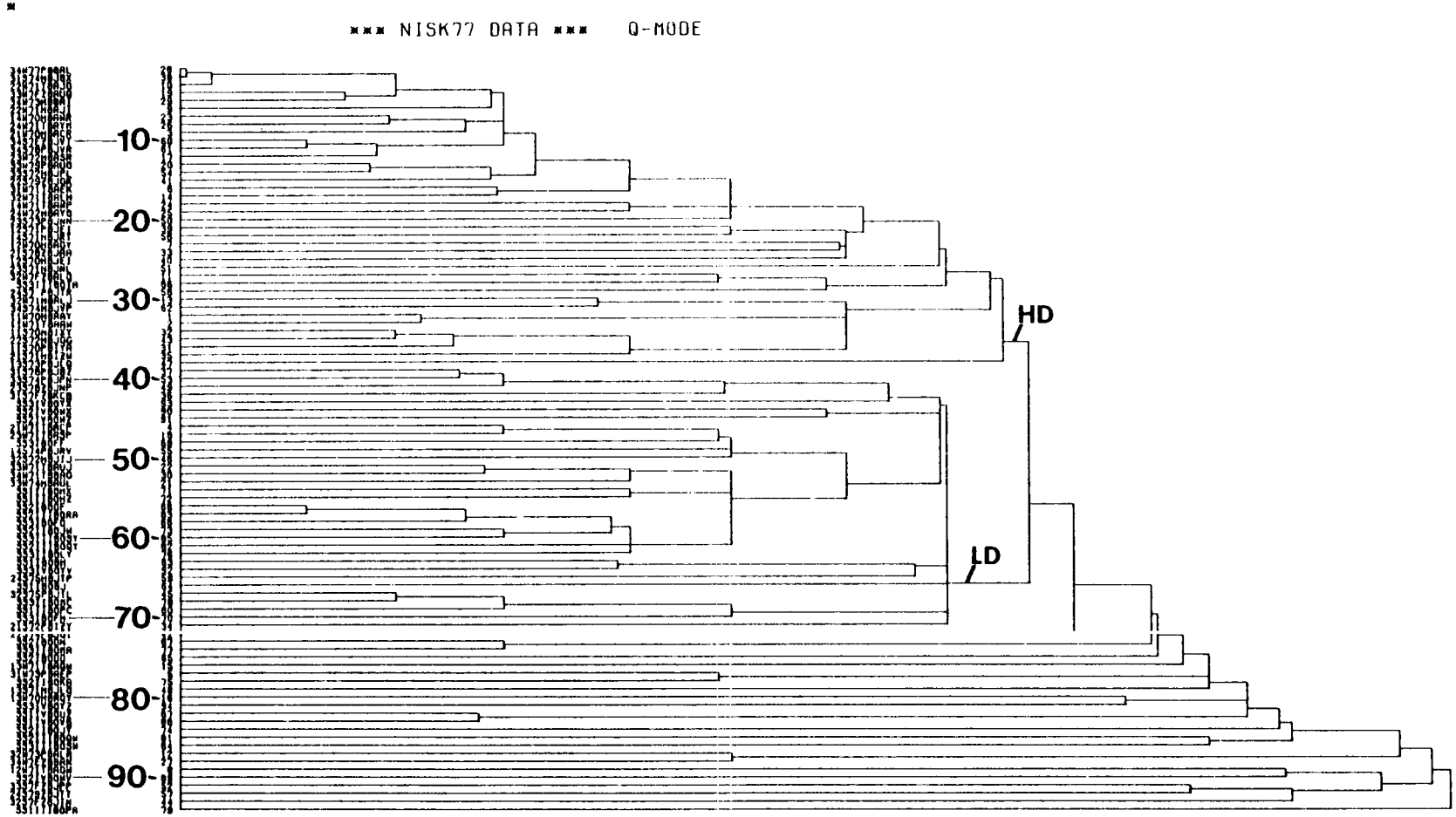
CONCLUSIONS

1. The planktonic foraminiferans appear to be good indicators of seasonality with the presence of *Globigerina falconensis, G. pachyderma*



FCC = food chain cluster
d = diatoms
h = herbivores

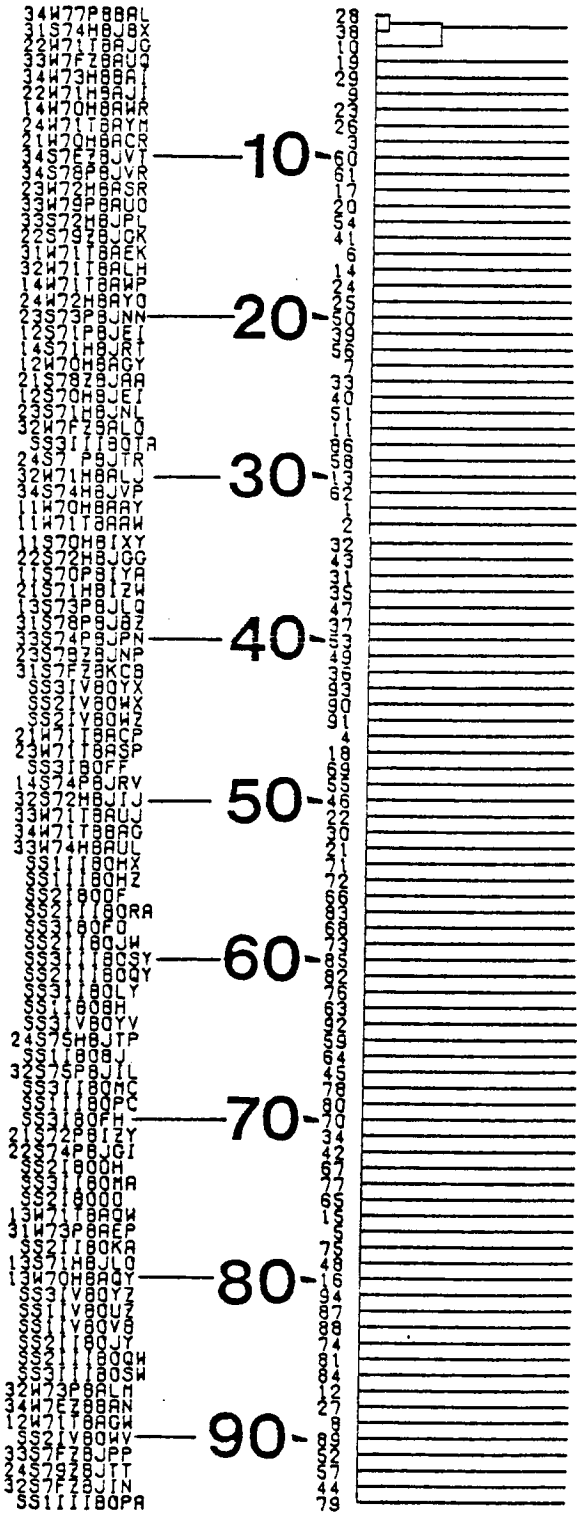
Figure 12.17 R-Mode General Microplankton Dendrogram for 1977 Niskin Data. Group Names in Left Hand Column can be Found in Complete Form in Table 1, Appendix K.



HD = high density
LD = low density

Figure 12.18 Q-Mode General Microplankton Dendrogram for Niskin Data, 1977.

Figure 12.18 Cont.'d. Key to Q-Mode General Microplankton Dendrogram, Niskin 1977. In Code Names in Left Hand Column W = winter, S = spring, SS = fall and four letter sequence (such as BBAL) refers to specific tow whose station, transect and depth information can be seen in Table 1, Appendix K.



and to a lesser degree *G. quinqueloba* indicative of winter and *G. bulloides* and *Globigerinoides ruber* indicative of summer (when *G. falconensis* and *G. pachyderma* were absent from the fauna).

2. The planktonic foraminiferans also appear to be indicative of surface and shallow water intrusions onto the shelf from offshore (and appear as "fingers" or ponds of such intrusions on planktonic foraminiferan density contour maps).

3. The radiolarians appear to be indicative of the same trends as stated for the planktonic foraminiferans. The radiolarians are also indicative of several other physical phenomena such as: upwelling, indicated by occurrences of *Spongotrochus glacialis*; deeper water movements, suggested by high density fingers or ponds of radiolarians at shelf-intermediate and deeper depths; and the provenance of these waters, such as from Gulf surface or shallow water indicated by the occurrences of *Anthocyrtidium cineraria* and *Disolenia zanquebarica*.

4. General microplankton from Niskin samples suggest conditions were eutrophic on the STOCS during the winter and spring of 1977. This eutrophism was apparently related to the dramatic upwelling on the STOCS during the winter and into the spring of 1977.

5. Figure 12.19 illustrates the general oceanographic trends for 1977 derived from the shelled microzooplankton and general microplankton data interpretation. The winter illustrated that ponds of shallow and deeper open-ocean Gulf water moved onto the STOCS probably due to eddies breaking off from the general southerly movement of the offshore wind driven current. Upwelling of deep open-ocean Gulf water occurred all along the STOCS at midshelf; this upwelled water then moved offshore at the surface resulting in eutrophism of the STOCS in winter. The spring figure illustrates that a lens of brackish water (from local and Mississ-

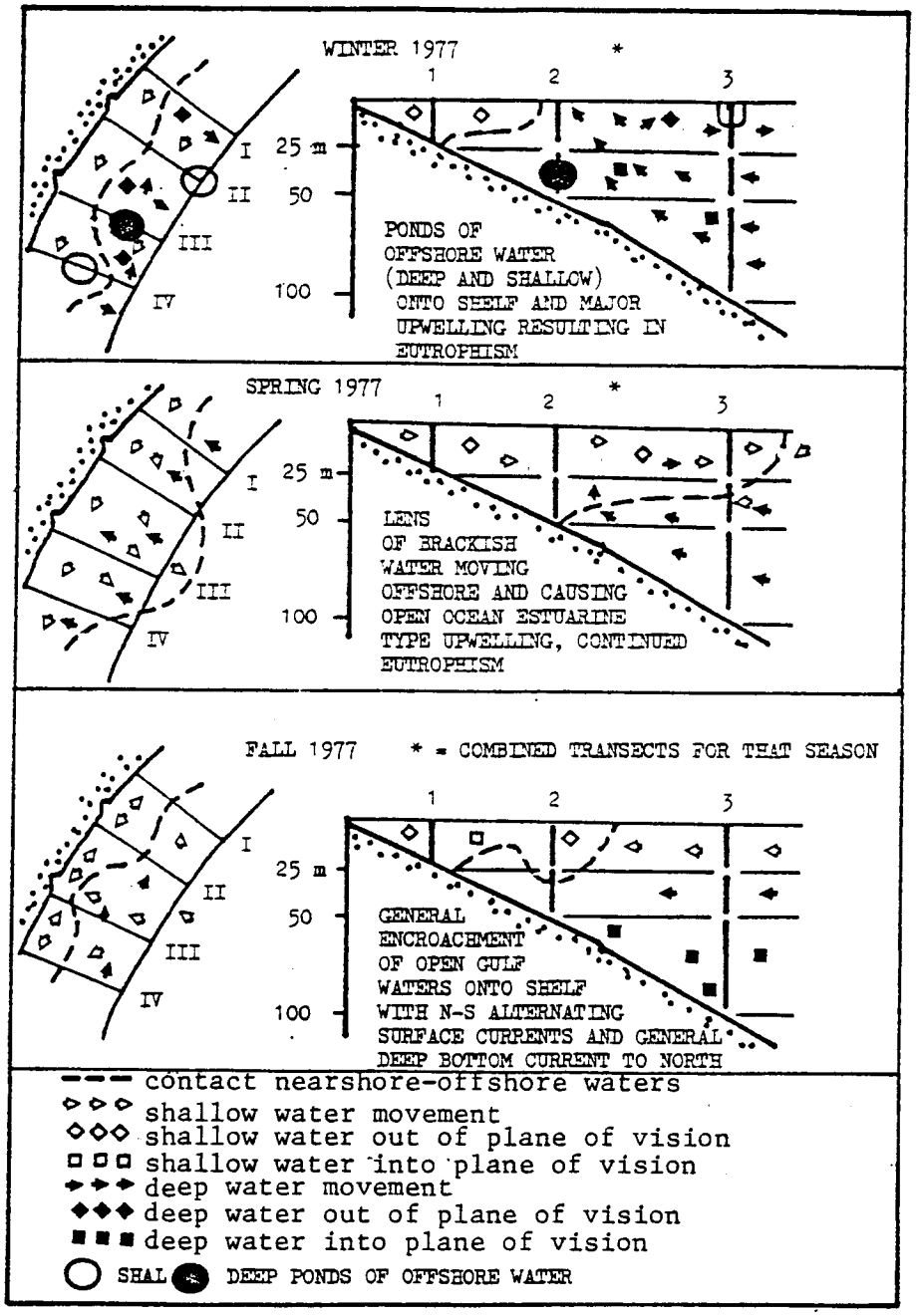


Figure 12.19 General Oceanographic Trends for 1977 from Shelled Microzooplankton and General Microplankton Data.

ippi River runoff) moved south across the STOCS with an offshore component at the surface that dragged surface and deeper open-ocean Gulf water shoreward under the pycnocline. Some of this "salt water wedge" of open Gulf water upwelled resulting in continued eutrophism in the STOCS in spring. The fall figure illustrates a general encroachment of open-ocean Gulf water throughout the water column. The nearshore surface currents in fall alternated north and south with a general deep bottom current to the north on the outer shelf.

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CHAPTER THIRTEEN

CILIATED PROTOZOA

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ABSTRACT

During 1977, 108 one-liter samples were collected from the STOCS. These samples, which were preserved with 1% basic Lugol's fixative, were analyzed for ciliated protozoa using the Utermohl (1931) method. Of the 86 protozoan species observed, 49 were tintinnids, 10 were oligotrichs, 5 were foraminifera, 10 were radiolarian/acantharia and 12 were "other" protozoa.

Protozoa reached an abundance maximum in early spring (March-April). There was a second abundance peak in September which was thought to be abnormal and a result of Hurricane Anita, which passed through the area at that time.

Oligotrichs were the most dominant group of protozoa on the STOCS. They were ubiquitous and abundant both spatially and temporally. The other protozoan groups tended to be less abundant and more restricted in space and time.

Protozoan biomass ranged from 1 to 348% of the macrozooplankton biomass, indicating that the protozoa are a significantly component of the zooplankton community.

Protozoan abundance was positively correlated with nannoplankton and silicate. Correlations with temperature, salinity, dissolved oxygen, netphytoplankton, nitrate and phosphate were not significant but the salinity relationship with protozoans was negative suggesting a possible ecological relationship.

INTRODUCTION

Marine protozoa have been generally ignored in most quantitative surveys of the flora and fauna of a given area. The reasons for this neglect are simple; the protozoa are generally too small to be collected with the larger-mesh-size nets normally used by investigators of zooplankton and they are ignored by those who study phytoplankton because most are non-photosynthetic. However, in recent years it has become clear that marine protozoa, especially the ciliates, comprise a significant fraction of the plankton community (Beers and Stewart, 1967, 1969, 1970, 1971; Johansen 1976).

Marine ciliates are voracious predators on nannoflagellates (Spittler, 1972; Blackburn, 1974; Heinbokel, 1977) and they in turn serve as food for macrozooplankters (Zsitzschel, 1967), including larval fish. Since the ciliates are most abundant during times of reduced net-phytoplankton (> 20 μm) abundance, it is probable that the ciliates serve as important links in the food web between the nannoplankton and macrozooplankton during these times because macrozooplankton generally are unable to utilize nannoplankton efficiently.

Marine ciliates exhibit nitrogen excretion rates one to two orders of magnitude greater than macrozooplankters (Johansen, 1976), hence they contribute significantly to the nitrogen budget of nearshore marine areas where they are most abundant. Their small size and rapid reproduction rates (Gold, 1968, 1971, 1973a; Heinbokel, 1977) enhance their potential as a food source for macrozooplankters.

In order to assess the role of marine protozoa in the food web of a particular area, information must first be gathered concerning the types and abundances of protozoa inhabiting that area. The kinds and amounts of

temporal and spatial variations in abundance should also be noted. In order to determine short-term and long-term effects of environmental perturbations on the marine protozoa, both short-term and long-term studies of the protozoan populations should be made. Although several qualitative studies have been made concerning the marine pelagic ciliates of the western Gulf of Mexico (Borror, 1962; Balech, 1967), no quantitative data exist for this group of organisms.

One-liter microzooplankton samples collected from the BLM-STOCS Transect II during 1975 and 1976 were later analyzed for ciliated protozoa content but proved to be totally inadequate due to poor and inconsistent preservation by the buffered formalin used to fix the samples (Johansen, 1978). Interpretation of the data was further hampered by infrequent sampling during 1975 when only three cruises occurred.

The purpose of this study was to determine the kinds and abundances of ciliated protozoa on the South Texas Outer Continental Shelf (STOCS) throughout the course of one year. Seasonal changes in abundance were to be noted and biomass estimates for this fraction of the zooplankton community were to be made.

MATERIALS AND METHODS

During three seasonal cruises in 1977, 1-liter water samples were collected with a 50-ℓ Niskin bottle from the surface and from one half the depth of the photic zone at Stations 1, 2 and 3 of Transects I, II, III and IV on the STOCS. Also, during six monthly cruises in 1977, 1-ℓ water samples were collected from the surface and from one half the depth of the photic zone at Stations 1, 2 and 3 of Transect II. These samples were preserved with 1% basic Lugol's fixative (Thompson, 1966).

A 500-ml aliquot of each 1-ℓ sample was placed in a graduated cylinder and allowed to settle for 24 hours. At this time, 400 ml were drawn off and the remaining 100 ml transferred to a Utermohl settling chamber. The ciliates were identified to species and enumerated. The foraminifera, radiolaria and acantharia were enumerated. Following counting, the aliquot was combined with the original sample, resettled, drawn down to 10 ml and archived.

Biomass estimates were calculated by estimating the volume of the ciliates (not including the lorica). Assuming a cell density of 1, $1\mu^3$ approximately equals 10^{-6} µg wet weight. Dry weight was assumed to be 13% of the wet weight (Beers and Stewart, 1970). Total dry weights (mg/m^3) were calculated by multiplying the abundance of each species in the sample by its respective volume, converting to dry weight and summing the individual estimates.

The Shannon-Wiener Index (Pielou, 1974) was used to calculate the species diversity of each sample. The Shannon-Wiener Index was calculated as follows:

$$H_s = \sum_{i=1}^{S} p_i \ln p_i \quad \text{where}$$

H_s = the diversity index of the sample;
S = the number of species in the sample;
p_i = the relative abundance of the ith species measured;
$\ln p_i$ = the natural log of p_i.

RESULTS AND DISCUSSION

In the 108 samples analyzed, 86 protozoan species were observed. Of these, 49 were tintinnids, 10 were oligotrichs, 5 were foraminifera, 10 were radiolaria/acantharia and 12 were "other" protozoan species.

Species lists and abundances for each sample are presented in Appendix L. The number of individuals of the various groups per liter, the percentage of the total protozoa of each group represented, number of species per

sample, species diversity indices, and total dry weight of the protozoa are presented in Table 13.1.

Table 13.2 indicates the distribution of the various species of Stations 1, 2 and 3. Values were obtained by averaging all data from each station regardless of transect, month or depth. Table 13.3 indicates the occurrence of the various species during the year. These values were obtained by averaging all data from each month regardless of transect, station or depth. Figure 13.1 shows the abundance of total protozoa for each station, depth and month for Transect II during 1977. Figures 13.2 through 13.4 show this information for the three seasonal cruises during 1977.

Protozoa on the STOCS reached a maximum abundance in early spring (March and April-Figure 13.1), somewhat later than the time of maximum abundance inshore in the Port Aransas shipping channel, where peak abundances occurred in January-February (Figure 13.5). This winter - early spring protozoan bloom was in stark contrast to that which generally occurs off the coast of Nova Scotia, where large numbers of protozoa are found in late summer, and early fall, July - September (Johansen, 1976). In general, the inshore stations exhibited greater concentrations of protozoa (Figures 13.1 - 13.4), which was to be expected, considering the higher nutrient and primary productivity levels to be found in more nearshore areas. The reasons for the rather large concentrations of protozoa at Station 3/II during March (Figure 13.1) were somewhat obscure but may have been related to an influx of nutrient-rich, highly productive Mississippi River water into the area. The large increase in protozoan abundance at Station 1/II during September (Figure 13.1) was thought to be a result of Hurricane Anita which passed through the area on 1-2 September. The storm apparently did not affect protozoan abundance at the offshore stations. The greatest con-

TABLE 13.1

STATISTICAL DATA FOR THE 1977 PROTOZOA SAMPLES

Explanation of Table:

SACD - sample code
S - station
T - transect
DATE - date
TIME - time of sampling
Z - depth of sample
TAPL - total number of protozoa/ℓ
TTPL - total number of tintinnids/ℓ
TOPL - total number of oligotrichs/ℓ
TFPL - total number of foraminifera/ℓ
TRPL - total number of radiolaria/acantharia/ℓ
TMPL - total number of miscellaneous protozoa/ℓ
TPCT - tintinnids as percent of total protozoa
OPCT - oligotrichs as percent of total protozoa
MPCT - miscellaneous protozoa (including foraminifera, radiolaria, and acantharia) as percent of total protozoa
NSPS - number of species/sample
SDI - Shannon-Wiever species diversity index
TDWT - total protozoan dry weight in mg/m^3

TABLE 13.1 CONT.'D

SACD	S	T	DATE	TIME	Z	TPPL	TTPL	TUPL	TFPL	TRPL	TMPL	TPCT	UPCT	MPCT	NSPS	SD1	TDWT
BSOM	1	1	012177	0830	01	2420	2020	332	0	0	68	83	14	3	17	1.077	2.14
BAAZ	1	1	012177	0830	02	3752	3364	276	4	0	108	90	7	3	18	.852	6.55
BSON	2	1	012177	1120	01	484	180	276	8	0	20	37	57	6	12	1.777	.54
BACS	2	1	012177	1120	14	528	8	488	4	16	12	2	92	6	15	1.971	4.00
BSOO	3	1	022177	1745	01	624	12	264	4	0	344	2	42	56	13	1.768	.92
BAEN	3	1	022177	1745	10	52	0	40	0	0	12	0	77	23	7	1.631	.18
BSOP	3	1	022177	1745	10	60	0	60	0	0	0	0	100	0	5	1.402	.11
BSOQ	3	1	022177	1745	10	56	0	48	4	0	4	0	86	14	6	1.593	.19
BSOR	1	2	011177	1620	01	1308	872	396	4	0	36	67	30	3	12	1.436	1.29
BAGZ	1	2	011177	1620	03	1268	696	544	4	0	24	55	43	2	15	1.615	1.22
BSOS	2	2	011177	1230	01	264	12	252	0	0	0	5	95	0	10	1.893	.39
BAJJ	2	2	011177	1230	09	764	64	672	4	0	24	8	88	4	14	1.976	1.36
BSOT	3	2	022277	0900	01	544	4	476	0	4	60	1	88	12	13	2.118	.98
BALK	3	2	022277	0900	09	316	0	300	4	0	12	0	95	5	10	1.608	.57
BSOU	3	2	022277	0900	09	308	0	272	4	4	28	0	88	12	9	1.715	.70
BSOV	3	2	022277	0900	09	404	0	360	16	0	28	0	89	11	9	1.699	.74
BSOW	1	3	012077	1630	01	2120	1464	548	0	0	108	69	26	5	16	1.450	1.78
BAGZ	1	3	012077	1630	03	3136	1856	1072	0	0	208	59	34	7	17	1.711	4.39
BSOX	2	3	012077	1130	01	1329	16	1113	4	4	192	1	84	15	16	2.067	1.42
BASS	2	3	012077	1130	14	953	8	905	0	0	40	1	95	4	12	1.682	.88
BSOY	3	3	012077	0800	01	312	12	300	0	0	0	4	96	0	8	1.796	.45
BAUM	3	3	012077	0800	26	208	8	196	0	4	0	4	94	2	8	1.605	.26
BSOZ	1	4	011977	1200	01	1228	760	424	0	0	44	62	35	4	15	1.574	1.51
BAWS	1	4	011977	1200	02	1576	536	960	0	0	80	34	61	5	14	1.950	2.38
BSPA	2	4	011977	1630	01	768	24	656	0	0	88	3	85	11	14	2.245	1.12
BAYP	2	4	011977	1630	11	692	44	540	0	0	108	6	78	16	13	2.131	.77
BSPB	3	4	011877	1100	01	236	4	228	0	0	4	2	97	2	8	1.612	.29
BBAJ	3	4	011877	1100	20	384	16	356	4	0	8	4	93	3	12	1.778	.51
BSPC	1	2	031577	1000	01	3984	1044	2224	0	0	716	26	56	18	16	2.177	8.32
BSPD	1	2	031577	1000	03	2652	688	1392	4	0	568	26	52	22	15	2.247	5.87
BSPE	2	2	031477	1215	01	1396	4	1336	0	0	56		96	4	11	1.835	3.20
BSPF	2	2	031477	1215	21	6552	4	1832	0	0	4716	0	28	72	14	1.193	4.81
BSPG	3	2	031477	1800	01	12595	0	11604	0	0	991	0	92	8	11	1.671	29.77
BSPH	3	2	031477	1800	21	4328	4	3932	0	0	392	0	91	9	13	1.843	4.13

TABLE 13.1 CONT.'D

SACD	S	T	DATE	TIME	Z	TPPL	TTPL	TOPL	TFPL	TRPL	TMPL	TPCT	OPCT	MPCT	NSPS	SDI	TDWT
BSPI	1	2	042177	0700	01	1124	292	592	0	0	240	26	53	21	18	2.436	2.25
BSPJ	1	2	042177	0700	01	1532	392	752	0	0	388	26	49	25	22	2.517	5.17
BSPK	1	2	042177	0700	01	1336	328	712	4	0	292	25	53	22	22	2.488	3.82
BSPL	1	2	042177	0700	02	1089	317	564	0	0	208	29	52	19	18	2.221	3.15
BSPM	2	2	042077	1145	01	2320	224	1800	4	0	292	10	78	13	10	1.735	4.18
BSPN	2	2	042077	1145	01	2384	248	1716	4	0	416	10	72	18	14	1.733	5.03
BSPO	2	2	042077	1145	01	2640	296	1860	0	32	452	11	70	18	11	1.761	4.92
BSPP	2	2	042077	1145	15	1072	120	548	0	0	404	11	51	38	11	1.999	2.20
BSPQ	3	2	042077	1800	01	2196	120	1600	4	0	472	5	73	22	15	1.995	3.71
BSPR	3	2	042077	1800	01	1956	84	1448	0	0	424	4	74	22	15	1.998	3.36
BSPS	3	2	042077	1800	01	2104	140	1536	0	0	428	7	73	20	16	2.083	3.88
BSPT	3	2	042077	1800	22	700	48	480	0	4	168	7	69	25	17	2.317	1.35
BIYB	1	1	052077	1710	01	708	212	288	0	0	208	30	41	29	17	2.217	1.75
BIYC	1	1	052077	1710	03	952	212	360	0	0	380	22	38	40	19	2.140	2.06
BJAB	2	1	052077	1315	01	872	32	508	0	0	332	4	58	38	14	2.216	1.72
BJAC	2	1	052077	1315	07	1144	16	800	0	0	328	1	70	29	17	2.301	2.88
BKCC	3	1	052077	0840	01	2076	60	1636	0	4	376	3	79	18	19	2.295	3.68
BKCD	3	1	052077	0840	22	452	12	408	0	8	24	3	90	7	14	2.048	.70
BJEJ	1	2	051977	0800	01	768	52	696	0	0	20	7	91	3	15	2.103	1.49
BJEK	1	2	051977	0800	04	952	72	852	4	0	24	8	89	3	16	2.053	1.94
BJGL	2	2	051977	1150	01	1472	16	1380	0	0	76	1	94	5	14	1.969	2.94
BJGM	2	2	051977	1150	12	2064	52	1948	0	0	64	3	94	3	14	1.935	3.32
BJIO	3	2	051877	1755	01	2036	4	1968	0	0	64		97	3	12	1.401	2.41
BJIP	3	2	051877	1755	14	996	24	872	0	0	100	2	88	10	15	1.923	1.79
BJLR	1	3	051777	1600	01	1324	0	828	4	0	484	1	63	37	12	1.791	1.90
BJLS	1	3	051777	1600	08	1040	20	784	8	0	228	2	75	23	14	2.075	1.66
BJNQ	2	3	051877	0800	01	1360	32	1288	8	0	32	2	95	3	16	1.911	3.16
BJNR	2	3	051877	0800	10	921	32	760	4	0	125	3	83	14	16	2.285	1.86
BSOA	2	3	051877	0800	10	700	24	612	0	0	64	3	87	9	14	1.924	1.30
BSOB	2	3	051877	0800	10	1312	8	1148	4	0	152	1	88	12	14	2.089	1.94
BJPQ	3	3	051877	1140	01	1528	44	1352	0	0	132	3	88	9	17	1.808	3.04
BJPR	3	3	051877	1140	12	960	0	888	4	0	68	0	93	7	11	1.772	1.52
BJRW	1	4	051777	0920	01	1604	8	1528	12	0	56		95	4	15	1.865	2.31
BJRX	1	4	051777	0920	11	728	8	668	12	0	40	1	92	7	13	1.945	1.82

TABLE 13.1 CONT.'D

SACD	S	T	DATE	TIME	Z	IPPL	ITPL	IOPL	IFPL	IRPL	IMPL	IPCT	OPCT	MPCT	NSPS	SDI	TDWT
BSOC	1	4	051777	0920	11	644	0	588	24	0	32	0	91	9	12	1.793	1.83
BSOD	1	4	051777	0920	11	832	4	744	28	0	56		89	10	14	2.001	2.01
BJIU	2	4	051677	1720	01	752	4	708	0	4	36	1	94	5	13	1.894	1.44
BJIV	2	4	051677	1720	29	428	12	392	4	0	20	3	92	6	12	1.902	.55
BSOE	2	4	051677	1720	29	572	12	536	0	0	24	2	94	4	10	1.772	.60
BSOF	2	4	051677	1720	29	604	12	532	0	0	60	2	88	10	13	1.910	1.11
BJUU	3	4	051677	1030	01	684	12	592	0	0	80	2	87	12	13	2.055	.88
BJUV	3	4	051677	1030	22	556	4	476	0	0	76	1	86	14	12	2.012	.95
BSOG	3	4	051677	1030	22	656	8	528	0	0	120	1	80	18	13	2.076	1.30
BSOH	3	4	051677	1030	22	628	24	520	0	4	80	4	83	13	14	2.085	1.31
BLES	1	2	070677	0900	01	372	8	240	0	0	124	2	65	33	11	2.059	1.58
BLET	1	2	070677	0900	10	496	8	444	0	0	44	2	90	9	12	2.011	1.17
BLGK	2	2	070677	1230	01	464	60	396	0	0	8	13	85	2	15	2.199	.90
BLGL	2	2	070677	1230	31	544	24	516	0	4	0	4	95	1	13	1.898	1.49
BLID	3	2	070677	1830	01	344	88	256	0	0	0	26	74	0	10	2.052	.70
BLIE	3	2	070677	1830	26	384	32	340	0	0	12	8	89	3	12	2.065	.63
BMUP	1	2	080477	0930	01	192	8	180	0	4	0	4	94	2	11	2.072	.38
BMUQ	1	2	080477	0930	10	152	0	152	0	0	0	0	100	0	7	1.830	.26
BSOI	1	2	080477	0930	10	264	4	248	0	0	12	2	94	5	11	1.996	.48
BSOJ	1	2	080477	0930	10	288	0	288	0	0	0	0	100	0	8	1.843	.46
BMSH	2	2	080477	1245	01	348	4	340	4	0	0	1	98	1	9	1.179	.35
BMSI	2	2	080477	1245	36	260	0	256	0	4	0	0	98	2	8	1.693	.51
BSOK	2	2	080477	1245	36	268	0	268	0	0	0	0	100	0	7	1.634	.48
BSOL	2	2	080477	1245	36	308	4	296	4	0	4	1	96	3	9	1.622	.43
BMUA	3	2	080477	1900	01	240	16	224	0	0	0	7	93	0	10	1.634	.32
BMUB	3	2	080477	1900	35	248	0	248	0	0	0	0	100	0	8	1.655	.35
BSPU	3	2	080477	1900	35	212	4	204	0	4	0	2	96	2	9	1.828	.47
BSPV	3	2	080477	1900	35	340	4	320	4	0	12	1	94	5	11	1.705	.53
BUBK	1	1	091177	1530	01	3696	44	3520	0	0	132	1	95	4	14	1.671	4.07
BUBL	1	1	091177	1530	03	4132	20	3744	0	0	368		91	9	14	1.643	4.14
BUDI	2	1	091177	1120	01	556	28	516	0	0	12	5	93	2	16	1.860	.60
BUDJ	2	1	091177	1120	13	1080	64	1004	0	0	12	6	93	1	16	1.869	1.16
BUFI	3	1	091177	0800	01	368	16	328	0	0	24	4	89	7	14	2.066	.54
BUFJ	3	1	091177	0800	19	192	8	172	0	0	12	4	90	6	10	1.968	.34

TABLE 13.1 CONT.'D

SACD	S	I	DATE	TIME	Z	TPPL	TTPL	TOPL	TFPL	TRPL	TMPL	TPCT	OPCT	MPCT	NSPS	SDI	TDWT
BOIA	1	2	091077	0830	01	3784	1564	2120	0	0	100	41	56	3	21	2.323	6.26
BOIB	1	2	091077	0830	03	3684	1492	2076	0	0	116	40	56	3	20	2.280	6.96
BOKB	2	2	091077	1200	01	396	36	360	0	0	0	9	91	0	10	2.043	.89
BOKC	2	2	091077	1200	14	540	32	504	0	4	0	6	93	1	13	1.689	4.92
BOMD	3	2	090977	1730	01	484	60	424	0	0	0	12	88	0	15	1.957	.53
BOME	3	2	090977	1730	07	296	48	248	0	0	0	16	84	0	12	1.938	.42
BOPD	1	3	090877	1300	01	18388	1984	16188	4	0	212	11	88	1	20	1.336	12.55
BOPE	1	3	090877	1300	03	14642	1784	12634	0	0	224	12	86	2	19	1.426	10.44
BORB	2	3	090877	1800	01	592	52	540	0	0	0	9	91	0	13	1.605	.73
BORC	2	3	090877	1800	13	308	20	276	0	0	12	6	90	4	11	1.752	.35
BOTB	3	3	090977	1020	01	384	12	356	0	0	12	3	94	3	11	1.994	.80
BOTC	3	3	090977	1020	23	424	24	372	0	0	28	6	88	7	13	2.071	.92
BOVC	1	4	090777	1830	01	7832	2304	5332	0	0	196	29	68	3	23	2.344	11.46
BOVD	1	4	090777	1830	02	12044	2640	9310	0	0	94	22	77	1	20	2.154	13.54
BOXA	2	4	090777	1400	01	312	64	248	0	0	0	21	79	0	12	1.850	.43
BOXB	2	4	090777	1400	07	588	356	212	0	4	16	61	36	3	18	2.424	.85
BOZA	3	4	090777	0815	01	140	8	128	0	4	0	6	91	3	9	1.895	.25
BOZB	3	4	090777	0815	40	172	12	160	0	0	0	7	93	0	11	2.085	.26
BSQE	1	2	102177	1255	01	3072	8	2880	0	0	184		94	6	12	1.504	1.70
BSQF	1	2	102177	1255	08	2112	0	2052	0	0	60	0	97	3	12	1.870	2.49
BSQG	2	2	102077	1155	01	456	0	456	0	0	0	0	100	0	8	1.812	.57
BSQH	2	2	102077	1155	13	600	4	592	0	0	4	1	99	1	10	1.714	.65
BSQI	3	2	102177	0820	01	344	12	324	4	0	4	3	94	2	12	2.061	.57
BSQJ	3	2	102177	0820	26	332	0	332	0	0	0	0	100	0	8	1.680	.35
BSRJ	1	2	110677	0800	01	656	84	436	0	0	136	13	66	21	12	2.058	1.00
BSPW	1	2	110677	0800	01	972	80	544	0	0	348	8	56	36	15	2.019	1.82
BSPX	1	2	110677	0800	01	1468	108	848	0	0	512	7	58	35	16	2.074	2.73
BSJC	1	2	110677	0800	07	1132	92	588	0	0	452	8	52	40	14	1.988	1.66
BSPY	1	2	110677	0800	07	1268	124	580	0	0	564	10	46	44	16	1.880	1.77
BSPZ	1	2	110677	0800	07	1204	68	580	0	0	556	6	48	46	14	1.793	1.20
BSKS	2	2	110577	1050	01	512	4	496	4	4	4	1	97	2	12	1.845	.56
BSKT	2	2	110577	1050	23	192	4	184	0	4	0	2	96	2	9	1.894	.28
BSMM	3	2	110577	1630	01	400	16	384	0	0	0	4	96	0	9	1.644	.54
BSUA	3	2	110577	1630	01	304	16	284	0	0	4	5	93	1	12	1.855	.39

TABLE 13.1 CONT.'D

SACD	S	T	DATE	TIME	Z	TPPL	TTPL	TOPL	TFPL	TRPL	TMPL	TPCT	OPCT	MPCT	NSPS	SDI	TDWT
BSQB	3	2	110577	1630	01	590	20	570	0	0	0	3	97	0	8	1.314	.32
BSMN	3	2	110577	1630	35	820	20	790	0	10	0	2	96	1	10	1.371	.46
BSQC	3	2	110577	1630	35	720	40	670	0	0	10	6	93	1	11	1.490	.41
BSQD	3	2	110577	1630	35	630	20	590	0	0	20	3	94	3	10	1.621	.55
BTXJ	1	2	120377	1335	01	3380	90	3050	0	0	240	3	90	7	14	2.038	5.08
BTXK	1	2	120377	1335	03	3040	50	2740	0	0	250	2	90	8	13	1.988	4.14
BUHD	1	2	120377	1335	03	2190	20	1860	0	0	310	1	85	14	11	2.016	2.65
BUHE	1	2	120377	1335	03	3670	80	2980	0	0	610	2	81	17	12	1.996	4.00
BTZB	2	2	120277	1200	01	3980	0	3900	0	0	80	0	98	2	8	1.498	2.78
BUHF	2	2	120277	1200	01	4500	0	4450	0	0	50	0	99	1	10	1.515	3.05
BUHG	2	2	120277	1200	01	3520	20	3470	0	0	30	1	99	1	10	1.507	2.68
BTZC	2	2	120277	1200	15	3250	20	3180	0	0	50	1	98	2	10	1.592	2.60
BUHH	2	2	120277	1200	15	2570	40	2490	0	0	40	2	97	2	12	1.610	1.95
BUHI	2	2	120277	1200	15	2530	30	2470	0	0	30	1	98	1	10	1.546	2.09
BUAU	3	2	120377	0930	01	1260	40	1220	0	0	0	3	97	0	11	1.575	1.35
BUHJ	3	2	120377	0930	01	1270	40	1220	0	0	10	3	96	1	12	1.701	1.44
BUHK	3	2	120377	0930	01	1510	60	1450	0	0	0	4	96	0	11	1.638	1.58
BUAV	3	2	120377	0930	13	1530	60	1450	0	10	10	4	95	1	12	1.773	2.00

TABLE 13.2

AVERAGE ABUNDANCE OF PROTOZOA BY SPECIES AT STATIONS 1, 2 AND 3 DURING 1977
(Numbers/ℓ)

Species	Station 1	Station 2	Station 3
Tintinnids			
Acanthostomella gracilis			1.1*
Acanthostomella norvegica			0.4*
Amphorides quadrilineata	0.2	1.6*	0.7
Climacocylis scalaroides	0.1	0.5	0.8*
Codonellopsis americana	3.6*	0.2	0.2
Coxliella pelagica		0.1*	
Dadayiella ganymedes	0.1	0.9	2.0*
Dadayiella jorgenseni		0.1*	
Dictyocysta lata	0.1		0.2*
Epiplocycloides acuta	0.2	1.4*	1.0
Eutintinnus apertus			0.1*
Eutintinnus lasus-undae	1.4	20.0*	8.9
Favella panamensis	0.3*		
Parundella attenuata		0.1*	
Parundella conica			0.1*
Proplectella claparedei			0.1*
Proplectella subcaudata			0.1*
Protorhabdonella curta		0.3	1.5*
Pseudometacylis ornata	0.3*	0.2	
Rhabdonella brandti			0.1*
Rhabdonella canelata			0.2*
Rhabdonella conica			0.1*
Rhabdonella hebe			0.1*
Rhabdonellopsis triton			0.3*
Salpingacantha undata		0.2*	0.1
Salpingella acuminata	0.6	0.4	0.9*
Salpingella minutissima		0.2*	
Steenstrupiella gracilis	0.1	0.2	0.5*
Stenosemella ventricosa	12.6*	0.4	
Tintinnidium incertum	306.1*	3.4	0.9
Tintinnopsis acuminata	29.4*	6.4	0.1
Tintinnopsis brandti	2.3*	0.1	
Tintinnopsis compressa	17.6*	3.0	1.2
Tintinnopsis dadayi	6.0*	2.0	
Tintinnopsis directa	3.2*	1.0	
Tintinnopsis fimbriata	0.1*		
Tintinnopsis lata	0.1*		
Tintinnopsis lobiancoi	119.8*	0.5	
Tintinnopsis minuta	3.4*	0.3	0.1
Tintinnopsis ovale	0.2*		
Tintinnopsis parvula	2.8*	0.1	
Tintinnopsis radix	0.2*		
Tintinnopsis sacculus	0.9*	0.1	
Tintinnopsis strigosa	0.1*		
Tintinnopsis tocantinensis	41.1*	1.3	0.1
Tintinnopsis tubulosa	0.8*	0.3	

TABLE 13.2 CONT.'D

Species	Station 1	2	3
Tintinnids cont.'d			
Tintinnus tubulosus	2.6*	1.3	0.9
Undella hyalina	0.2	0.5	0.5
Xystonella treforti		0.1	
Oligotrichs			
Lohmaniella oviformis	82.4*	68.1	50.5
Strombidium accuminatum	27.2*	2.0	2.6
Strombidium calkinsi	71.6*	47.6	46.7
Strombidium conicum	227.8*	128.9	91.7
Strombidium cornucopiae	12.1*	0.4	0.3
Strombidium ovale	437.3*	274.6	160.5
Strombidium strobilus	122.0*	59.8	108.5
Strombidium sulcatum	761.2*	293.9	245.6
Strombidium typicum	114.6	142.8*	134.2
Tontonia gracillima	18.6*	12.4	8.3
Foraminifera			
Bolivina striatula	2.0*	0.3	0.1
Bucella frigida	0.1*	0.1	
Cornuspira planorbis	0.1*		
Globigerina pachyderma	0.2	0.2	0.7*
Hastigerina pelagica		0.6*	0.2
Radiolaria/Acantharia			
Actinosphaera eichhorni		0.1*	
Calacylas monumentum		0.1	0.1*
Ceratospyris sp.		0.1	0.1*
Clathroconicum sp.			0.1*
Cubothalus regularis		0.1*	
Lithelius alveolina		0.1*	
Lithomellisa setosa		0.2	0.4*
Sphaerozoum punctata	0.1	0.8*	0.2
Spongosphaera streptacantha		0.2*	0.1
Zygocircus piscicaudata		0.1	0.1*
Other Protozoa			
Didinium gigantea	1.0*	0.2	
Ephelota geminaria	8.9*	8.0	5.4
Euglypha laevis		0.1*	
Euplotes minuta	0.8	0.3	3.7*
Euplotes sexcostatus	5.8	4.1	8.2*
Mesodinium rubrum	105.5*	104.8	24.7
Nassula microspora	14.6*	1.0	1.8
Tiarina fucus	0.4	0.8	1.0*
Tiarina fusus	35.0	49.1*	40.4
Tiarina gigantea	36.5*	1.4	0.3
Tricophyra columbiae	0.4*		
Unidentified protozoa	0.2*		

*Maximum Abundance

TABLE 13.3

AVERAGE PROTOZOAN ABUNDANCE (INDIVIDUALS/ℓ) BY SPECIES FOR EACH SAMPLING MONTH IN 1977

Species	Jan	Feb	Mar	Apr	May	July	Aug	Sept	Oct	Nov	Dec
Tintinnids											
Acanthostomella gracilis				1.0							2.6*
Acanthostomella norvegica											1.4*
Amphorides quadrilineata	0.2				2.6	2.7*		0.8			
Climacocylis scalaroides				1.3	1.2	2.0*		0.2			
Codonellopsis americana				0.7	0.1			2.2*		9.1	0.7
Coxliella pelagica						0.7*					
Dadayiella ganymedes	0.2			1.7	2.8*	0.7		0.2		1.7	0.7
Dadayiella jorgenseni					0.1*						
Dictyocysta lata	0.8*										
Epiplocycloides acuta	1.2							3.2*	0.7	0.7	1.4
Eutintinnus apertus								0.2*			
Eutintinnus lasus-undae				101.3*	2.2	18.7	10.1	4.6	1.3		1.4
Favella panamensis	0.8*										
Parundella attenuata								0.2			
Parundella conica							0.3*				
Proplectella claparedei										3.7*	0.7
Proplectella subcaudata					0.1*						
Protorhabdonella curta				0.3	0.2	3.3	10.1*	0.5	0.7	1.3	1.4
Pseudometacylis ornata					0.8*						
Rhabdonella brandti										0.6*	
Rhabdonella canelata										0.7*	
Rhabdonella conica						1.3*					
Rhabdonella hebe								0.2*			
Rhabdonellopsis triton				0.7*	0.2						
Salpingacantha undata				0.3	0.1					0.3*	
Salpingella acuminata											7.1*
Salpingella minutissima								0.5*			
Steenstrupiella gracilis	0.4		0.7		0.4		0.7			0.7*	
Stenosemella ventricosa			280.0	1.0	8.1			0.3		26.3*	
Tintinnidium incertum	520.0*			81.4	2.9			90.2	1.3	2.3	19.3
Tintinnopsis acuminata	25.0			1.3	3.0			49.3*			

TABLE 13.3 CONT.'D

Species	Jan	Feb	Mar	Apr	May	July	Aug	Sept	Oct	Nov	Dec
Tintinnids cont.'d											
Tintinnopsis brandti					0.9			3.8*			
Tintinnopsis compressa	31.6*	1.0	8.0	4.7	1.0			13.1			
Tintinnopsis dadayi	1.8			9.0	0.1			10.3*			
Tintinnopsis directa								8.6*			
Tintinnopsis fimbriata	0.2*										
Tintinnopsis lata	0.2*										
Tintinnopsis lobiancoi	0.2			0.3	3.0			246.3*			
Tintinnopsis minuta	8.4	0.5		0.7*	0.2						
Tintinnopsis ovale	0.2*							0.2			
Tintinnopsis parvula	6.2		2.0*	0.3				0.2			
Tintinnopsis radix					0.1			0.2*			
Tintinnopsis sacculus								2.0*			
Tintinnopsis strigosa				0.3*							
Tintinnopsis tocantinensis											
Tintinnopsis tubulosa	0.2				0.2		0.3	87.7*			
Tintinnus tubulosus	0.2			10.7*	0.6	6.7	0.3	0.5		1.7*	
Undella hyalina		0.5		0.3	1.2*			2.7		0.3	
Xystonella treforti						0.7*				0.3	0.7
Oligotrichs											
Lohmaniella oviformis	56.6	64.5	48.5	31.3	24.4	6.0	8.0	70.5	41.3	35.1	327.9*
Strombidium accuminatum	1.6	2.0	19.7	5.3	1.0			51.6*		0.9	6.4
Strombidium calkinsi	47.6	41.0	179.0*	92.0	74.2	32.2	15.0	54.4	32.7	13.9	41.4
Strombidium conicum	63.4	16.0	415.5	111.7	87.6	53.3	56.0	229.1	147.3	86.3	440.7*
Strombidium cornucopiae				4.3	0.8	0.7		18.5*	1.3	3.1	4.3
Strombidium ovale	83.7	36.5	575.7	89.3	83.4	44.0	24.7	722.9	246.0	187.4	892.1
Strombidium strobilus	36.6	9.0	914.0*	138.3	74.8	62.7	36.0	98.5	60.0	24.3	88.6
Strombidium sulcatum	194.8	58.5	428.2	306.3	326.0	112.0	89.3	1230.7*	451.3	136.4	648.6
Strombidium typicum	42.2	4.5	1036.8*	354.6	125.8	48.7	20.0	53.4	110.7	47.3	114.3
Tontonia gracillima	0.2		2.7	0.7	51.8*	6.0	3.0	2.5	15.3	4.1	2.1

TABLE 13.3 CONT.'D

Species	Jan	Feb	Mar	Apr	May	July	Aug	Sept	Oct	Nov	Dec
Foraminifera											
Bolivina striatula				0.3	3.5*			0.2			
Bucella frigida	0.4*										
Cornuspira planorbis	0.2*										
Globigerina pachyderma	0.6	2.5*	0.7	0.3	0.1		0.3		0.7	0.3	
Hastigerina pelagica	0.6	1.5*		0.7			0.7				
Radiolaria/Acantharia											
Actinosphaera eichhorni								0.2*			
Calocylas monumentum							0.7*				
Ceratospyris sp.								0.3*			
Clathroconicum sp.				0.3*							
Cubothalus regularis	0.2*										
Lithelius alveolina	0.2*										
Lithomellisa setosa	0.6									1.0*	0.7
Sphaerozoum punctata				2.7*	0.4		0.3			0.3	
Spongosphaera streptacantha					0.2	0.7*					
Zygocircus piscicaudata	0.2	1.0*									
Other Protozoa											
Dididium gigantea	0.8			2.7	0.7					0.9	
Ephelota geminaria	8.2	6.0	56.3*	11.3	3.1					3.9	14.3
Euglypha laevis	0.2*							1.5	10.0		
Euplotes minuta					5.2	6.7	10.1*				
Euplotes sexcostatus				4.0	22.4*	20.0		1.5			
Mesodinium rubrum	14.8	3.9	926.3*	3.0	29.0			2.2		180.3	105.7
Nassula microspora	0.4		139.2*	1.7				22.5	30.0		
Tiarina fucus	0.2				1.5	2.7*	0.7		1.3		1.4
Tiarina fusus	22.8	10.0	53.3	269.3*	61.0	1.3		0.5	0.7		
Tiarina gigantea	11.2	1.5	64.7*	28.7	1.4	0.7	0.3	0.5		1.1	0.7
Tricophyra columbiae							0.3	6.1			
Unidentified Protozoa				1.0*				0.7			

*Maximum Abundance

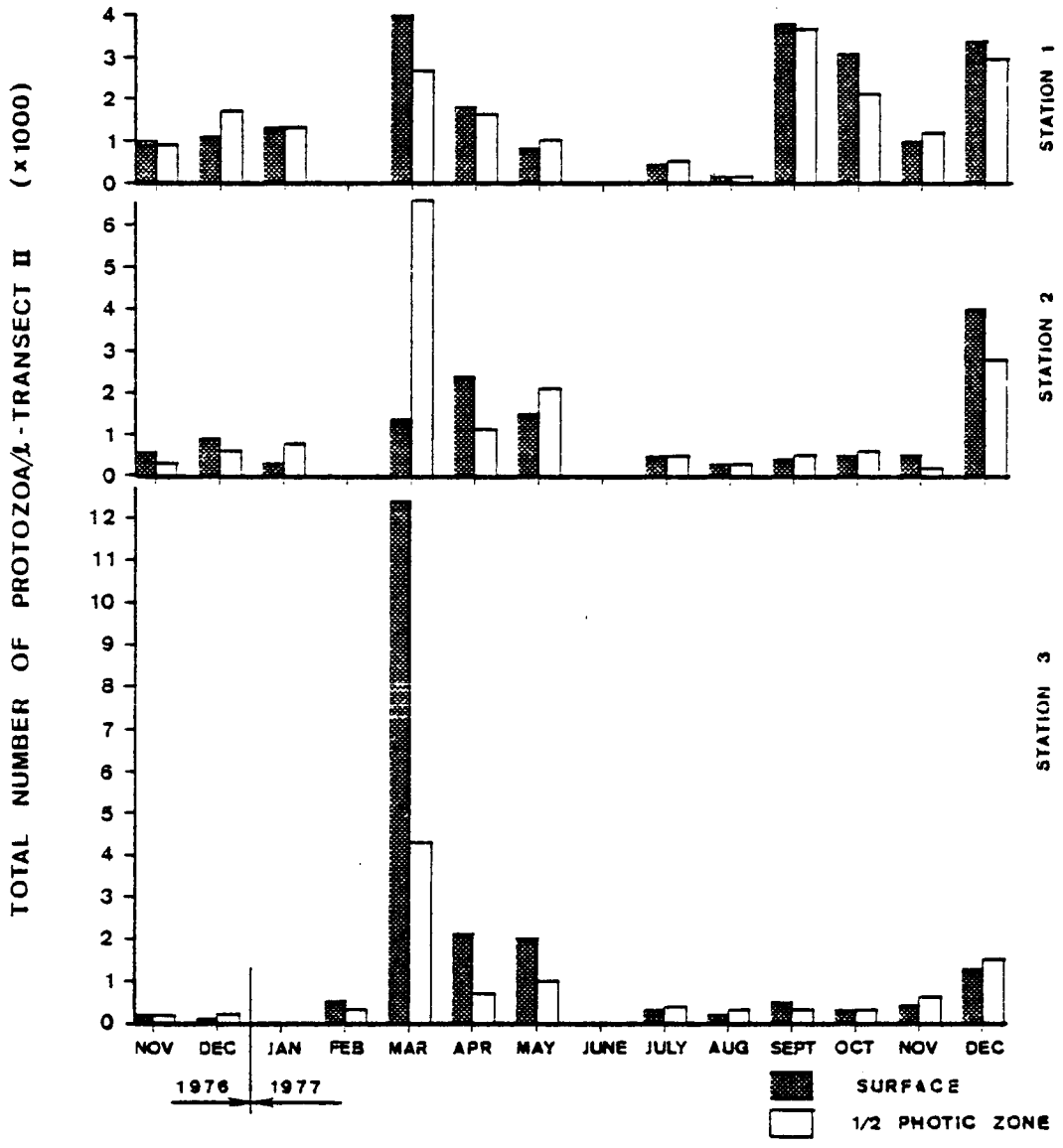

Figure 13.1 Abundance of Protozoa on STOCS, Transect II, 1977.

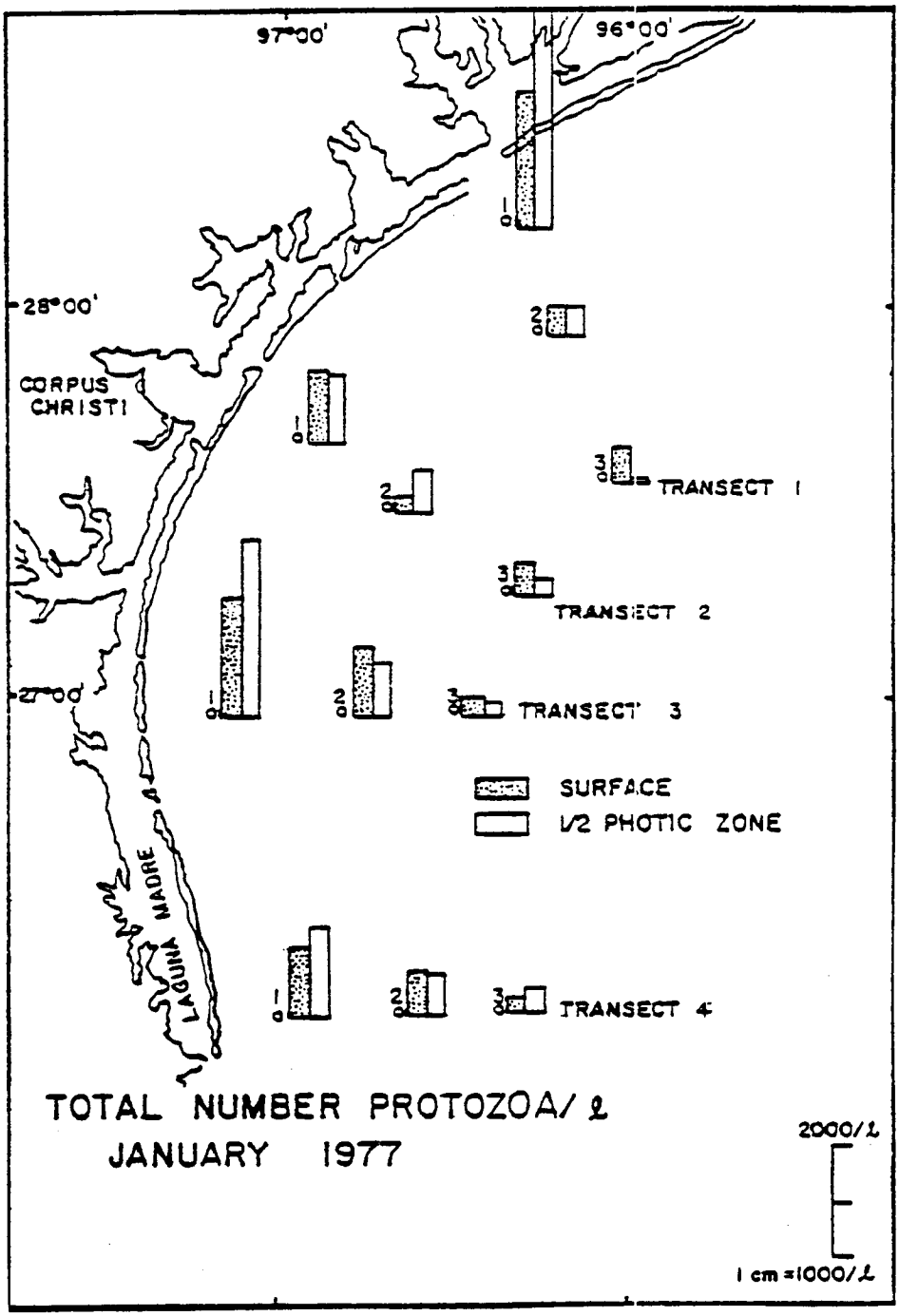

Figure 13.2 Total Number of Protozoa/ℓ Collected During the Winter Cruise 1977.

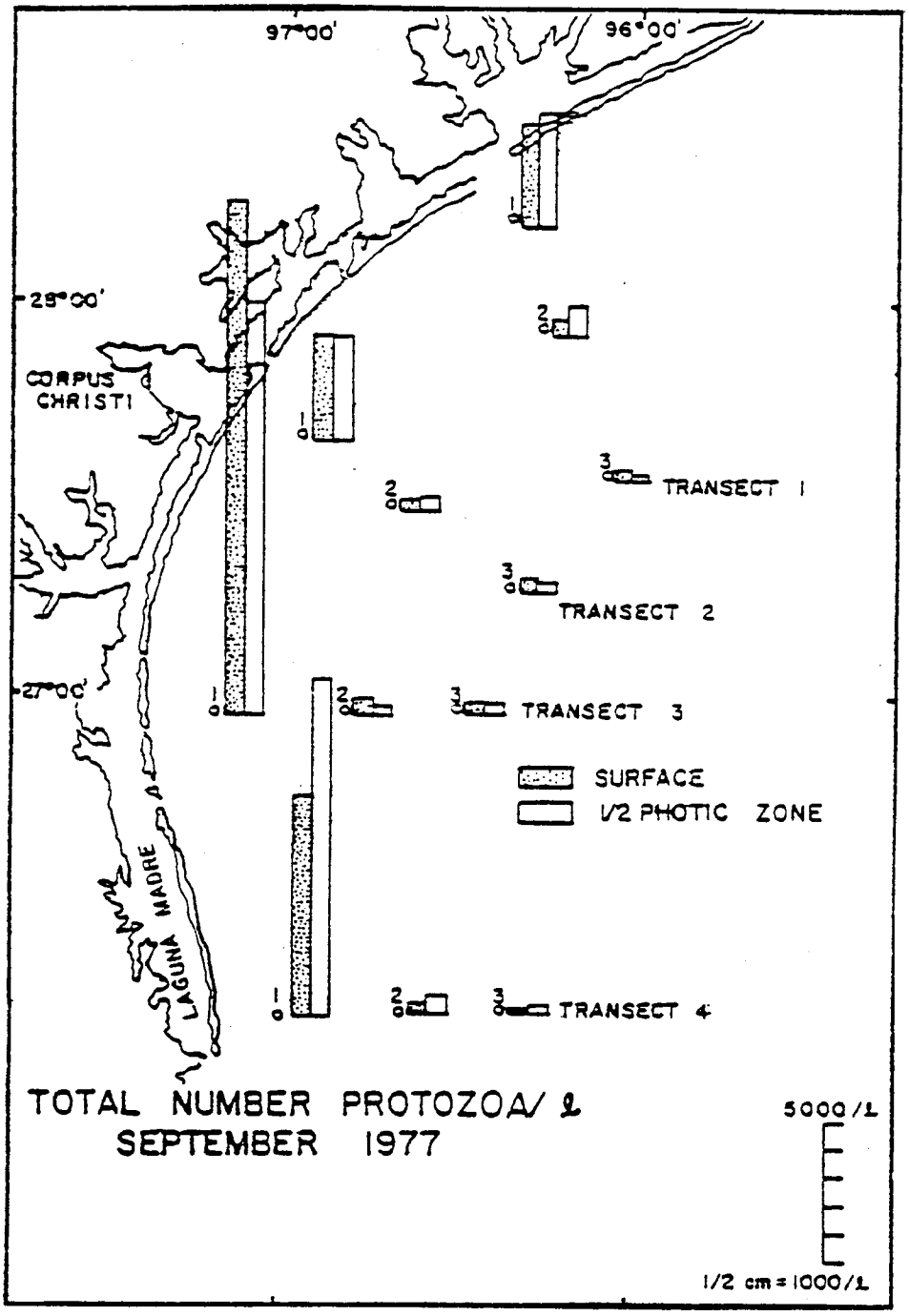

Figure 13.3 Total Number of Protozoa/ℓ Collected During the Spring Cruise 1977.

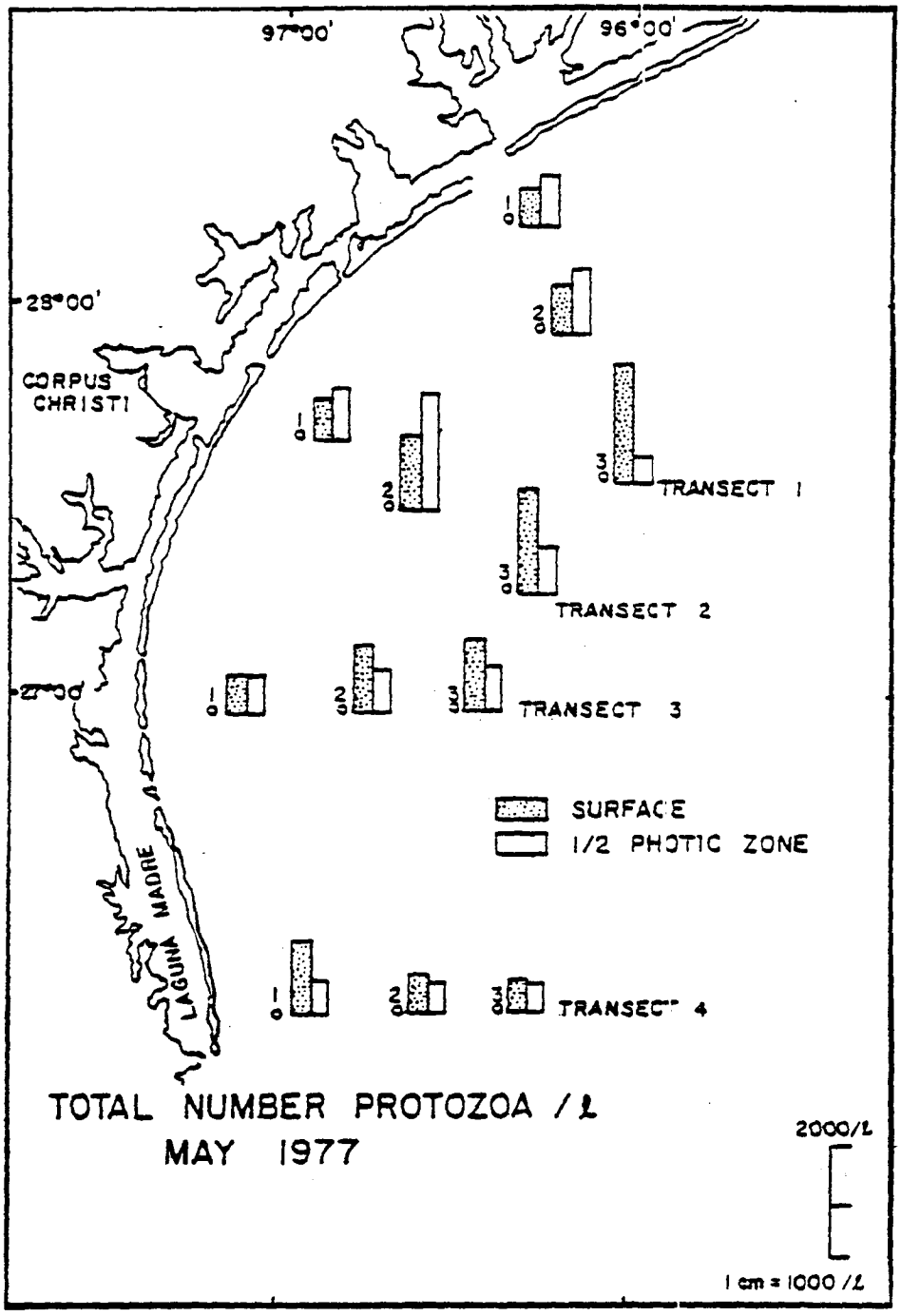

Figure 13.4 Total Number of Protozoa/ℓ Collected During the Fall Cruise 1977.

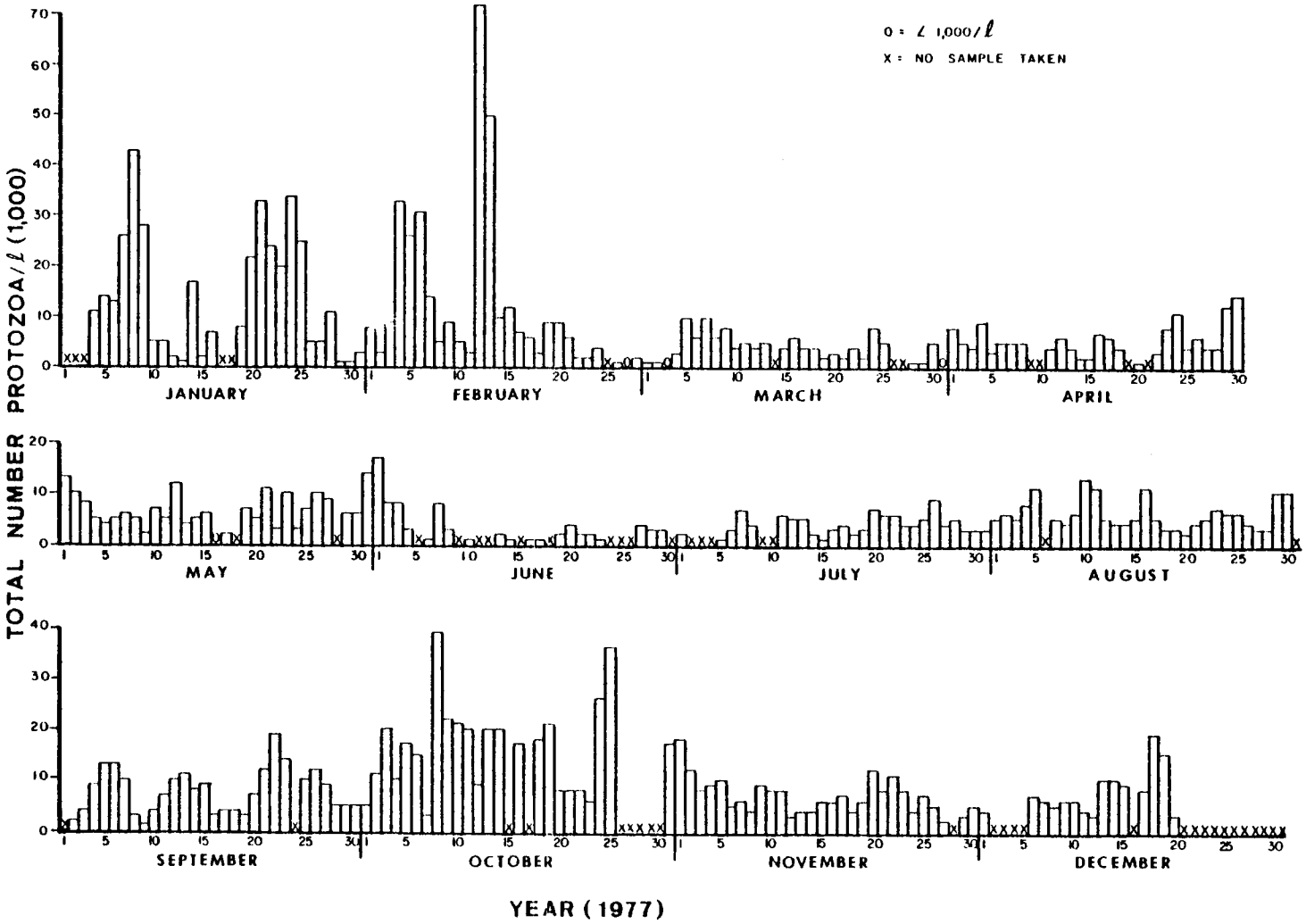

Figure 13.5 Abundance of Protozoa in the Port Aransas Shipping Channel.

centration of protozoa in September occurred at Stations 1/III and 1/IV, which were the closest stations to the path of the hurricane. It was thought that increased mixing of the water as a result of the storm provided the nutrients necessary for a phytoplankton bloom which was followed by the protozoan bloom. The hurricane did not appear to have much effect on the protozoan populations in the Port Aransas shipping channel unless the increased numbers found in October are interpreted as a delayed response (Figure 13.6). At any rate, no protozoan bloom was observed in the shipping channel during the fall of 1976 (Figure 13.6). It is regrettable that no comparative data exist for this study. Until more data are available on the long- and short-term effects of environmental perturbations, much of the discussion above, and to follow, is purely speculative.

The distribution patterns of the 1977 data reflected those of the 1975-76 data (Johansen, 1978). For example, the data revealed that the oligotrichs, as a group, were widely distributed in space (Table 13.2) and time (Table 13.3). Most of the oligotrich species were most common at the inshore stations (Station 1), but usually existed in considerable numbers all across the shelf, gradually decreasing in abundance with increasing distance from land. Oligotrichs appeared to be more abundant in March, September and December (September values may be abnormal because of Hurricane Anita). The tintinnid species, on the other hand, were more restricted in spatial and temporal distribution. For example, the hyaline- and sculptured-loricate forms (*e.g. Acanthostomella, Dadayiella, Eutintinnus, Parundella, Proplectella* and *Rhabdonella*) tended to inhabit more offshore regions while the agglomerate- and arenaceous-loricate forms (*e.g. Codonellopsis, Tintinnidium, Tintinnopsis*) tended to inhabit inshore areas (Table 13.2). Foraminifera were more common in inshore areas and tended to be most abundant in winter. Radiolarian/acantharia were almost totally

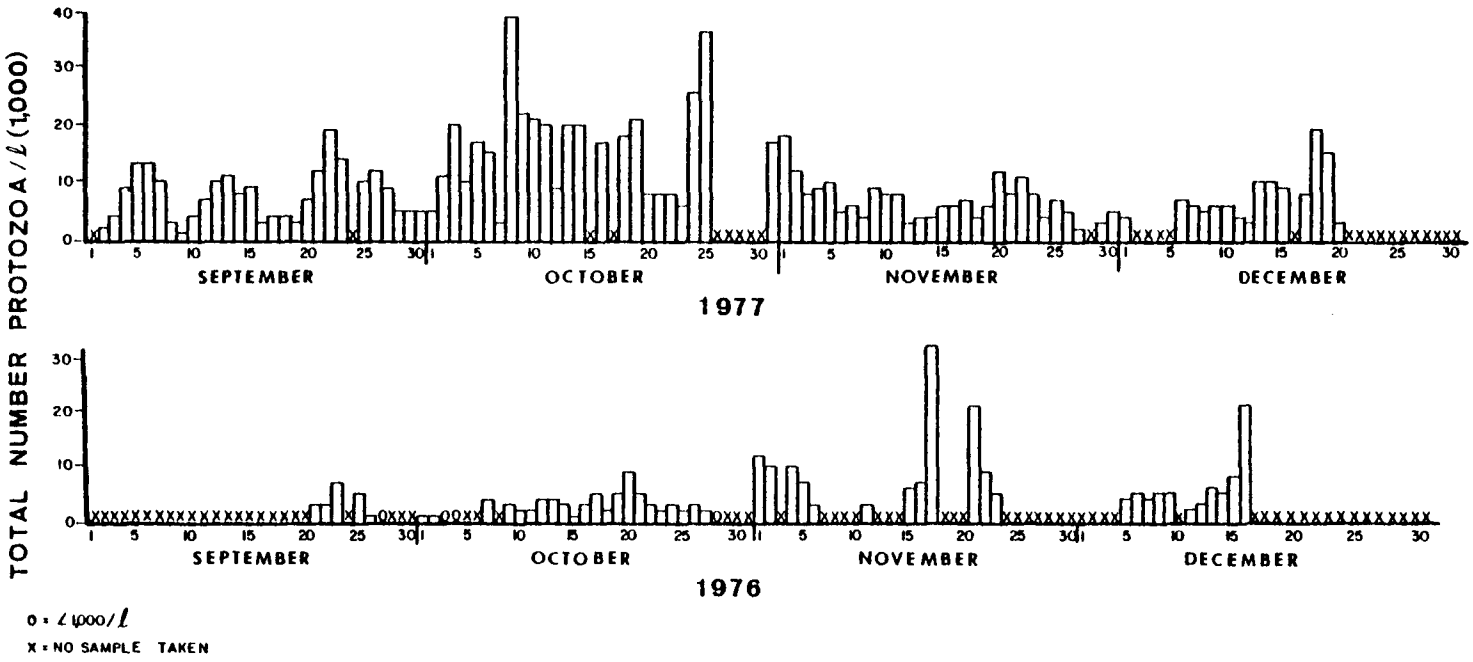

Figure 13.6 Comparison of Protozoan Abundance in the Port Aransas Shipping Channel During Fall 1976 and 1977.

restricted to the two offshore stations and were slightly more abundant during the cooler months of the year. The "other" protozoa were somewhat intermediate in abundance and distribution between the ubiquitous oligotrichs and the rare foraminifera-radiolaria/acantharia.

Figure 13.7 shows that the oligotrichs were the most dominant marine protozoa. They particularly dominated the offshore station community. There is practically no information in the literature for this group of organisms. The reason for this lack of knowledge is that they are rarely seen. Though closely related to the tintinnids, the oligotrichs possess very delicate loricae which will not pass intact through any form of filtering apparatus (nets, screens, etc.).

Tintinnids constituted the greatest numerical percentage of the protozoan community primarily during the winter at the inshore stations (Station 1, all transects)(Figures 13.8 and 13.9). There was a secondary increase in the percentage of tintinnids at Stations 1/II, 1/III, 1/IV and 2/IV in September (Figure 13.8) but again, this may have been a result of the hurricane. The higher percentage of tintinnids at Station 1/I in May and 1/II in March and April may have again reflected the effects of an influx of Mississippi River water into these areas. The percentage of tintinnids comprising the protozoan community in 1977 ranged from 0 - 86.9%.

Protozoan biomass as a percentage of macrozooplankton biomass (based on unpublished data supplied by Dr. Taisoo Park) ranged from 1% (Station 3/II, January) to 348% (Station 1/III, September) (Figure 13.10). Off the coast of Nova Scotia, protozoan biomass usually exceeded 10% of the macrozooplankton biomass and during August the protozoan biomass was twice that of the macrozooplankton biomass (Johansen, 1976). On the STOCS in September, the protozoan biomass was at least half that of the macrozooplankton at 5 of the 12 stations (Figure 13.10).

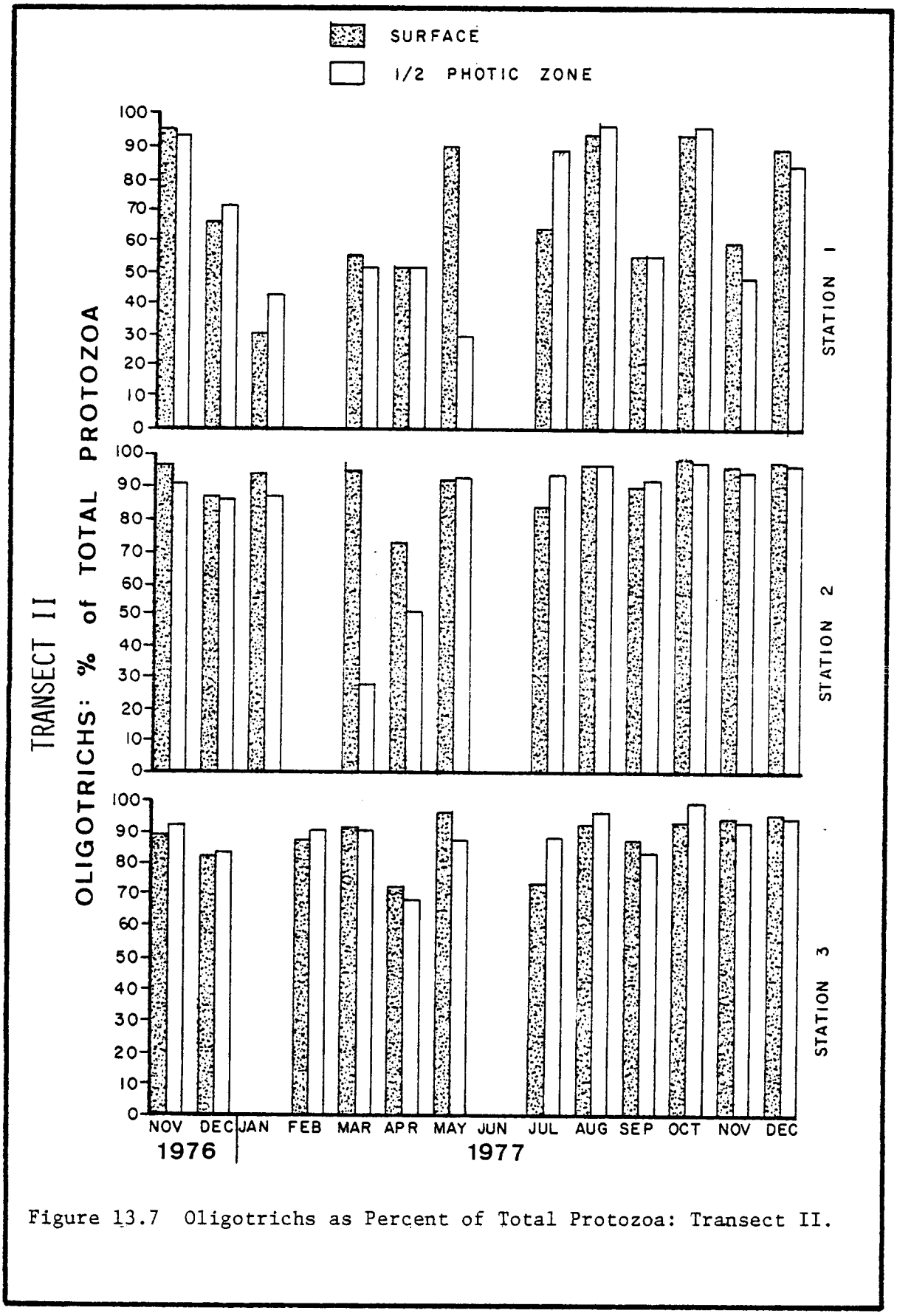

Figure 13.7 Oligotrichs as Percent of Total Protozoa: Transect II.

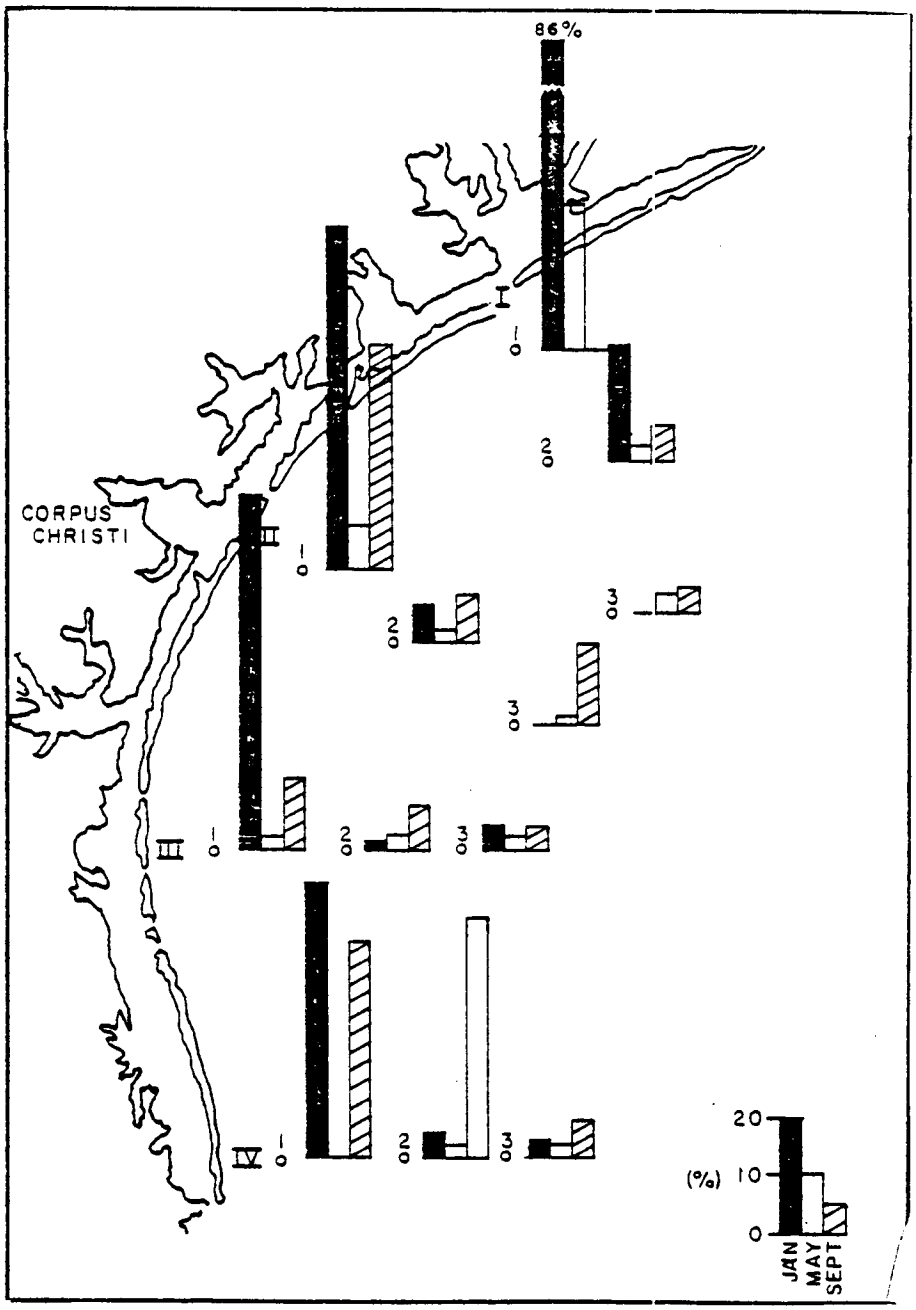

Figure 13.8 Tintinnids as Percent of Total Protozoa: 1977.

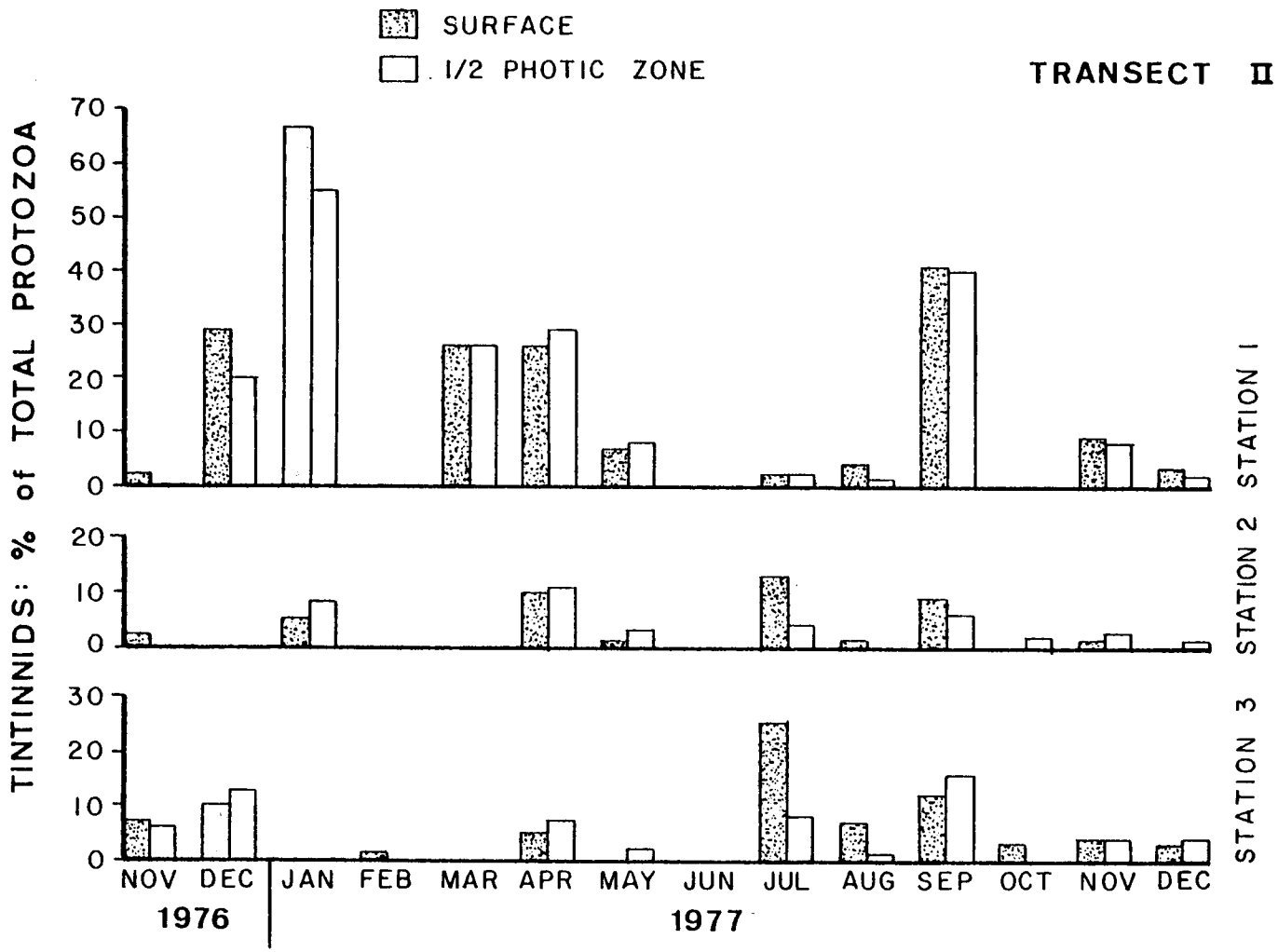

Figure 13.9 Tintinnids as Percent of Total Protozoa: Transect II, 1977.

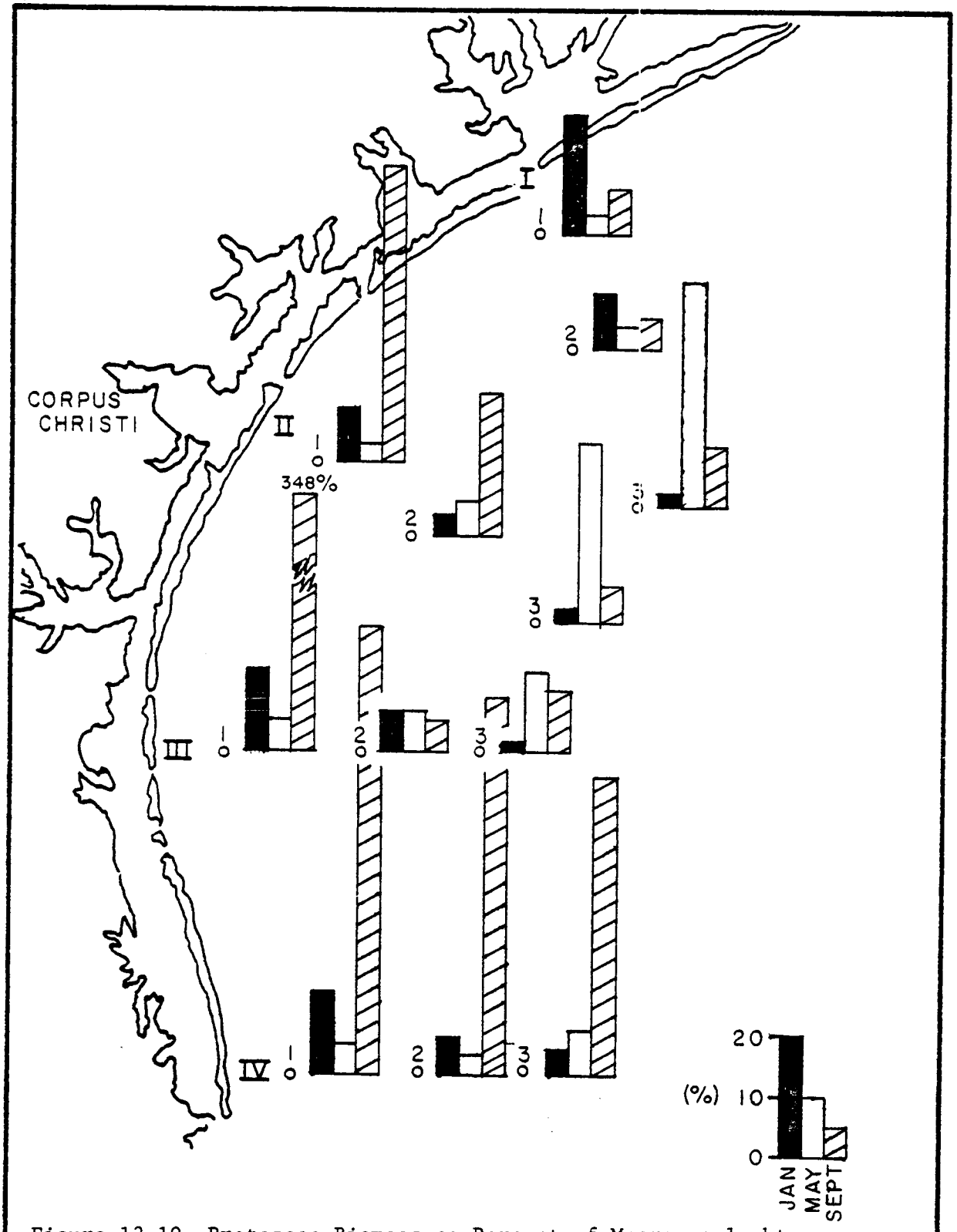

Figure 13.10 Protozoan Biomass as Percent of Macrozooplankton Biomass: 1977.

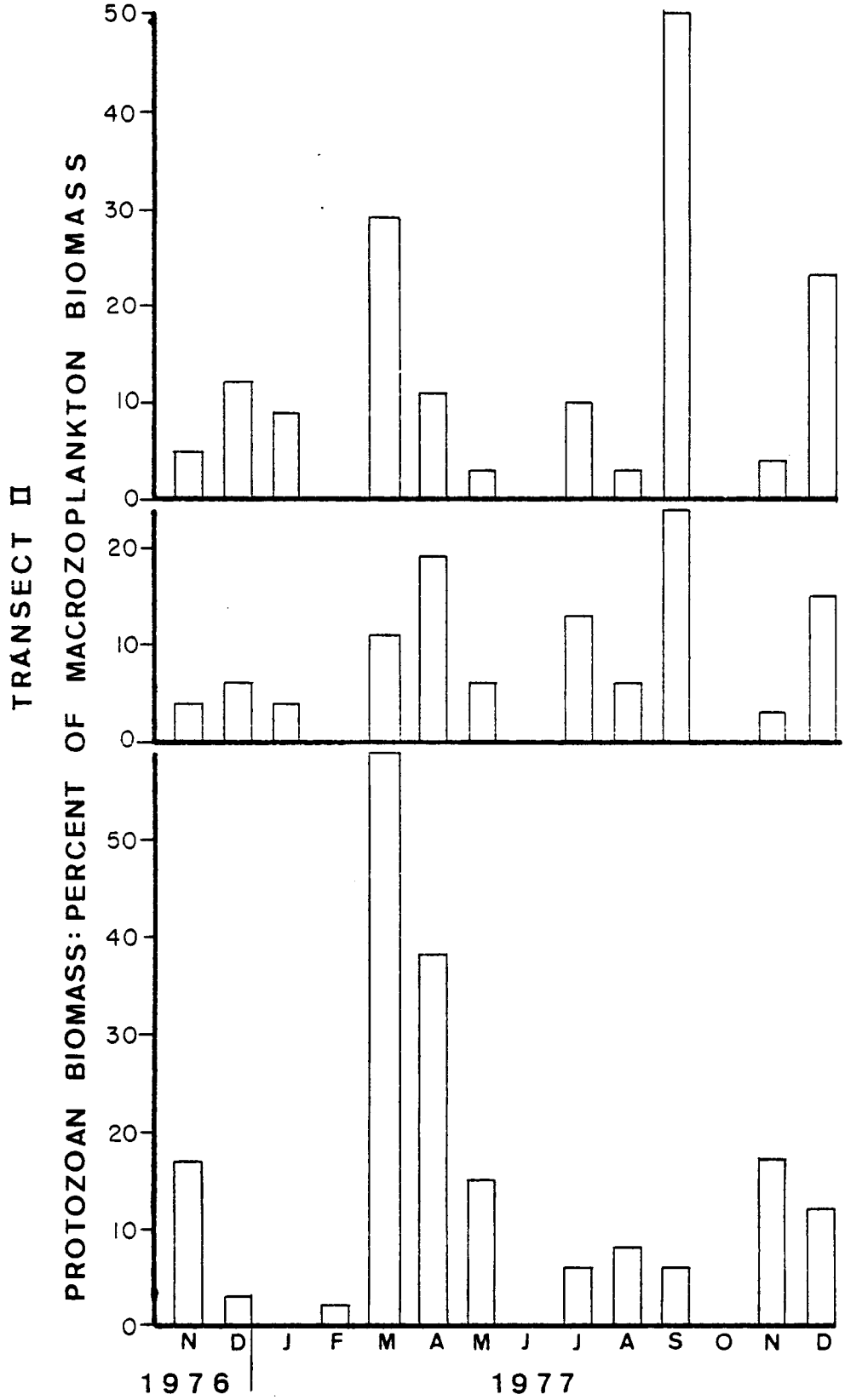

Figure 13.11 Protozoan Biomass as Percent of Macrozooplankton Biomass: Transect II.

It is tempting to speculate that the hurricane damaged many of the larger macrozooplankton while increasing the nutrient availability for the phytoplankton, which subsequently bloomed. The protozoa were immediately able to respond to this increased food source and therefore, they too bloomed. There is no hard evidence to support this speculated phytoplankton - protozoa - macrozooplankton relationship. Some extra protozoan samples taken at Station 1/II in October showed that the increased abundance of the protozoa remained until October (Figure 13.1). Unfortunately, no macrozooplankton samples were collected in October.

By November, the number of individuals of protozoa (Figure 13.1) as well as the percentage of protozoan biomass as opposed to macrozooplankton biomass (Figure 13.11) were greatly reduced. It has always been a difficult problem in a field study of limited scope to determine whether the protozoa abundance drops off because the protozoa were absent or due to heavy grazing by macrozooplankters. From the data recorded here, only speculative statements could be made about subsequential blooms of phytoplankters, protozoa and macrozooplankters. The fact that the protozoan biomass has at times exceeded the macrozooplankton biomass by a factor of three indicated that the protozoa were a significant fraction of the zooplankton community and as such deserve further study.

Species diversity indices varied erratically both temporally and spatially (Figures 13.12 and 13.13). These indices were somewhat higher than those calculated for protozoan communities off the coast of Nova Scotia where indices rarely were greater than 1.5 (Johansen, 1976). This was in agreement with the theory that the number of species increases with decreasing distance from the equator.

Correlation coefficients were calculated for relationships between protozoan abundance and various physical and chemical parameters measured

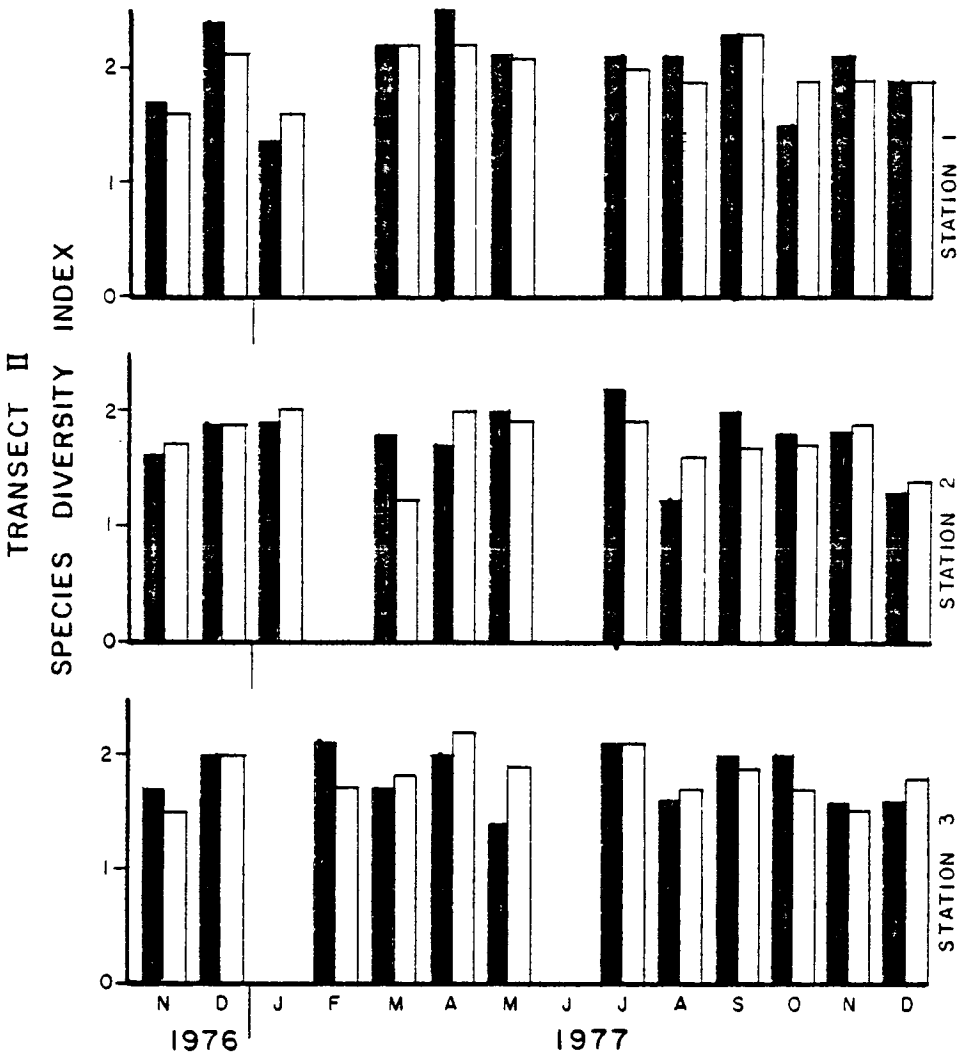

Figure 13.12 Species Diversity Index: Transect II 1977.

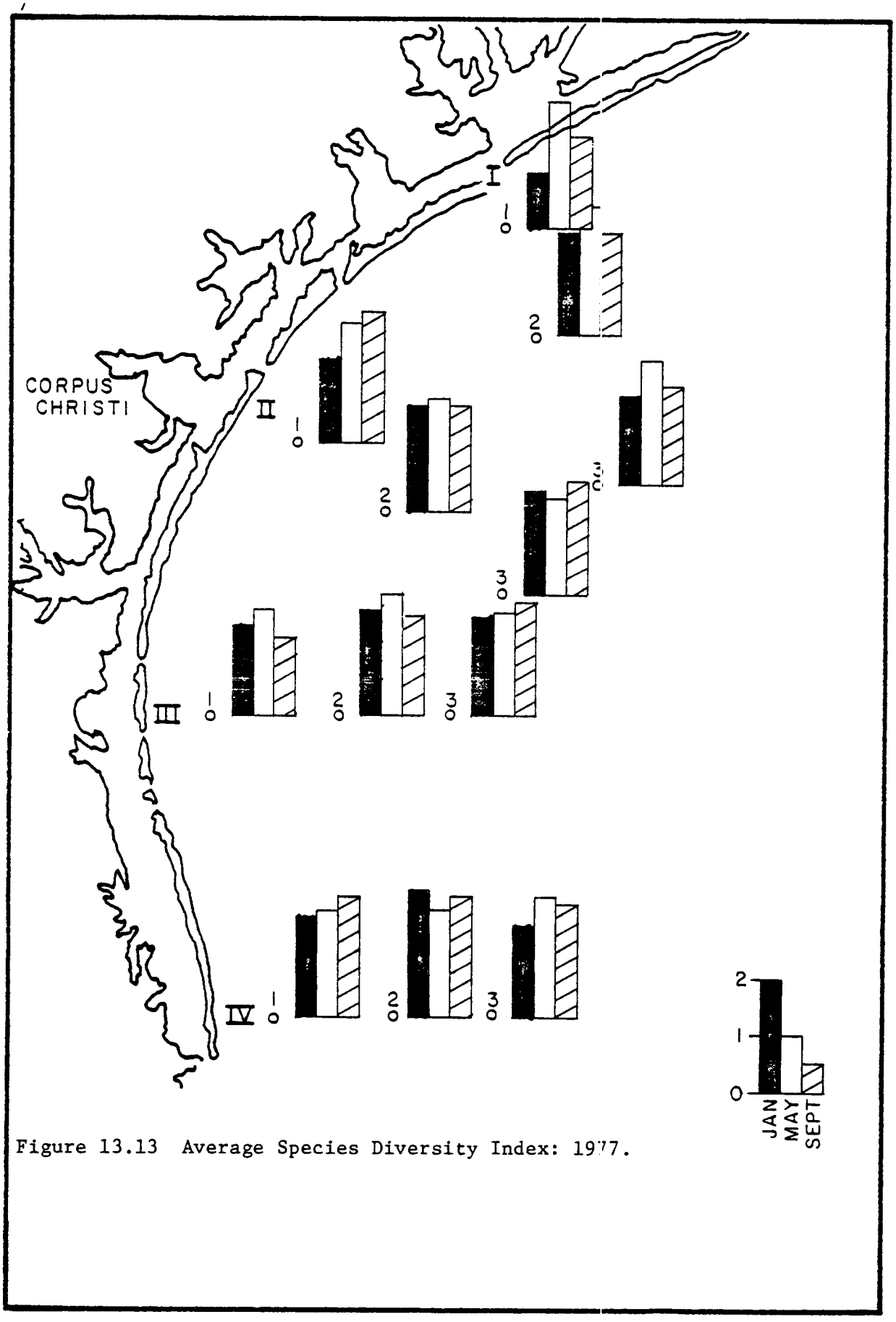

Figure 13.13 Average Species Diversity Index: 1977.

on the same cruises during which ciliated protozoan samples were collected. These correlation coefficients are listed in Table 13.4. None of the correlation coefficients were particularly high. One of the stronger relationships was with nannoplankton, which would be expected since nannoplankton is a natural food source of protozoa. This direct correlation between protozoa and nannoplankton was also evident in data from Nova Scotia (Johansen, 1976).

It seemed reasonable to assume that since protozoa were more abundant during the cooler months of the year, temperature, in some way, must have affected their distribution. However, no correlation was evident. Off the Nova Scotia coast, for example, the annual summer bloom of tintinnids did not occur unless there was a sudden drop (6°C) in water temperature in mid-summer (Johansen, 1976). Yet, on a yearly basis, there was no significant correlation with temperature. The same situation occurred in trying to correlate salinity with protozoan abundance (Table 13.4). The correlation was negative, but not significantly so. Samples collected on a daily basis from the Port Aransas shipping channel during January-March 1977, however showed a very clear, inverse correlation between salinity and protozoan abundance (Figure 13.14). It was difficult to sort out such relationships with so few samples from the STOCS.

In order to understand the protozoa better, it may be necessary to: a) collect and analyze more samples during a shorter period of time; b) correlate the abundance of individual species with the various parameters; or c) study the effects of such parameters under laboratory conditions as has been done by others (Gold, 1973b; Gold and Morales, 1974). The use of non-parametric statistics may also be useful.

A lack of correlation with dissolved oxygen was not surprising.

TABLE 13.4

CORRELATION COEFFICIENTS OF PROTOZOAN ABUNDANCE AGAINST VARIOUS PHYSICAL AND CHEMICAL PARAMETERS

Parameter	Correlation Coefficient
Temperature	0.039
Salinity	-0.030
Dissolved Oxygen	0.062
Nitrate	0.144
Phosphate	0.235
Silicate	0.572
Net-Phytoplankton Chlorophyll *a*	0.095
Nanno-Phytoplankton Chlorophyll *a*	0.555

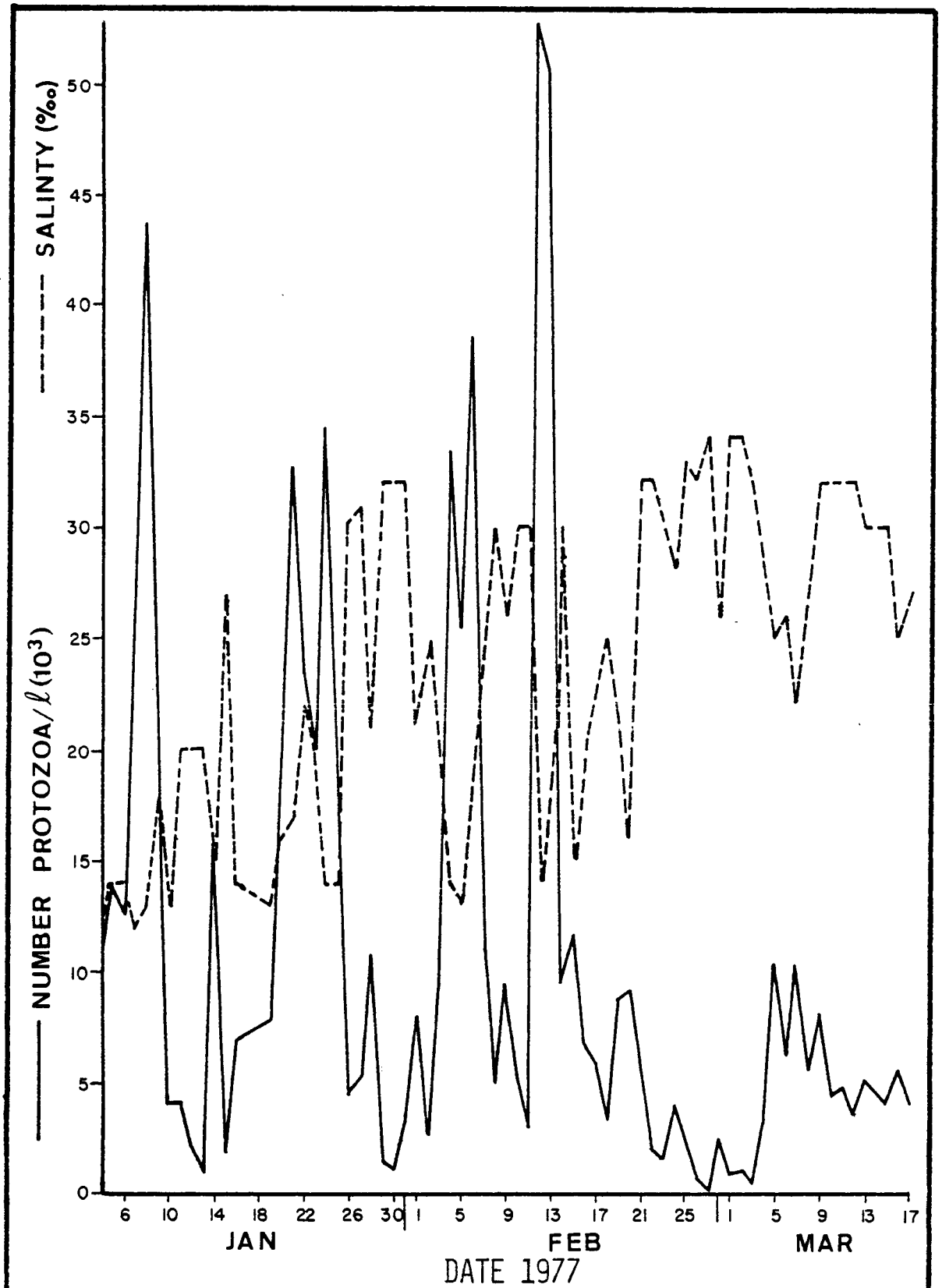

Figure 13.14 Abundance of Protozoa as Related to Surface Salinity in the Port Aransas Shipping Channel.

Although protozoa generally exhibit high rates of oxygen utilization (Johansen, unpublished data), it was not likely that oxygen levels in the water column of the STOCS were ever limiting.

The meaning of the correlations with nutrients was unclear. High dissolved silicate values indicated a lack of diatoms in the water. Johansen (1976) has noted that tintinnids, at least, were not present during diatom blooms off Nova Scotia. Correlations with nitrate and phosphate were not significant.

There is increasing evidence (Hirota and Szyper, 1976; Beers *et al.*, 1977) that stressed ecosystems tend to go from a macrozooplankton - net-phytoplankton community to a microzooplankton - nannoflagellate community. If this is the case, a frequent and long-lasting monitoring of the changes in abundance and composition of the planktonic community (phytoplankton, microzooplankton, macrozooplankton) may most quickly reveal detrimental short-term and long-term effects on the health of the entire STOCS ecosystem.

CONCLUSIONS

1. Protozoa on the STOCS reached a maximum in abundance in early spring (March-April).

2. A second protozoan abundance peak was noted in September 1977 but this peak was thought to be abnormal and a result of Hurricane Anita which passed through the area at that time.

3. Oligotrichs were the dominant protozoan group on the STOCS, both spatially and temporally. The other protozoan groups tended to be more restricted both in space and time.

4. Protozoan biomass ranged from 1 to 348% of the macrozooplankton biomass, indicating that protozoa are a significant component of the zooplankton community.

5. Species diversity was high during most of the year and varied erratically.

6. The abundance of protozoa was positively correlated with nannoplankton chlorophyll _a_ and with silicate. Correlation with salinity was negative, but not significant. Correlations with temperature, dissolved oxygen, net-phytoplankton chlorophyll _a_, nitrate and phosphate were not significant. Although some data exist that indicate a significant correlation between protozoan abundance and temperature, salinity and net-phytoplankton, the relatively low sampling frequency in this study may have masked such relationships.

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CHAPTER FOURTEEN

ZOOPLANKTON PROJECT

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ABSTRACT

This report details the significant findings of the third year (1977) of zooplankton studies on the South Texas Outer Continental Shelf. When grouped by depth related stations, transects and seasons, the data show many of the trends observed in past years.

Biomass and zooplankton numbers increased shoreward during all seasons. Averaged for the entire year, Transect I produced the highest biomass and Transect II the highest numerical abundances; Transects III and IV generally produced lower abundances of zooplankton than Transects I and II.

The best represented major taxa were Copepoda, Ostracoda, Amphipoda, Cnidaria, Mollusca, Chaetognatha, Larvacea and Cladocera. Ostracods rivaled the copepods in abundance, especially during the winter and spring. Cladocera and Mollusca were most abundant in the spring at nearshore stations. Amphipoda, Cnidaria, Chaetognatha and Larvacea occurred in moderate numbers throughout the area and their numbers were generally greatest in the spring.

Copepod numbers increased shoreward from winter to spring; however, their abundances relative to the total zooplankton decreased from winter to spring indicating that other forms increased faster. About 75% of the copepods were calanoids and 25% cyclopoids. Calanoid relative abundances increased shoreward throughout the year. Female copepods maintained average relative abundance of about 50% throughout the year. In winter, developmental stages in the copepods were 40-60% of the copepod population, but decreased to less than 25% in the spring. A total of 150 species of adult female copepods were identified in 1977: 97 calanoids, 49 cyclopoids, and 4 harpacticoids. The most abundant species were *Paracalanus quasimodo, Clausocalanus furcatus* and *Clausocalanus jobei,* (Calanoida), and *Corycaeus americanus, Oncaea mediterranea* and *Oithona plumifera* (Cyclopoida).

Species diversities, coefficients of equitability (E) and numbers of adult female copepod species increased seaward. In general, equitabilities were quite variable and considerably lower than the theoretical maximum of 1.0.

Changes in temperature, salinity and chlorophyll a values showed some correlation with changes in zooplankton abundances. The maximum abundances of zooplankton occurred at nearshore stations in the spring when temperatures were in the upper half of their annual range and salinities were at their yearly low. In general, zooplankton abundances were highest at stations where chlorophyll a values were highest during each season.

Data for the three years of this study were compared to those from samples collected for three years between 1963 and 1965. Numerical abundances and relative abundances of component taxa, followed similar patterns of spatial and temporal distribution in both studies. However, at the species level, the small, estuarine copepods *Paracalanus crassirostris, Acartia tonsa* and *Oithona nana* were more abundant in the historical samples than in the recent samples.

INTRODUCTION

The zooplankton project was initiated in October 1974 to provide basic data which, in conjunction with concurrent studies of other biological and physical parameters, would characterize the pelagic marine environment of the South Texas Outer Continental Shelf (STOCS). Many of the basic features of the zooplankton community were revealed after the first year of study. However, to better define the complex nature of zooplankton distribution, the study area was subjected to a second (1976) and then a third (1977) year of intensive investigation. In all three years, data were gathered from 12 sites (Stations 1-3, all transects) on a seasonal basis (winter, spring and summer). Following the analysis of data collected in 1975 some changes in the data gathering regime were deemed appropriate.

Initially, two replicate samples were taken during both day and night at each station. Since the entire water column was sampled by oblique tow, little difference was noted between the data from day and night samples. Consequently, a diel-flexible program was adopted in which only one series of replicate samples were taken per station per cruise. The data further revealed considerable variation in results between replicate tows; therefore, in 1976, three replicate samples were collected during each station occupation and the two with the most similar volumes of water filtered were analyzed. This produced better agreement of the data between replicates. In 1976 the sampling frequency on Transect II was increased by two monthly cruises between each seasonal cruise for a better look at short-interval changes in the zooplankton community. Further refinements required by contract in 1976 included the discontinuance of the wet volume biomass measurements, the addition of Foraminifera and Radiolaria counts and the separation of the phylum Mollusca into component lower taxa. Data collec-

tion for the Foraminifera and Radiolaria was discontinued when it was found that the mesh size (233 μm) of the sampling gear was too large to adequately sample them.

This report concerns results of the third consecutive year (1977) of the zooplankton studies. The sampling regime and analytical requirements, evolved by 1976, were continued without modification in 1977. In addition to the normal sampling design, a sample was also collected at each station for taxonomic enumeration in conjunction with the trace metals and hydrocarbon sampling programs for zooplankton body burdens.

METHODS

Sampling

The study was based on zooplankton samples collected from 12 stations, three on each of four transects. All 12 stations were sampled during the three seasonal sampling periods. In addition to the seasonal sampling, the three Transect II stations were sampled during the six monthly sampling periods. During each sampling, each station was occupied once and three replicate samples were taken.

Standard 1-m NITEX nets of 233 μm mesh size were used. A digital flowmeter (Model 2030, GENERAL OCEANICS) was mounted centrally in the mouth of the net to determine the amount of water filtered in each tow, and a time-depth recorder (Model 1170-250, BENTHOS) was attached near the net to determine the maximum sampling depth. The water column was sampled from the surface to near-bottom by means of oblique tows of about 15-minutes duration. During the tow, ship speed was maintained constant at about 2.5 knots. The volume of water filtered was calculated from flowmeter and tow duration data. After the tow, the net was rinsed down using the deck hose. The contents of the cod-end were drained through a 100 μm NITEX

net, transferred to a jar, and preserved with buffered formalin.

Sample Analysis

Two comparable samples were selected for analysis from the three replicate samples taken at each station according to the similarity in the amount of water filtered and in the settling volume of organisms. The samples were split with a FOLSOM plankton splitter to achieve adequate subsamples for archiving and analysis. The subsample size for biomass determination was adjusted to the capacity of the crucible to be used (50 ml).

For dry weight determination, subsamples were washed with tap water through tared PYREX 50-ml filtering crucibles with fritted discs of 40 to 60 μm pore size. Suction filtration at 10-15 psi was used to expedite removal of interstitial water. The subsamples were dried in the crucibles at 55°C to a constant weight, and the weight of the crucible plus sample was recorded to the nearest milligram. Ashing to a constant weight was accomplished in a muffle furnace (BLUE "M", Model M25A-1A) at 550°C, and the weight of crucible plus ash was recorded to the nearest milligram. The weight of the empty crucible was subtracted, yielding the subsample dry weight and ash weight from which the ash-free dry weight was calculated.

Each subsample was sorted into major taxa in a BOGOROV plankton sorting tray, and all the individuals were counted. The copepods, which were usually the numerically dominant form, were most intensively studied. They were first separated into three sub-orders (Calanoida, Cyclopoida, and Harpacticoida), and then each sub-order was separated into adult females, males and immature copepodid forms for enumeration. All adult female copepods were identified to species and enumerated.

The species diversity index was calculated for each sample on the

basis of adult female copepods and according to the Shannon-Weaver function. The coefficient of equitability (E) was calculated for each sample using the formula:

$$E = \frac{H\ (S)}{H_{max}\ (S)}$$

where E = coefficient of equitability, H(S) = observed species diversity, and $H_{max}(S) = \log_2 S$ (maximum species diversity for a given S).

RESULTS AND DISCUSSION

Field data for each sample analyzed, including date and time of collection and volume of water filtered are recorded in Table 1, Appendix M. Zooplankton biomass in terms of dry weight (mg/m^3) and ash-free dry weight (mg/m^3) along with subsample size used to measure these values are also included in Table 1, Appendix M. Since replicate samples yielded similar biomass measurements in most cases, these results were averaged to simplify interpretation and presentation. Subsamples, analyzed for taxonomic composition and numerical abundances, ranged in size from 1/1024 to 1/64 and yielded from 1226 to 5832 zooplankters per subsample (Table 2, Appendix M). The numbers of organisms per subsample were converted to numbers of individuals per volume of water filtered and are considered later in greater detail.

Biomass

Biomass data, considered as the mean dry weight of two replicate samples from each station (Stations 1-3, all transects), ranged from 73.5 mg/m^3 at Station 1/I in the spring, to 1.9 mg/m^3 at Station 2/IV in the summer of 1977 (Table 14.1, Figure 14.1). Monthly data (Stations 1-3, Transect II) ranged from 53.8 mg/m^3 dry weight at Station 2/II in May-June to 2.6 mg/m^3 at Station 3/II in November (Table 14.2, Figure 14.2). The

TABLE 14.1

BIOMASS (DRY WEIGHT, mg/m^3) AT EACH STATION
MEAN OF FOUR SAMPLES FOR 1975 AND TWO SAMPLES FOR 1976 AND 1977

Year	Transect	Winter				Spring				Summer			
		Station 1	2	3	Mean	Station 1	2	3	Mean	Station 1	2	3	Mean
1975	I	15.0	16.2	4.5	11.9	89.4	27.3	9.1	41.9	72.8	12.4	7.7	31.0
	II	29.9	15.4	15.8	20.4	37.6	35.1	7.0	26.6	49.1	10.8	6.9	22.3
	III	23.7	17.3	17.5	19.5	28.9	9.9	7.7	15.5	32.2	15.4	12.0	19.9
	IV	20.4	16.7	15.7	17.6	47.5	28.1	8.8	28.1	22.3	38.2	11.1	23.9
	Mean	22.3	16.4	13.4		50.9	25.1	8.2		44.1	19.2	9.4	
1976	I	9.7	26.7	11.5	16.0	51.3	60.5	8.1	40.0	28.5	26.4	4.4	19.8
	II	15.1	31.0	15.4	20.5	38.0	69.0	8.6	38.5	20.1	8.2	14.6	14.3
	III	16.0	13.6	19.5	16.4	71.3	70.6	22.0	54.6	69.1	13.3	21.6	34.9
	IV	26.0	14.0	10.7	16.9	27.0	19.3	7.7	18.0	20.5	16.3	5.3	14.0
	Mean	16.7	21.3	14.3		46.9	54.9	11.6		34.7	16.1	11.5	
1977	I	21.8	24.8	23.0	23.2	73.5	67.0	5.9	48.8	61.6	16.1	4.6	27.4
	II	14.1	22.3	47.9	28.1	51.9	53.8	14.5	40.1	13.2	11.2	7.5	10.6
	III	21.6	17.0	21.0	19.9	33.6	28.5	15.9	26.0	3.3	10.0	7.1	6.8
	IV	13.7	15.7	9.8	13.1	41.2	35.7	14.4	30.4	16.6	1.9	5.3	7.9
	Mean	17.8	20.0	25.4		50.1	46.3	12.7		23.7	9.8	6.1	

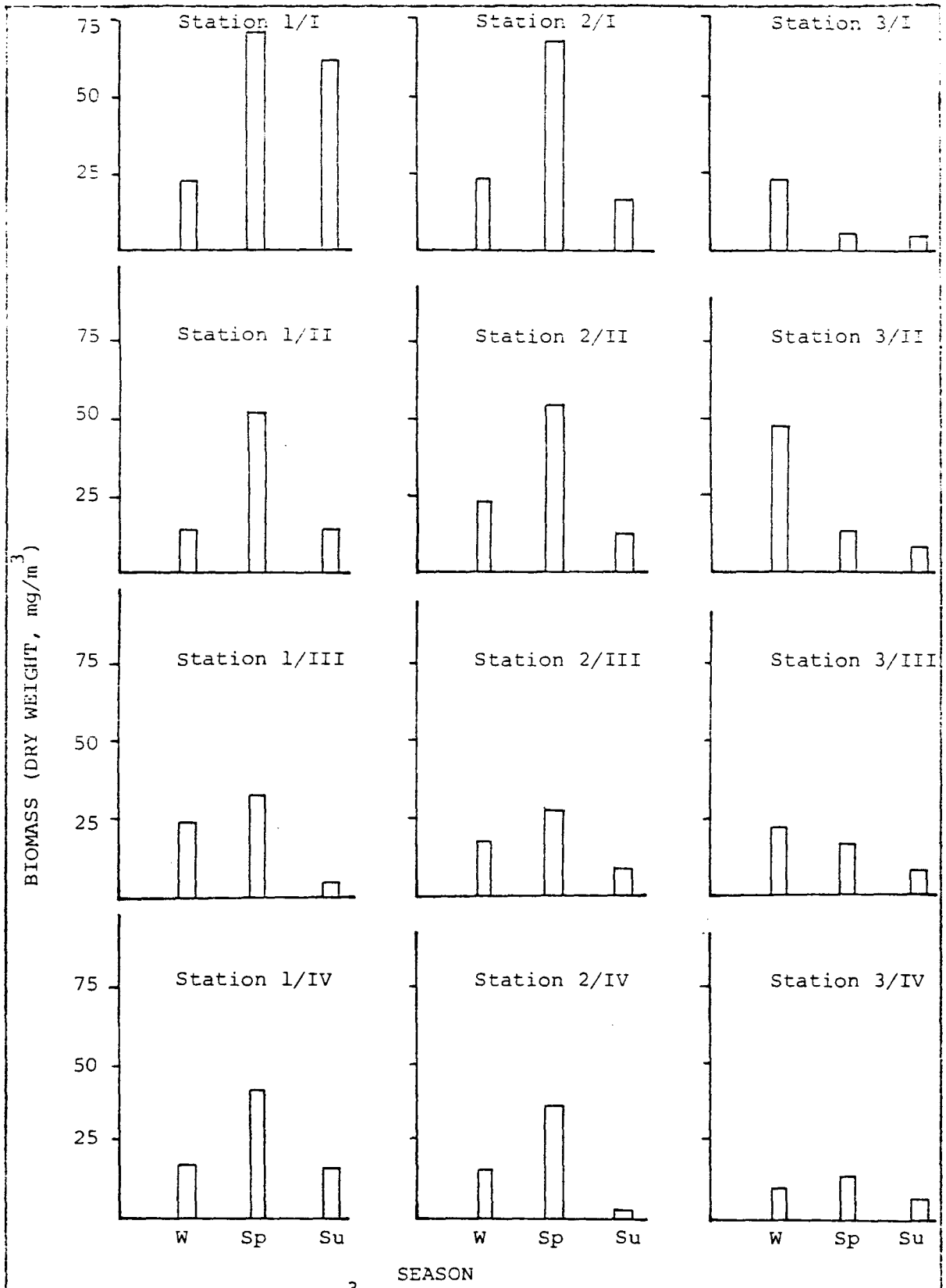

Figure 14.1. Biomass (mg/m^3) in terms of the mean dry weight of two replicate samples, collected seasonally from Stations 1-3, all transects.

TABLE 14.2

BIOMASS (DRY WEIGHT, mg/m^3) ON TRANSECT II IN 1976 AND 1977. MEAN OF TWO SAMPLES AT EACH STATION

Year	1976				1977			
Month / Station	1	2	3	Mean	1	2	3	Mean
January/February	15.1	31.0	15.4	20.5	14.1	22.3	47.9	28.1
March	21.1	16.1	17.2	18.1	24.7	37.4	28.9	30.3
April	28.6	14.9	12.2	18.6	33.0	22.0	8.2	21.1
May/June	38.0	69.0	8.6	38.5	51.9	53.8	14.5	40.1
July	21.3	15.9	4.7	14.0	15.4	9.4	11.2	12.0
August	28.3	11.8	13.3	17.8	11.6	7.8	5.4	8.3
September	20.1	8.2	14.6	14.3	13.2	11.2	7.5	10.6
November	36.2	18.1	11.4	21.9	41.2	16.5	2.6	20.1
December	17.6	15.0	11.4	14.7	17.6	16.8	13.5	16.0
Mean	25.1	22.2	12.1	19.8	24.7	21.9	15.5	20.7

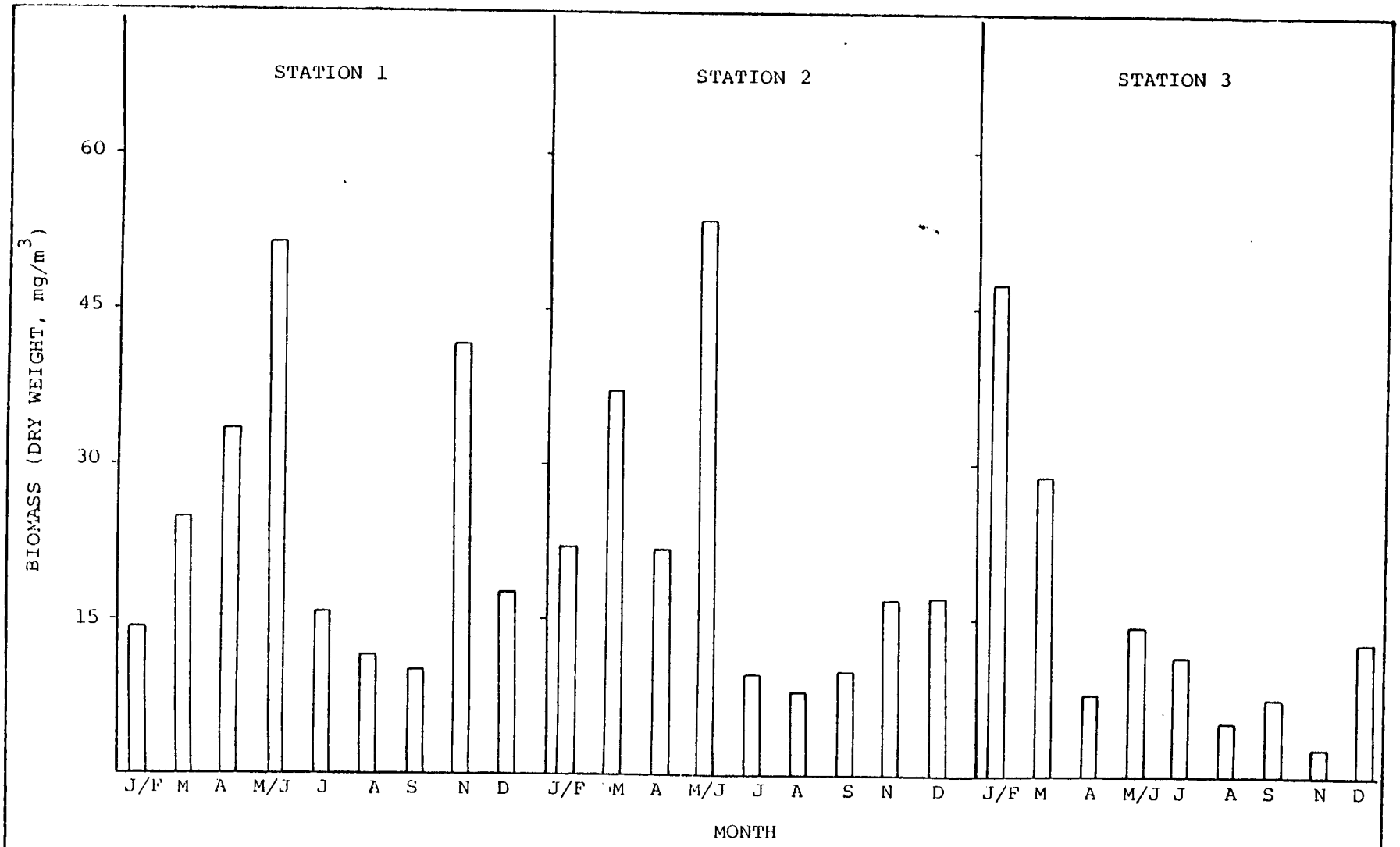

Figure 14.2. Biomass (mg/m^3) in terms of the mean dry weight of two replicate samples, collected at approximately monthly intervals in 1977, from Stations 1-3, on Transect II.

1977 annual mean for seasonal data was 23.9 mg/m^3, and the annual mean for data collected monthly was 20.7 mg/m^3. The highest biomass weight and the annual mean weight recorded in 1977 were very similar to those reported in the previous two years of this study.

Certain patterns of spatial and temporal biomass distribution reported in 1975 and 1976 were also recognized in the 1977 data. To put the relationship between biomass and station depth (or distance from shore) into perspective, the seasonal data from all four transects were averaged station by station (Table 14.3). This condensation of data showed that in 1977 the most productive station was Station 1 with an annual mean of 30.5 mg/m^3 dry weight and the least productive was Station 3 with 14.7 mg/m^3. On a seasonal basis, the highest biomass value was 50.1 mg/m^3 at Station 1 in the spring, and the lowest was 6.1 mg/m^3 at Station 3 in the summer. Seasonal changes in biomass distribution were pronounced at all three stations in 1977. Stations 1 and 2 (the nearshore and intermediate stations) produced springtime values of 50.1 and 46.3 mg/m^3, respectively, which were more than double those of winter. Conversely, at Station 3, the biomass decreased by half from winter (25.4 mg/m^3) to spring (12.7 mg/m^3). This springtime decrease in biomass at Station 3 was also observed in 1975 and 1976, but during those years the winter values were much smaller (14.3 mg/m^3, 1976, and 13.4 mg/m^3, 1975) and the springtime decreases lower in amplitude. Spatial variations in biomass abundance were characterized by a shoreward increase in dry weight in the spring and summer in 1977. In the spring biomass values increased aburptly from 12.7 mg/m^3 at Station 3 to 46.3 mg/m^3 at Station 2, and 50.1 mg/m^3 at Station 1. Shoreward increases were also well defined in the summer when the greatest increase took place between Station 2 (9.8 mg/m^3) and Station 1 (23.7 mg/m^3). Spatial relationships in the winter, however, show that biomass values

TABLE 14.3

AVERAGE SEASONAL BIOMASS (DRY WEIGHT, mg/m^3) FOR EACH STATION
MEAN OF FOUR TRANSECTS FOR EACH STATION

Year	Station	Winter	Spring	Summer	Mean
1975	1	22.3	50.9	44.1	39.1
	2	16.4	25.1	19.2	20.2
	3	13.4	8.2	9.4	10.3
Mean		17.4	28.1	24.2	
1976	1	16.7	46.9	34.7	32.8
	2	21.3	54.9	16.1	30.8
	3	14.3	11.6	11.5	12.5
Mean		17.4	37.8	20.8	
1977	1	17.8	50.1	23.7	30.5
	2	20.0	46.3	9.8	25.4
	3	25.4	12.7	6.1	14.7
Mean		21.1	36.4	13.2	
Three-Year Mean	1	18.9	49.3	34.2	34.1
	2	19.2	42.1	15.0	25.4
	3	17.7	10.8	9.0	12.5
Mean		18.6	34.1	19.4	

increased seaward. When winter biomass values for 1975 and 1976 were compared to those for 1977, it was found that they were fairly similar from year to year at Stations 1 and 2, but the biomass value at Station 3 (25.4 mg/m^3) in 1977 was about twice as large as those of earlier years (Table 14.3). Whereas the biomass data, compared by stations, showed well defined patterns of temporal and spatial distribution, biomass values compared by transects were poorly patterned.

When all three stations were averaged for each transect by season for 1977 (Table 14.4), biomass values ranged from 48.8 mg/m^3 on Transect I in the spring, to 6.8 mg/m^3 on Transect III in the summer. The annual mean for each transect suggests the presence of a southerly directed gradient of declining biomass production. In other words, the highest annual mean (33.1 mg/m^3) was found on Transect I, the second highest (26.3 mg/m^3) on Transect II, and third (17.6 mg/m^3) on Transect III, and the lowest (17.1 mg/m^3) on Transect IV. This gradient also appeared in 1975 and 1976, but it was interrupted by occasional values on Transect III or IV which were higher than those on Transects I or II. However, when the annual means for all three years were averaged by transect, Transect I (with 28.9 mg/m^3) was clearly the most productive and Transect IV (with 18.9 mg/m^3) the least.

Numerical Abundance of Zooplankton

Zooplankton numbers, considered as the mean of two replicate samples from each station ranged from 11,030.4 per m^3 at Station 1/II in spring, to 433.9 per m^3 at Station 2/IV in the summer of 1977 (Table 14.5, Figure 14.3). Monthly data (Transect II) ranged from 11,030.4 per m^3 at Station 1/II in May-June (spring), to 490.7 per m^3 at Station 3/II in April (Table 14.6, Figure 14.4). The 1977 annual mean number for data collected seasonally was 2636.5 per m^3, and the annual mean for data collected monthly was

TABLE 14.4

AVERAGE SEASONAL BIOMASS (DRY WEIGHT, mg/m^3) FOR EACH TRANSECT
MEAN OF THREE STATIONS FOR EACH TRANSECT

Year	Transect	Winter	Spring	Summer	Mean
1975	I	11.9	41.9	31.0	28.3
	II	20.4	26.6	22.3	23.1
	III	19.5	15.5	19.9	18.3
	IV	17.6	28.1	23.9	23.2
Mean		17.4	28.0	24.3	
1976	I	16.0	40.0	19.8	25.2
	II	20.5	38.5	14.3	24.4
	III	16.4	54.6	34.9	35.3
	IV	16.9	18.0	14.0	16.3
Mean		17.5	37.8	20.8	
1977	I	23.2	48.8	27.4	33.1
	II	28.1	40.1	10.6	26.3
	III	19.9	26.0	6.8	17.6
	IV	13.1	30.4	7.9	17.1
Mean		21.1	36.3	13.2	
Three-Year Mean	I	17.0	43.6	26.1	28.9
	II	23.0	35.1	15.7	24.6
	III	18.6	32.0	20.5	23.7
	IV	15.8	25.5	15.3	18.9
Mean		18.6	34.0	19.4	

TABLE 14.5

NUMERICAL ABUNDANCE OF ZOOPLANKTON PER m^3 AT EACH STATION
MEAN OF FOUR SAMPLES FOR 1975 AND TWO SAMPLES FOR 1976 AND 1977

Year	Transect	Winter				Spring				Summer			
		Station			Mean	Station			Mean	Station			Mean
		1	2	3		1	2	3		1	2	3	
1975	I	1061.3	1255.5	317.0	877.9	8380.8	1087.5	494.5	3320.9	2701.5	1261.3	807.3	1590.0
	II	2848.0	1490.0	1054.5	1797.5	3516.5	2809.5	451.8	2259.3	3006.0	453.0	651.3	1370.1
	III	2196.8	1471.0	920.0	1529.3	2292.3	676.8	539.5	1169.5	1654.3	1740.0	1221.0	1538.4
	IV	2355.3	1268.0	1023.3	1548.9	1538.0	1617.5	880.8	1345.4	1536.3	3572.0	754.3	1954.2
	Mean	2115.3	1371.1	828.7		3931.9	1547.8	591.6		2224.5	1756.6	858.5	
1976	I	743.9	1370.7	948.1	1020.9	2001.4	5090.6	589.9	2560.6	907.8	1881.4	844.8	1211.3
	II	1948.3	1411.8	918.4	1426.2	1866.9	3705.3	475.6	2015.9	3756.8	324.9	954.7	1678.8
	III	1474.5	660.0	849.3	994.6	2397.1	2247.2	1316.9	1987.1	7872.1	1600.5	2055.6	3842.7
	IV	3915.1	1602.9	586.3	2034.8	2149.4	941.2	519.6	1203.6	1565.0	660.3	640.8	955.4
	Mean	2020.4	1261.3	825.5		2103.7	2996.2	725.5		3525.4	1116.8	1124.0	
1977	I	1784.4	1778.7	1244.9	1602.7	3791.2	6837.1	607.8	3745.4	7433.9	1718.7	1294.9	3482.5
	II	1564.4	1851.6	3953.6	2456.5	11030.4	6468.2	913.2	6137.3	1840.1	2496.9	1571.9	1969.6
	III	2831.2	977.2	1450.4	1752.9	6861.4	3392.5	992.6	3748.8	439.1	855.3	858.3	717.6
	IV	2210.3	1973.4	695.5	1626.4	6045.3	3498.7	1265.6	3603.2	1320.1	433.9	630.7	794.9
	Mean	2097.6	1645.2	1836.1		6932.1	5049.1	944.8		2758.3	1376.2	1089.0	

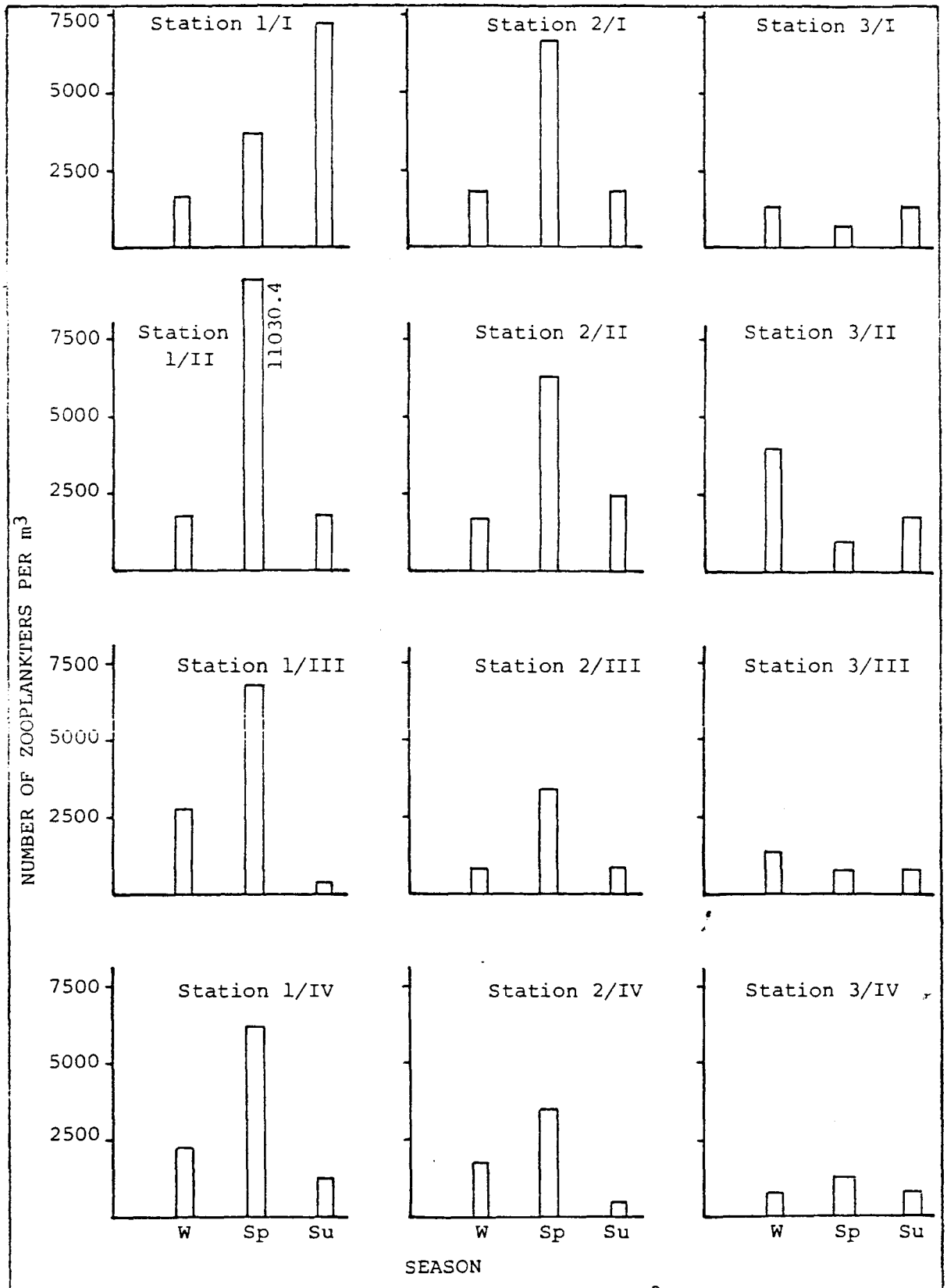

Figure 14.3 The mean number of zooplankters per m^3 from two replicate samples collected seasonally in 1977, from Stations 1-3, all transects.

TABLE 14.6

NUMERICAL ABUNDANCE OF ZOOPLANKTON PER m^3
ON TRANSECT II IN 1976 AND 1977
MEAN OF TWO SAMPLES AT EACH STATION

Year	1976				1977			
Month / Station	1	2	3	Mean	1	2	3	Mean
January/February	1948.3	1411.8	918.4	1426.2	1564.4	1851.6	3953.6	2456.5
March	3784.8	997.8	956.1	1912.9	1398.4	2378.5	1018.8	1598.6
April	5123.1	1145.2	736.0	2334.8	5126.2	2035.5	490.7	2550.8
May/June	1866.9	3705.3	475.6	2015.9	11030.4	6468.2	913.2	6137.3
July	2401.8	1779.2	412.0	1531.0	1457.9	721.1	780.9	986.6
August	12141.5	666.0	768.8	4525.4	1135.6	1115.6	856.7	1036.0
September	3756.8	324.9	954.7	1678.8	1840.1	2496.9	1571.9	1969.6
November	2062.6	1270.1	1230.8	1521.2	2323.1	1724.1	524.5	1523.9
December	4008.1	2818.6	1140.6	2655.8	1817.5	1453.1	760.7	1343.8
Mean	4121.5	1568.7	843.7		3077.1	2249.4	1207.9	

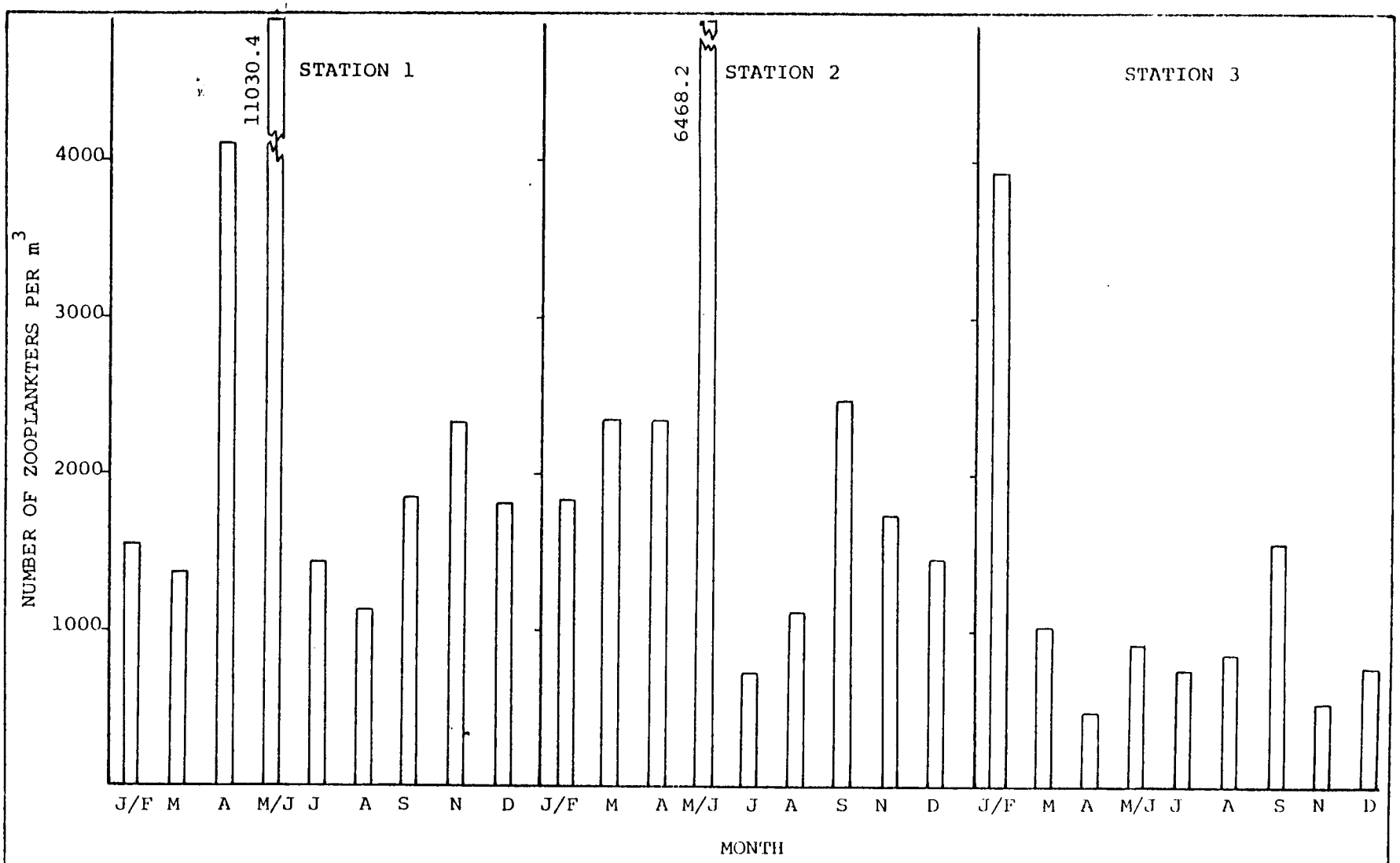

Figure 14.4 The mean number of zooplankters per m^3 from two replicate samples, collected at about monthly intervals in 1977, from Stations 1-3, on Transect II.

2178.1 per m^3. The highest number (11,030.4 per m^3) of zooplankters found from seasonal data in 1977 was considerably larger than extreme numbers collected seasonally in 1976 (7872.1 per m^3, Station 1/III, summer) or in 1975 (8380.8 per m^3, Station 1/I, spring). It is however, similar to the largest number (12,141.5 per m^3, Station 1/II, August) reported in 1976 monthly samples. It should be noted that these extremely high numbers occurred at the same station, two months apart, in consecutive years (May-June, 1977 and August, 1976), and that in both instances, the cladoceran genus *Penilia* was very abundant. The annual mean number (2636.5 per m^3) of zooplankters collected seasonally in 1977 was about one-third again as large as the numbers reported in 1975 (1691.8 per m^3) and 1976 (1744.3 per m^3), but the annual means (2178.0 per m^3, 1976 and 2178.1 per m^3, 1977) for both years of monthly data were almost exactly the same.

When averaged by station (mean of four transects) for each season (Table 14.7), zooplankton numbers showed patterns of spatial and temporal distribution similar to those found in the biomass. Station 1 was the most productive with an annual mean number of 3929.3 zooplankters per m^3 and Station 3 was the least productive with 1290.0 per m^3. On a seasonal basis, zooplankton numbers ranged from 6932.1 per m^3 at Station 1 in the spring to 944.8 per m^3 at Station 3 in spring. Seasonal fluctuations in zooplankton numbers were well defined at all three stations in 1977. Stations 1 and 2 produced springtime numbers of 6932.1 and 5049.1 per m^3 respectively, which were more than double those of winter. The numbers at Station 3, however, reduced by half (from 1836.1 to 944.8 per m^3) between winter and spring. These seasonal changes in zooplankton numbers agree in direction of change and amplitude with the changes observed in the biomass. Spatially, zooplankton numbers increased shoreward in all three seasons. The most abrupt changes took place in the spring when the number

TABLE 14.7

AVERAGE SEASONAL NUMERICAL ABUNDANCE OF ZOOPLANKTON PER m^3
FOR EACH STATION
MEAN OF FOUR TRANSECTS FOR EACH STATION

Year	Station	Winter	Spring	Summer	Mean
1975	1	2115.3	3931.9	2224.5	2757.2
	2	1371.1	1547.8	1756.6	1558.5
	3	828.7	591.6	858.5	759.6
Mean		1438.4	2023.8	1613.2	
1976	1	2020.4	2103.7	3525.4	2549.8
	2	1261.3	2996.2	1116.8	1791.4
	3	825.5	725.5	1124.0	891.7
Mean		1369.1	1941.8	1922.1	
1977	1	2097.6	6932.1	2758.3	3929.3
	2	1645.2	5049.1	1376.2	2690.2
	3	1836.1	944.8	1089.0	1290.0
Mean		1859.6	4308.7	1741.2	
Three-Year Mean	1	2077.8	4322.6	2836.1	3078.8
	2	1425.9	3197.7	1416.5	2013.4
	3	1163.4	754.0	1023.8	980.4
Mean		1555.7	2758.1	1758.8	

(5049.1 per m^3) at Station 2 was five times as large as that at Station 3 (944.8 per m^3). Although shoreward increases in biomass were evident in 1975 and 1976, the difference in numbers between successive stations was never more than three-fold. In contrast to the variations in zooplankton numbers when compared by station and season, the differences in numbers between transects were small.

Viewed as the average of three stations for each transect and season (Table 14.8), zooplankton numbers ranged from 6137.3 per m^3 in spring on Transect II, to 717.6 per m^3 in summer on Transect III. In 1977, all four transects showed two to three-fold increases from winter to spring and decreases of varying magnitude from spring to summer. Transect II was much more productive in the winter (2456.5 per m^3) and spring (6137.3 per m^3) than the other three transects (1600-1750 per m^3, winter and 3600-3750 per m^3, spring). In the summer, Transects I and II , with 3482.5 and 1969.6 zooplankters per m^3, respectively, were well separated in terms of abundance from Transects III and IV, with 717.6 and 794.9 per m^3, respectively. The three year means for all the transects (Table 14.8) showed that zooplankton numbers were slightly lower on Transects III and IV (1920.1 and 1674.1 per m^3, respectively) than on Transects I and II (2156.9 and 2345.7 per m^3, respectively).

The copepoda as a group accounted for a significant portion of the zooplankton throughout 1977. They were not, however, as abundant in proportion to the total zooplankton as they were in 1975 and 1976 (Table 14.9). In 1975, the Copepoda accounted for over 70% of the zooplankton numbers in half the samples taken, and in only 3 of the 36 seasonal samples did they account for less than 50%. Percentages were somewhat lower in 1976, but still the Copepoda accounted for more than 60% of the zooplankton in 21 of the 36 seasonal samples with only seven samples composed of less than 50%

TABLE 14.8

AVERAGE SEASONAL NUMERICAL ABUNDANCE OF ZOOPLANKTON PER m^3
FOR EACH TRANSECT
MEAN OF THREE STATIONS FOR EACH TRANSECT

Year	Transect	Winter	Spring	Summer	Mean
1975	I	877.9	3320.9	1590.0	1929.6
	II	1797.5	2259.3	1370.0	1808.9
	III	1529.3	1169.5	1538.4	1412.4
	IV	1548.9	1345.4	1954.2	1616.2
Mean		1438.4	2023.8	1613.1	
1976	I	1020.9	2560.6	1211.3	1597.6
	II	1426.2	2015.9	1678.8	1707.0
	III	994.6	1987.1	3842.7	2274.8
	IV	2034.8	1203.6	955.4	1397.9
Mean		1369.1	1941.8	1922.0	
1977	I	1602.7	3745.4	3482.5	2943.5
	II	2456.5	6137.3	1969.6	3521.1
	III	1752.9	3748.8	717.6	2073.1
	IV	1626.4	3603.2	794.9	2008.2
Mean		1859.6	4308.7	1741.2	
Three-Year Mean	I	1167.2	3209.0	2094.6	2156.9
	II	1893.4	3470.8	1672.8	2345.7
	III	1425.6	2301.8	2032.9	1920.1
	IV	1736.7	2050.7	1234.8	1674.1
Mean		1555.7	2758.1	1758.8	

TABLE 14.9

PERCENTAGE COMPOSITION OF COPEPODS IN TOTAL ZOOPLANKTON AT EACH STATION
MEAN OF FOUR SAMPLES FOR 1975 AND TWO SAMPLES FOR 1976 AND 1977

Year	Transect	Winter				Spring				Summer			
		Station			Mean	Station			Mean	Station			Mean
		1	2	3		1	2	3		1	2	3	
1975	I	85.5	57.8	72.7	72.0	92.0	76.0	64.3	77.4	61.8	59.6	66.6	62.7
	II	85.9	74.6	70.0	76.8	61.4	34.3	82.4	59.4	71.9	66.7	79.9	72.8
	III	93.0	82.7	66.6	80.8	84.1	63.5	66.3	71.3	67.5	66.2	72.3	68.7
	IV	89.4	79.8	77.5	82.2	52.5	67.2	40.3	53.3	63.4	36.3	80.9	60.2
	Mean	88.5	73.7	71.7		72.5	60.3	63.3		66.2	57.2	74.9	
1976	I	61.9	46.6	75.6	61.4	46.1	36.2	73.9	52.1	53.6	34.7	69.1	52.5
	II	74.2	52.1	72.8	66.4	58.6	50.8	73.9	61.1	18.8	75.2	68.1	54.0
	III	58.1	76.5	85.0	73.2	31.0	56.8	68.6	52.1	52.9	66.6	63.5	61.0
	IV	77.7	47.2	63.4	62.8	68.8	73.1	68.1	70.0	75.0	69.3	75.2	73.2
	Mean	68.0	55.6	74.2		51.1	54.2	71.1		50.1	61.5	69.0	
1977	I	50.7	39.9	80.0	56.9	73.8	24.8	48.2	48.9	90.7	60.7	70.1	73.8
	II	29.3	40.9	35.5	35.2	43.1	26.9	39.6	36.5	76.5	72.1	62.9	70.5
	III	35.6	55.6	60.9	50.7	24.3	37.9	47.8	36.7	57.0	54.6	62.6	58.1
	IV	59.6	45.1	74.3	59.7	39.0	41.6	58.6	46.4	50.9	30.2	76.5	52.5
	Mean	43.8	45.4	62.7		45.1	32.8	48.6		68.8	54.4	68.0	

copepods. In 1977, copepod percentages rarely exceeded 60% (only 11 replicate sets), while values of less than 50% were found from more than half of the combined winter and spring samples. Monthly data from Transect II (Table 10) indicated that in 1977 relative abundance of copepods was usually less than 50% at all three stations from January-February through May-June and greater than 70% from July to December. In general, copepod percentages were lower in the spring than the winter or summer of all three years. This pattern indicated that taxa other than the Copepoda increased in numbers more rapidly in the spring. Taxa other than the Copepoda which were significant because of their large numbers, or consistent numerical contribution to the zooplankton community, included the Ostracoda, Amphipoda, Cnidaria, Mollusca, Chaetognatha, Cladocera and Larvacea (Table 3, Appendix M).

The ostracods, composed almost entirely of the species *Euconchoecia chierchiae* were the most or second most abundant taxon throughout the study area in the winter of 1977 and they ranked first or second in abundance in half the spring and summer samples. In 1977, the ostracods were highly concentrated about Station 2 on all four transects in the spring. In fact, the highest number (4377.0 per m^3) recorded for the year occurred at Station 2/I in the spring. In the winter, the ostracods were uniformly distributed throughout the study area with the highest number (2155.7 m^3) at Station 3/II. In the summer the ostracods appeared in much lower numbers, of which the largest was 295.8 per m^3 (Station 3/II; they were most concentrated at Station 3 on all four transects.

The Mollusca as a group ranked near the Copepoda and Ostracoda in terms of numerical abundance. The greatest concentration (2350.1 per m^3) of molluscs in 1977, occurred in the April monthly samples from Station 1/II in concert with the maximum abundance (2699.1 per m^3) observed in

TABLE 14.10

PERCENTAGE COMPOSITION OF COPEPODS IN TOTAL ZOOPLANKTON
ON TRANSECT II IN 1976 AND 1977
MEAN OF TWO SAMPLES AT EACH STATION

Year	1976				1977			
Month / Station	1	2	3	Mean	1	2	3	Mean
January/February	74.1	50.8	71.4	65.4	29.3	40.9	35.5	35.2
March	38.4	55.5	72.2	55.4	80.0	39.3	52.5	57.3
April	39.1	77.6	66.0	60.9	45.0	41.9	68.3	51.7
May/June	52.2	50.6	71.8	58.2	43.1	26.9	39.6	36.5
July	45.0	42.5	52.6	46.7	73.1	68.6	67.0	69.6
August	4.2	50.9	59.1	38.1	88.1	69.8	55.7	71.2
September	18.8	24.4	66.1	53.1	76.5	72.1	62.9	70.5
November	66.4	65.3	39.4	57.0	86.8	82.6	70.2	79.9
December	50.1	41.5	55.6	49.1	81.8	53.3	48.6	61.2
Mean	43.1	56.6	61.6		67.1	55.0	55.6	

1976. In all three years of the study, they were best represented (300-500 per m^3) in the spring at nearshore stations when large numbers of pelecypod and gastropod larvae were reported. During the winter and summer molluscan abundances (30-100 per m^3) were lower than in spring, but evenly distributed throughout the area.

The Chaetognatha, composed primarily of small neritic species, were uniformly distributed throughout the study area during each season. Their numbers increased from about 60 per m^3 in winter to about 200 per m^3 in spring. Monthly data from Transect II showed that their abundances were greatest in May-June, even at Station 3 where the abundances of zooplankton numbers and biomass were lowest.

The Amphipoda, primarily hyperiids, did not rank with the Copepoda, Ostracoda, and Mollusca as large contributors to zooplankton numbers. They did, however, occur consistently throughout the area, with centers of abundance (50-100 per m^3) formed at Station 1 or 2 in the spring.

The Cnidaria, composed mainly of hydromedusae and the zooids of siphonophores, were uniform in number throughout the area during each season. Winter and spring abundances (30-50 per m^3) were twice as large as summer values at most stations. Monthly data for cnidarian medusae on Transect II showed that, during an annual cycle, abundances were highest from January-February to July and lowest between August and December.

The Larvacea, pelagic tunicates, primarily of the genus *Oikopleura*, ranged in numbers from 261.3 per m^3 (Station 1/IV, spring) to 2.0 per m^3 (Station 1/III, spring) without forming recognizable patterns of temporal or spatial distribution. The thaliacean genus *Doliolum*, a pelagic tunicate, occurred with fair regularity throughout the year and produced an annual maxima of 96.7 per m^3 in March at Station 2/II. Closely related to *Doliolum*, the genus *Salpa* occurred sporadically and was most abundant (90.0 per m^3)

in August at Station 3/II.

The Cladocera, composed mainly of the genus *Penilia*, produced extreme abundances (2251.7 per m^3, Station 1/II and 200.9 per m^3, Station 1/III) in the 1976 summer seasonal samples. Their greatest abundance (10,331.1 per m^3) during the three year study was found in the August 1976 sample from Station 1/II. In 1977 they were most abundant (4711.0 per m^3) at Station 1/II in the May-June seasonal cruise and produced numbers over 1000 per m^3 at Stations 1/III, 2/III and 1/IV. In 1975 the largest number recorded (328.2 per m^3, Station 1/I, summer) was much lower than in following years. *Penilia* is small and soft-bodied and therefore probably does not contribute significantly to the dry-weight biomass. This would explain the apparent discrepancies in the relationship between total zooplankton numbers and biomass weights during periods when *Penilia* were very abundant (summer 1976, Stations 1/II and 1/III; spring 1977, Stations 1/II, 1/III, 2/III and 1/IV).

The decapod genus *Lucifer* occurred throughout the study area, but it was most concentrated (about 30 per m^3) at Stations 1 and 2 in the spring and summer of all three years. Barnacle larvae, consisting of naupliar and cyprid stages, occurred sporadically without forming patterns of seasonal or spatial concentrations. They did, however, consistently produce annual maxima at Station 1/I in all three years (171.7 per m^3, spring 1975, 55.9 per m^3, winter 1976, and 253.8 per m^3, winter 1977). Larval forms of crustaceans including decapod zoea, crab megalops, stomatopod larvae, mysids and some forms not assignable to specific taxa, collectively contributed minor numbers to the zooplankton, which were typically highest in May/June and September (Table 3, Appendix M).

Numerical Abundance of Copepods

Copepod numbers, considered as a total of adults and developmental

stages, ranged from 6743.3 per m^3 (Station 1/I, September) to 130.6 per m^3 (Station 2/IV, September) in 1977 (Table 14.11). Numerical maxima reported in 1976 (4156.7 per m^3, Station 1/III, September) and 1975 (7683.1 per m^3, Station 1/I, May-June) differed from each other and the one reported for 1977, in terms of amplitude, seasonality and location. Compared to the numbers reported throughout the study area, these maxima represented localized extremes in copepod abundance. For the most part, area-wide averages of copepod numbers (500-1000 per m^3) were fairly similar throughout the nine seasonal cruises of the three-year period. Data averaged by transects for each station (Table 14.12) showed that patterns of seasonal distribution were irregular. In spring 1975, copepod numbers at Station 1 increased sharply while they declined at Stations 2 and 3. In spring, 1976, copepod numbers at Station 2 increased while numbers at Stations 1 and 3 declined, and in spring, 1977, copepod numbers at Stations 1 and 2 increased while numbers at Station 3 declined. In spite of the somewhat inconsistent nature of depth-related distributions on a seasonal basis, annual means for each station suggested a strong shoreward gradient of increasing copepod numbers during each of the three years. Data averaged by stations for each transect (Table 14.13) showed less variability among transects than among stations. Annual means for each transect suggested that in 1975 and 1977 copepod numbers tended to follow biomass values in a southerly decline from Transect I to IV. In 1976, however, annual means were higher on Transects III and IV than on Transects I and II. In general, monthly data (Table 11.14) indicated that on Transect II copepods were somewhat more abundant in 1977 than in 1976. The highest numbers (4745.5 per m^3) recorded in 1977 occurred at Station 1/II in May-June and the lowest (335.1 per m^3) occurred at Station 3/II in April. In 1977, two well formed peaks of copepod abundance occurred at Station 1. The

TABLE 14.11

NUMERICAL ABUNDANCE OF COPEPODS PER m^3 AT EACH STATION
MEAN OF FOUR SAMPLES FOR 1975 AND TWO SAMPLES FOR 1976 AND 1977

Year	Transect	Winter				Spring				Summer			
		Station 1	2	3	Mean	Station 1	2	3	Mean	Station 1	2	3	Mean
1975	I	909.0	712.9	229.7	617.2	7683.1	741.8	317.2	2914.0	1569.9	741.4	534.4	948.6
	II	2489.5	1110.8	734.5	1444.9	2174.3	913.8	372.6	1153.6	2074.7	295.7	520.4	963.6
	III	2047.8	1229.6	577.0	1284.8	1928.6	425.9	343.7	899.4	1129.9	1011.1	891.6	1010.9
	IV	2119.5	1009.4	794.4	1307.8	668.9	463.0	487.6	539.8	959.0	1312.8	611.5	961.4
	Mean	1891.5	1015.7	583.9		3113.7	636.1	380.3		1433.4	840.3	639.5	
1976	I	459.7	637.4	714.6	603.9	925.4	1829.6	419.8	1058.3	483.1	686.6	565.2	578.3
	II	1443.0	717.5	655.3	938.6	978.6	1822.4	340.9	1047.3	694.5	241.8	624.6	520.3
	III	857.4	494.3	713.3	688.3	744.5	1252.0	889.4	962.0	4156.7	1054.6	1272.9	2161.4
	IV	3042.6	746.0	368.0	1385.5	1465.9	682.3	342.1	830.1	1175.4	451.1	399.8	675.4
	Mean	1450.7	648.8	612.8		1028.6	1396.6	498.0		1627.4	608.5	715.6	
1977	I	898.2	754.7	997.5	883.5	2832.6	1702.9	291.8	1609.1	6743.3	1066.0	918.7	2909.3
	II	462.7	758.7	1410.4	877.3	4745.5	1747.5	355.0	2282.7	1411.4	1744.2	995.2	1383.6
	III	994.4	467.9	883.5	781.9	1682.1	1272.6	460.5	1138.4	246.4	467.8	539.5	417.9
	IV	1318.3	890.1	516.0	908.1	2354.2	1459.7	740.0	1518.0	672.3	130.6	483.9	428.9
	Mean	918.4	717.9	951.9		2903.6	1545.7	461.8		2268.4	852.2	734.3	

TABLE 14.12

AVERAGE SEASONAL NUMERICAL ABUNDANCE OF COPEPODS PER m^3 FOR EACH STATION
MEAN OF FOUR TRANSECTS FOR EACH STATION

Year	Station	Winter	Spring	Summer	Mean
1975	1	1891.5	3113.7	1433.6	2146.3
	2	1015.7	636.1	840.3	830.7
	3	583.9	380.3	639.5	534.6
Mean		1163.7	1376.7	971.1	
1976	1	1450.7	1028.6	1627.4	1368.9
	2	648.8	1396.6	608.5	884.6
	3	612.8	498.0	715.6	608.8
Mean		904.1	974.4	983.8	
1977	1	918.4	2903.6	2268.4	2030.1
	2	717.9	1545.7	852.2	1038.6
	3	951.9	461.8	734.3	716.6
Mean		862.7	1637.1	1284.9	
Three-Year Mean	1	1420.2	2348.6	1776.5	1848.4
	2	794.1	1192.8	767.0	918.0
	3	716.2	431.7	696.5	620.0
Mean		976.8	1324.4	1080.0	

TABLE 14.13

AVERAGE SEASONAL NUMERICAL ABUNDANCE OF COPEPODS PER m^3 FOR EACH TRANSECT
MEAN OF THREE STATIONS FOR EACH TRANSECT

Year	Transect	Winter	Spring	Summer	Mean
1975	I	617.2	2914.0	948.6	1493.3
	II	1444.9	1153.6	963.6	1187.4
	III	1284.8	899.4	1010.9	1065.0
	IV	1307.8	539.8	961.4	936.3
Mean		1163.7	1376.7	971.1	
1976	I	603.9	1058.3	578.3	746.8
	II	938.6	1047.3	520.3	835.4
	III	688.3	962.0	2161.4	1270.6
	IV	1385.5	830.1	1013.1	1076.6
Mean		904.1	974.4	1068.3	
1977	I	883.5	1609.1	2909.3	1800.6
	II	877.3	2282.7	1383.6	1514.5
	III	781.9	1138.4	417.9	779.4
	IV	908.1	1518.0	428.9	951.7
Mean		862.7	1637.1	1284.9	
Three-Year Mean	I	701.5	1860.5	1478.7	1346.9
	II	1086.9	1494.5	955.8	1179.1
	III	918.3	999.9	1196.7	1038.3
	IV	1200.5	962.6	801.1	988.1
Mean		976.8	1329.4	1108.1	

TABLE 14.14

NUMERICAL ABUNDANCE OF COPEPODS PER m^3
ON TRANSECT II IN 1976 AND 1977
MEAN OF TWO SAMPLES AT EACH STATION

Year	1976				1977			
Month / Station	1	2	3	Mean	1	2	3	Mean
January/February	1443.0	717.5	655.3	938.6	462.7	758.7	1410.4	877.3
March	1435.5	516.6	690.4	880.8	1120.1	934.3	533.5	862.6
April	2045.0	884.1	485.4	1138.2	2304.8	853.0	335.1	1160.3
May/June	978.6	1822.4	340.9	1047.3	4745.5	1747.5	355.0	2282.7
July	1118.2	652.0	216.4	662.2	1051.8	494.8	522.1	689.1
August	484.6	338.8	454.4	425.9	1001.7	769.1	474.6	748.5
September	694.5	241.8	624.6	520.3	1411.4	1744.2	995.2	1383.6
November	1361.6	830.8	473.0	888.5	2044.3	1420.3	367.7	1277.4
December	1970.8	1158.7	644.5	1258.0	1489.1	767.3	369.7	875.4
Mean	1281.3	795.9	509.4		1734.8	1054.4	595.9	

first and largest (4745.5 per m^3) occurred in May-June and the second (2044.3 per m^3) occurred in November. Copepod numbers at Station 2/II ranged from 500 to 1000 per m^3 except in May-June and September when they increased to over 1700 per m^3. The temporal variation of copepod numbers at Station 3/II followed the pattern established by the biomass and total zooplankton in that copepods were more abundant in the winter than in the spring.

Three suborders of the Copepoda (the Calanoida, Cyclopoida and Harpacticoida) were identified in this study. The orders Calanoida and Cyclopoida together accounted for more than 99% of the Copepoda in most of the 1977 samples (Table 6, Appendix M). Harpacticoid percentages in 1977 were generally less than 1% and ranged from 18.2 (Station 2/IV, September) to less than 0.05% (Station 2/IV, May-June; 1/II, July; 1/II, August; and 1/II, September). The relative abundances of Calanoida in 1977 ranged from 98.4 (Station 1/I, September) to 41.4% (Station 3/III, May-June). Since the harpacticoid fraction of the Copepoda was small, cyclopoid relative abundances varied proportionately with the calanoids. Throughout the nine seasonal cruises (1975-1977), calanoid relative abundances increased shoreward while cyclopoid percentages increased seaward. This trend was not obvious, however, in spring 1977 when cyclopoid percentages were high throughout the study area.

Mature female copepods accounted for about 50% of the copepod population in each season of 1977 (Tables 14.15 and 14.16). In summer, relative abundances of females ranged from 60 to 70% at Station 3 with percentages declining shoreward on all transects. They were, however, fairly consistent throughout the study area in the winter (40-50%), and spring (50-60%). Within the Calanoida, males generally occupied less than 15% of the population, but among the Cyclopoida, the percentages of males were frequently

TABLE 14.15

PERCENTAGE COMPOSITION OF ADULT FEMALES IN TOTAL COPEPODS AT EACH STATION
MEAN OF FOUR SAMPLES FOR 1975 AND TWO SAMPLES FOR 1976 AND 1977

Year	Transect	Winter				Spring				Summer			
		Station 1	2	3	Mean	Station 1	2	3	Mean	Station 1	2	3	Mean
1975	I	55.4	43.1	47.6	48.7	43.5	46.4	50.2	36.7	44.5	52.2	64.2	53.6
	II	51.7	61.7	57.5	57.0	57.5	41.6	50.0	49.7	48.1	60.8	64.5	57.8
	III	37.1	53.1	58.5	49.6	33.1	52.2	46.1	43.8	45.8	66.5	65.0	59.1
	IV	49.9	43.8	40.1	44.6	32.1	47.7	51.2	43.7	53.7	57.6	58.6	56.6
	Mean	48.5	50.4	50.9		41.6	47.0	49.4		48.0	59.3	63.1	
1976	I	54.4	51.1	45.5	50.3	40.2	44.7	57.0	47.3	37.6	45.7	65.4	49.6
	II	59.4	48.4	37.5	48.4	43.7	43.9	52.4	46.7	44.4	61.3	63.8	56.5
	III	58.8	35.5	41.5	45.3	40.4	51.1	60.3	50.6	47.4	72.9	77.0	65.8
	IV	56.4	45.7	35.6	45.9	56.9	73.8	57.3	62.7	68.6	73.4	75.8	72.8
	Mean	57.3	45.2	40.0		45.3	53.4	56.8		49.5	63.3	70.5	
1977	I	39.4	42.2	35.9	39.2	44.1	57.8	52.0	51.3	22.4	38.3	62.6	41.1
	II	50.3	49.3	45.3	48.3	59.2	42.7	56.3	52.7	33.9	45.8	63.5	47.7
	III	53.3	45.5	46.0	48.3	43.9	54.6	47.7	48.7	18.9	64.9	68.4	50.7
	IV	61.4	46.8	44.2	50.8	55.7	61.3	48.6	55.2	53.4	43.3	74.3	57.0
	Mean	51.1	46.0	42.9		50.7	54.1	51.2		32.2	48.1	67.2	

TABLE 14.16

PERCENTAGE COMPOSITION OF ADULT FEMALES
IN TOTAL COPEPODS AT EACH STATION
MEAN OF TWO SAMPLES AT EACH STATION

Year	1976				1977			
Month / Station	1	2	3	Mean	1	2	3	Mean
January/February	59.4	48.4	37.5	48.4	50.3	49.3	45.3	48.3
March	74.6	63.8	49.3	62.6	48.7	46.9	50.9	48.8
April	80.9	59.1	57.2	65.7	56.6	57.5	56.3	56.8
May/June	43.7	43.9	52.4	46.7	59.2	42.7	56.3	52.7
July	47.6	62.6	62.0	57.4	74.8	78.4	53.6	68.9
August	41.6	66.1	60.0	55.9	74.0	71.6	55.3	67.0
September	44.4	61.3	63.8	56.5	33.9	45.8	63.5	47.7
November	33.4	46.9	65.1	48.1	22.8	27.8	58.7	36.4
December	44.6	48.6	53.1	48.8	44.9	60.7	55.9	53.8
Mean	52.2	55.6	55.6		51.7	53.4	55.1	

greater than those of females and immatures combined (Table 6, Appendix M). Immature copepods maintained uniform relative abundances (about 50%) within the copepods during all three seasons in 1975 and 1976 (Table 14.17). In 1977, immature forms, although well represented, occupied a noticeably smaller percentage of the copepod population, especially in the spring (generally less than 25%). The relative abundance of immature copepods was higher than 50% only at Station 1/I in winter and Stations 1/I, 1/II and 1/III in summer. Monthly data for Transect II showed that percentages of immature copepods fell between 40 and 60% in most of the 1976 samples, but in 1977 their percentages were considerably lower (Table 14.18). Furthermore, the annual mean percentage (29.0%) of immature copepods in the 1977 monthly samples was only about half as great as the annual mean percentage (49.1%) in 1976. It should be noted that aside from the indications of temporal and spatial variations found in 1977, the seasonal data for all three years clearly demonstrated the persistent occurrence of immature copepods, which seemed to indicate a fairly uniform copepod production throughout the area all year long.

In 1977, adult female copepods ranged in numbers from 2807.9 per m^3 (Station 1/II, May-June) to 46.9 per m^3 (Station 1/III, September), with area-wide averages that fluctuated around 500 per m^3 (Table 14.19). The monthly data from Transect II showed a peak of female abundance (2807.9 per m^3) at Station 1 in May-June 1977 which was comparable to a similar peak (1769.1 per m^3) that occurred a month earlier in 1976 (Table 14.20). Otherwise, the temporal and spatial distribution of adult females was generally similar between the two years. Each species was carefully enumerated to estimate its relative abundance on the basis of adult females.

During 1977, a total of 150 species of adult female copepods were identified: 97 calanoid species, 49 cyclopoid species and 4 harpacticoid

TABLE 14.17

PERCENTAGE COMPOSITION OF IMMATURES IN TOTAL COPEPODS AT EACH STATION
MEAN OF FOUR SAMPLES FOR 1975 AND TWO SAMPLES FOR 1976 AND 1977

Year	Transect	Winter				Spring				Summer			
		Station			Mean	Station			Mean	Station			Mean
		1	2	3		1	2	3		1	2	3	
1975	I	35.2	58.8	77.2	57.1	50.4	75.9	63.1	63.1	49.8	59.6	51.8	53.7
	II	52.6	38.8	50.7	47.4	65.1	78.4	67.7	70.4	61.0	46.8	45.7	51.2
	III	92.7	64.0	43.2	66.8	46.2	65.5	73.7	61.8	50.7	46.3	47.2	48.1
	IV	88.4	69.8	72.2	76.8	73.3	47.8	53.1	58.1	44.4	39.3	55.3	46.3
	Mean	67.2	57.9	61.0		58.8	66.9	64.4		51.5	48.0	50.0	
1976	I	49.2	28.8	23.3	33.8	61.5	41.7	60.7	54.6	59.0	67.5	41.4	56.0
	II	33.5	24.3	77.5	45.1	43.8	39.6	54.8	46.1	35.0	35.5	49.2	39.9
	III	43.1	82.7	67.1	64.3	54.9	45.9	40.8	42.2	83.2	29.2	31.9	48.1
	IV	73.3	65.9	88.6	75.9	41.1	24.1	63.2	42.8	42.8	30.3	42.1	38.4
	Mean	49.8	50.4	64.1		50.3	37.8	54.9		55.0	40.6	41.2	
1977	I	34.0	48.5	53.7	45.4	19.7	27.2	31.7	26.2	54.2	39.8	28.2	40.7
	II	33.8	37.4	39.5	36.9	7.3	24.5	25.1	19.0	53.0	44.3	25.6	41.0
	III	26.9	45.6	43.2	38.6	24.8	18.3	28.2	23.8	70.4	27.1	21.2	39.6
	IV	25.4	42.1	42.0	36.5	16.3	21.3	30.9	22.8	43.9	44.5	19.2	35.9
	Mean	30.0	43.4	44.6		17.0	22.8	29.0		55.4	38.9	23.6	

TABLE 14.18

PERCENTAGE COMPOSITION OF IMMATURES IN TOTAL COPEPODS
ON TRANSECT II IN 1976 AND 1977
MEAN OF TWO SAMPLES AT EACH STATION

Year	1976				1977			
Month / Station	1	2	3	Mean	1	2	3	Mean
January/February	33.5	24.3	77.5	45.1	33.8	37.4	39.5	36.9
March	25.5	41.9	61.2	42.9	12.1	39.1	39.4	30.2
April	17.8	62.4	55.0	45.1	24.4	21.1	32.9	26.1
May/June	43.8	39.6	54.8	46.1	7.3	24.5	25.1	19.0
July	52.4	40.2	65.3	52.6	7.0	14.4	33.6	18.3
August	60.2	42.8	46.8	49.9	7.8	19.4	33.0	20.1
September	35.0	35.5	49.2	39.9	53.0	44.4	25.6	40.0
November	66.7	63.4	40.5	56.9	40.3	26.3	33.0	33.2
December	62.4	69.1	58.5	63.3	44.6	30.9	32.1	35.9
Mean	44.1	46.6	56.5		25.6	28.6	32.7	

TABLE 14.19

NUMERICAL ABUNDANCE OF ADULT FEMALE COPEPODS PER m^3 AT EACH STATION
MEAN OF FOUR SAMPLES FOR 1975 AND TWO SAMPLES FOR 1976 AND 1977

Year	Transect	Winter				Spring				Summer			
		Station			Mean	Station			Mean	Station			Mean
		1	2	3		1	2	3		1	2	3	
1975	I	490.0	313.4	190.1	304.2	3436.1	363.4	158.2	1319.2	621.6	392.4	342.3	452.1
	II	1245.1	685.2	419.5	783.3	1339.5	382.4	185.9	635.9	1035.9	174.9	338.1	516.3
	III	769.9	670.2	336.7	592.3	640.8	235.9	156.9	344.5	508.1	671.6	584.6	588.1
	IV	1060.5	440.0	320.0	606.8	239.7	228.5	251.9	240.0	502.6	718.6	352.9	524.7
	Mean	891.4	527.2	296.3		1414.0	302.6	188.2		667.1	489.4	404.5	
1976	I	249.6	334.3	327.1	303.7	370.2	816.5	238.6	475.1	182.1	294.0	364.1	280.1
	II	871.8	346.9	244.3	487.7	424.9	796.1	178.6	466.5	307.3	143.5	398.5	283.1
	III	504.4	175.4	296.6	325.5	299.9	645.1	534.4	493.1	1970.8	768.7	978.7	1239.4
	IV	1770.8	338.5	128.1	745.8	875.3	502.7	196.0	524.7	801.4	327.3	303.2	477.3
	Mean	849.1	298.8	249.0		492.6	690.1	286.9		815.4	383.4	511.1	
1977	I	354.7	318.8	359.0	344.2	1247.9	984.7	151.6	794.7	1508.6	408.6	575.0	830.7
	II	233.0	374.2	639.7	415.6	2807.9	746.1	199.9	1251.3	478.4	799.6	632.2	636.7
	III	530.9	213.0	407.2	383.7	738.1	694.9	219.5	550.8	46.9	303.4	369.1	239.8
	IV	810.3	416.7	228.5	485.2	1311.6	894.5	359.3	855.1	359.3	56.5	359.3	258.4
	Mean	482.2	330.7	408.6		1526.4	830.1	232.6		598.3	392.0	483.9	

TABLE 14.20

NUMERICAL ABUNDANCE OF ADULT FEMALE COPEPODS PER m^3
ON TRANSECT II IN 1976 AND 1977
MEAN OF TWO SAMPLES AT EACH STATION

Year	1976				1977			
Month / Station	1	2	3	Mean	1	2	3	Mean
January/February	871.8	346.9	244.3	487.7	233.0	374.2	639.7	415.6
March	1073.8	298.4	340.4	570.9	545.3	437.9	271.8	418.3
April	1769.1	521.8	277.3	856.1	1303.4	490.9	188.7	661.0
May/June	424.9	796.1	178.6	466.5	2807.9	746.1	199.9	1251.3
July	564.5	385.0	134.2	361.2	786.6	388.0	280.0	484.9
August	203.9	222.7	272.6	233.1	741.6	550.3	262.2	518.0
September	307.3	143.5	398.5	283.1	478.4	799.6	632.2	636.7
November	465.4	394.9	308.0	389.4	642.7	985.5	215.7	614.6
December	885.9	566.1	342.5	598.2	669.3	465.4	206.7	447.1
Mean	729.6	408.4	277.4		912.0	582.0	321.9	

species (Table 7, Appendix M). Calanoid species which consistently accounted for a significant fraction of the 1977 copepod population were ranked in declining order of abundance: *Paracalanus indicus, Paracalanus quasimodo, Clausocalanus jobei, Clausocalanus furcatus, Paracalanus aculeatus, Temora turbinata* and *Centropages velificatus*. Three other species, which were often very abundant in estuarine areas, appeared in highly localized, large abundances in 1977. These species were *Acartia tonsa* (787.5 per m^3, Station 1/II, May-June), *Centropages hamatus* (253.4 per m^3, Station 1/II, March), and *Acartia lilljeborgii* (131.3 per m^3, Station 1/I, September).

Paracalanus indicus and *Paracalanus quasimodo* are so similar morphologically and in distribution that for the purpose of data analysis their numbers were summed and reported under the classification "*Paracalanus parvus* group" (Tables 14.21 and 14.22). The maximum abundance (1178.9 per m^3, Station 1/II, May-June) reported for this group in 1977 was similar in magnitude and location of occurrence to the maximum number (1125.3 per m^3, Station 1/II, May-June) reported in 1975. In 1976, however, their numbers peaked (1502.4 per m^3) at Station 1/IV in January-February. The maxima for all three years represented localized extreme numbers, with average abundances centered around 200 per m^3. Spatially, this group showed a shoreward increase in numbers which was usually most pronounced in May-June. Considered on a monthly basis on Transect II (Table 14.22) the *Paracalanus parvus* group occurred in the greatest concentrations (more than 1100 per m^3) at Station 1 between April and May-June of 1977 and in April (more than 1500 per m^3) of 1976.

Ranked second in abundance, *Clausocalanus jobei* was slightly larger in general density than *Clausocalanus furcatus* in 1977, but in 1975 and 1976 it was relatively low in numbers. Spring 1977 and 1976 data showed

TABLE 14.21

NUMERICAL ABUNDANCE OF *Paracalanus indicus* AND *Paracalanus quasimodo* PER m^3 AT EACH STATION .
MEAN OF FOUR SAMPLES FOR 1975 AND TWO SAMPLES FOR 1976 AND 1977

Year	Transect	Winter				Spring				Summer			
		Station				Station				Station			
		1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
1975	I	264.0	70.8	2.0	112.3	578.0	195.4	12.8	262.1	232.7	40.5	1.8	91.7
	II	749.1	247.2	49.7	348.7	1125.3	199.5	9.3	444.7	566.7	3.4	2.5	190.9
	III	515.9	30.6	30.2	192.2	205.9	65.7	7.7	93.1	123.1	55.1	19.2	65.8
	IV	927.1	154.2	18.5	366.6	122.7	41.7	22.0	62.1	66.1	121.9	25.0	71.0
	Mean	614.0	125.7	25.1		508.0	125.6	13.0		247.2	55.2	12.1	
1976	I	134.7	115.5	33.0	94.4	102.0	154.3	8.2	88.2	63.6	54.5	2.0	40.0
	II	737.4	60.0	7.6	268.3	10.6	140.8	8.2	53.2	33.2	2.3	1.9	12.5
	III	367.1	7.1	99.2	157.8	56.5	85.6	46.6	68.5	1121.0	38.5	15.7	391.7
	IV	1502.4	200.6	1.6	568.2	141.3	112.5	10.4	88.1	1.0	16.3	1.5	6.3
	Mean	685.4	95.8	35.4		77.6	123.3	24.5		304.7	27.9	5.3	
1977	I	211.1	132.9	26.9	123.6	178.9	122.2	22.1	107.7	317.2	105.9	17.3	146.8
	II	131.4	150.6	305.7	195.9	1178.9	250.5	17.0	482.1	231.7	175.3	13.8	140.3
	III	261.6	61.7	68.5	130.6	518.5	73.3	12.1	201.3	12.1	16.7	6.4	11.7
	IV	522.5	209.7	3.6	245.3	797.6	162.7	47.5	335.9	13.8	1.1	0.7	5.2
	Mean	281.7	138.7	101.2		668.5	152.2	24.7		143.7	74.7	9.6	

TABLE 14.22

NUMERICAL ABUNDANCE OF *Paracalanus indicus* AND *Paracalanus quasimodo*
ON TRANSECT II IN 1976 AND 1977
MEAN OF TWO SAMPLES AT EACH STATION

Year	1976				1977			
Month / Station	1	2	3	Mean	1	2	3	Mean
January/February	737.4	60.0	7.6	268.3	131.4	150.6	305.7	195.9
March	768.3	126.9	12.3	302.5	154.2	199.4	76.9	143.5
April	1564.7	256.9	11.5	611.0	1108.5	327.5	25.2	487.1
May/June	10.6	140.8	8.2	53.2	1178.9	250.5	17.0	482.1
July	170.0	23.7	0.2	64.6	70.3	4.9	12.4	29.2
August	75.9	22.9	10.6	36.5	23.4	25.6	2.3	17.1
September	33.2	2.3	1.9	12.5	231.7	175.3	13.8	140.3
November	144.3	93.4	22.5	86.7	40.9	169.6	1.2	70.6
December	568.1	103.7	29.2	233.7	532.1	80.0	10.9	207.7
Mean	452.5	92.3	11.6		385.7	153.7	51.7	

well formed concentrations of *Clausocalanus jobei* about Station 2, and summer results for all three years illustrated strong concentrations at Station 3 with a complete lack of occurrence at most of the shallow stations. Monthly data for Transect II showed that in 1976 patterns of spatial and temporal distribution of *Clausocalanus jobei* were poorly formed, but in 1977 they produced spring peaks at Stations 1 and 2 and winter and summer peaks at Station 3. *Clausocalanus furcatus*, a typical oceanic calanoid, was well concentrated at the seaward stations in summer 1975 and 1977 (Table 14.23). In 1976, while still primarily concentrated at Station 3, the spring and summer data showed a strong shoreward increase in their numbers on Transect IV. A similar strong shoreward increase in this species on Transect II appeared in the July and August 1977 monthly data with numbers in excess of 300 per m^3 occurring in both months at Station 1 (Table 14.24).

Paracalanus aculeatus was regular in occurrence but without discernible patterns of abundance in winter and spring 1977. Their greatest concentrations during the three years occurred in the summer with maximum abundances produced at Station 1 in 1975 and 1976 (219.8 per m^3, Station 1/IV, 1975; and 50.9 per m^3, Station 1/II, 1976). In summer 1977 their numbers were well concentrated about Station 2 with the annual maximum (186.5 per m^3) occurring at Station 2/II.

Temora turbinata, typically a nearshore form, was not well represented in the winter of all three years and in the spring of 1975 and 1976. In 1977, spring abundances at Station 1 (average of all four transects) averaged 194.6 per m^3 in contrast with 1.5 per m^3 in 1976 and 21.0 per m^3 in 1975. Similarly, summer 1977 abundances at Station 1 were larger than previous years with the annual high value (689.0 per m^3) occurring at Station 1/I. Annual averages for each station on Transect II (collected monthly)

TABLE 14.23

NUMERICAL ABUNDANCE OF *Clausocalanus furcatus* PER m^3 AT EACH STATION
MEAN OF FOUR SAMPLES FOR 1975 AND TWO SAMPLES FOR 1976 AND 1977

Year	Transect	Winter				Spring				Summer			
		Station			Mean	Station			Mean	Station			Mean
		1	2	3		1	2	3		1	2	3	
1975	I	4.2	35.9	25.1	21.7	4.4	14.8	28.9	16.0	1.3	129.6	91.6	74.2
	II	67.4	150.1	201.1	139.5	8.5	10.2	30.7	16.5	9.7	55.5	96.5	53.9
	III	11.3	346.7	133.8	163.9	1.1	22.6	30.7	18.1	13.5	248.2	145.7	135.8
	IV	29.9	108.1	74.9	71.0	1.9	5.6	38.3	15.3	14.6	128.5	142.6	95.2
	Mean	28.7	160.2	108.7		4.0	13.3	32.2		9.8	140.5	119.1	
1976	I	6.1	11.8	55.1	24.3	0.4	31.0	27.3	19.6	0	8.7	142.3	50.3
	II	10.9	8.0	22.5	13.8	24.6	10.7	22.1	18.9	0.9	36.9	117.7	51.8
	III	14.4	16.3	47.4	26.0	16.8	68.5	34.9	40.1	2.5	262.5	281.3	182.1
	IV	54.9	11.7	8.4	25.0	370.6	75.5	8.8	151.6	344.9	139.7	82.7	189.1
	Mean	21.6	12.0	33.4		103.1	46.3	23.3		87.1	112.0	156.0	
1977	I	0.3	8.7	20.9	10.0	18.4	255.1	7.5	93.7	0	13.9	128.0	47.3
	II	1.9	15.6	27.2	14.9	6.9	75.7	34.3	39.0	0.4	43.2	122.3	55.3
	III	3.2	6.5	13.2	7.6	13.3	22.8	5.9	14.0	0.1	19.9	59.9	26.6
	IV	18.2	19.7	5.1	14.3	104.7	81.5	16.1	67.4	0	10.6	132.6	47.7
	Mean	5.9	12.6	16.6		35.8	108.8	16.0		0.1	21.9	110.7	

TABLE 14.24

NUMERICAL ABUNDANCE OF *Clausocalanus furcatus* PER m^3
ON TRANSECT II IN 1976 AND 1977
MEAN OF TWO SAMPLES AT EACH STATION

Year	1976				1977			
Month / Station	1	2	3	Mean	1	2	3	Mean
January/February	10.9	8.0	22.5	13.8	1.9	15.6	27.2	14.9
March	10.0	48.7	65.1	41.3	0.3	4.6	2.4	2.4
April	12.4	31.7	75.4	39.8	1.0	30.7	17.3	16.3
May/June	24.6	10.1	22.1	18.9	6.9	75.7	34.3	39.0
July	72.1	53.8	5.4	43.8	316.7	121.5	23.6	153.9
August	1.7	12.3	24.7	12.9	359.6	228.2	31.4	206.4
September	0.9	36.9	117.7	51.8	0.4	43.2	122.3	55.3
November	14.8	82.1	127.8	74.9	0	353.4	60.1	137.8
December	12.3	119.1	77.3	69.6	1.1	130.8	50.3	60.7
Mean	17.7	44.7	59.8		76.4	111.5	41.0	

showed that *Temora turbinata* was most abundant at Station 1 in both 1976 and 1977.

Centropages velificatus occurred with fair consistency throughout the study area with the best defined distributional patterns and greatest abundances (over 200 per m^3) occurring at Station 2 in the spring of 1976 and 1977. However, in 1975, seasonal data showed a shoreward gradient of increasing numbers in all three seasons. Annual averages for each station in the monthly data for Transect II indicated a shoreward increase of *Centropages velificatus* numbers during both 1976 and 1977.

The most abundant cyclopoid copepods in the 1977 data, ranked in declining order of abundance, were *Corycaeus americanus, Oithona plumifera, Oncaea venusta, Oncaea mediterranea* and *Farranula gracilis*. *Corycaeus americanus* was, in all three years poorly represented (generally less than two per m^3) in the summer. It was somewhat more abundant in winter, and well represented in the spring, particularly at Station 1/III (157.7 per m^3) in 1975; at Station 2/II (90.2 per m^3) in 1976, and at Station 1/II (477.6 per m^3) in 1977. Monthly data from Transect II, averaged by station for 1977 showed a strong shoreward gradient of increasing numbers.

Oithona plumifera was most abundant at the offshore stations in the summer of all three years; however, monthly data from Transect II indicated, on the basis of annual averages for each station, maximum concentrations about Station 2 in both 1976 and 1977. Abundances of *Oncaea venusta* were variable both spatially and seasonally. In 1975 the greatest numbers (124.2 per m^3) occurred at Station 3/III in summer; in 1976 (176.7 per m^3) at Station 1/IV in summer; and in 1977 (181.0 per m^3) at Station 2/I in spring. In general, numerical abundances were distributionally erratic in the winter and spring, but formed seaward gradients of increasing numbers

in the summer of all three years. As with *Oithona plumifera*, monthly data from Transect II showed annual mean concentrations of *Oncaea venusta* to be largest at Station 2.

The numbers of *Oncaea mediterranea* recorded at each station during all three years were almost invariably lowest at Station 1 (all transects) with values increasing in a seaward direction. Temporally, *Oncaea mediterranea* was most equally distributed throughout the area in winter, with a reduction of occurrences at Station 1 in the spring and with almost no representation at Stations 1 and 2 in the summer. Monthly data showed that *Oncaea mediterranea* was well concentrated at Station 3 throughout the year in both 1976 and 1977.

Farranula gracilis was not as well represented in 1977 as in previous years; however, trends of seasonal and spatial distribution of abundance were in agreement. Winter occurrences were rare at Station 1 and abundances were low throughout the area. In the spring, their numbers increased somewhat but patterns of regional distribution were still poorly defined. Maximum abundances of *Farranula gracilis* occurred in the summer with the largest average numbers occurring at the deepest stations. Monthly data from Transect II showed that the largest numbers of *Farranula gracilis* occurred in July and August, between seasonal cruises, at Stations 1 and 2 in both 1976 and 1977. Therefore, annual means from monthly data reflected a greater general abundance of this species at Station 2 than was apparent from strictly seasonal data.

Species Diversity

The number of adult female copepods identified, number of copepod species found, species diversity index (based on adult female copepods), and coefficient of equitability (calculated from the diversity index for

each station) are presented in Table 10, Appendix M. In general, the trend for diversity indices and equitability coefficients to increase with depth and species numbers, which was observed in 1975 and 1976, continued in 1977. The highest species diversity (4.74), coefficient of equitability (0.7797), and number of species (68) occurred together at Station 3/I in the spring along with one of the lowest numbers of female copepods (151.6 per m^3). The lowest overall diversities and equitabilities occurred in the summer seasonal samples. The lowest station by station values occurred in the monthly samples on Transect II where the lowest diversity (1.28), equitability (0.3480) and number of species (14) were found at Station 1/II in April along with one of the larger numbers of female copepods (1303.4 per m^3).

Interrelationship Between Zooplankton and Environmental Parameters

As in the past two years of the study, those physical and biological parameters, measured by other investigators, which had the greatest potential for interrelationships with the zooplankton were temperature, salinity and chlorophyll a measurements. Surface values for temperature and salinity and mean water column values for chlorophyll a are considered in the discussion below.

On a seasonal basis, water temperatures in the winter of 1977 were lower than in either 1975 to 1976 and showed a seaward gradient of increasing temperatures. Spring temperatures in 1977 were very uniform throughout the area and more comparable to 1975 spring values than those of 1976 which were about 2° higher. In the summer, 1977 temperatures were higher by an average of 1-2°C than in preceding years. Generally speaking, zooplankton numbers, biomass values and the relative abundances of individual taxa are poorly correlated to temperature on a station by station basis. In a

broader sense, however, springtime increases in the zooplankton correspond directly to the increase in temperature at Stations 1 and 2. A further increase in temperature by summer was usually accomplished by reductions in biomass and zooplankton numbers. One exception to this generalized pattern occurred at Station 1/I (in summer 1977) where large values were recorded for both biomass (61.6 mg/m^3) and zooplankton numbers (7433.9 per m^3, largely composed of immature calanoids) in the summer when temperatures were highest. The monthly data from Transect II showed that at Stations 1 and 2 temperatures and zooplankton abundances increased simultaneously until temperatures reached springtime values; then the zooplankton varied in abundance with a net decline as temperatures approached summer levels. In the summer a second peak of zooplankton numbers (primarily copepods) occurred at all three stations. The biomass at Station 3 showed an inverse relationship to temperature in 1977 in that winter values for biomass and zooplankton numbers (primarily ostracods) were highest when temperatures were lowest and decreased with increasing temperatures. However, zooplankton numbers (primarily ostracods and the copepod *Clausocalanus furcatus*) increased again in September 1977 when the temperature was at its yearly maximum.

In 1977, salinity values varied seasonally in the same pattern observed in earlier years. That is, salinities decreased throughout the area between winter and spring, then increased from spring to summer. Zooplankton abundances at Stations 1 and 2 increased from winter to spring in conjunction with reduced salinities. The largest biomass values in seasonal samples accompanied low spring salinities at Station 1/I and 1/II. Similarly, zooplankton numbers, comprised primarily of ostracods, cladocerans, and copepods (*Temora turbinata* and *Paracalanus parvus* group), were also very high during the spring at Stations 1/I and 1/II. Zooplankton abundances

at Station 3 correlated poorly with changes in salinity in that, biomass decreased from winter to spring as salinities decreased but continued to decrease from spring to summer as salinities increased. Zooplankton numbers, however, fluctuated throughout the seasons in fair agreement with changes in salinity. In the monthly data zooplankton biomass and numerical values at Stations 1 and 2 increased from winter to spring as salinities gradually decreased. Between May-June and July, zooplankton values abruptly decreased to about 20-25% of the May-June values. This was accompanied by approximately a five parts-per-thousand increase in salinity. Throughout the rest of 1977 salinities at Stations 1 and 2 remained well above springtime levels, and zooplankton abundances remained close to the July levels. Some correlation between salinity and the zooplankton could be seen within individual seasons. For instance, in the winter and spring zooplankton abundances generally increased shoreward along each transect accompanied by decreasing salinities. In the summer, however, the data appeared grouped in opposing corners of the study area, separated by a line from Station 1/IV in the southwest corner to Station 3/I in the northeast corner. Below the line in the southeast corner, salinities were at their annual maxima (36 ppt) and zooplankton abundances were at their lowest. Above the line in the northwest corner, salinities decreased northward accompanied by an increase in zooplankton abundances. In general, maximum zooplankton abundances in 1977 occurred in the spring at the shallow stations when salinities were the lowest for the year and temperatures were in the upper half of their range.

Chlorophyll _a_ values decreased seaward during all seasons of 1977 in conformity to the findings of past years. Winter values at all stations were the highest for the year in 1977. At Stations 2 and 3 chlorophyll _a_ values generally declined from winter through spring and summer,

but at Station 1 the values on most transects were higher in the summer than in the spring. At Stations 1 and 2 chlorophyll a values declined from winter to spring as biomass and zooplankton numbers increased. In spite of this apparent inverse seasonal relationship, chlorophyll a values were highest at stations where zooplankton abundances were highest. In the summer, however, chlorophyll a values showed an increase at Stations 1/II, 1/III and 1/IV while zooplankton abundances showed a sharp decline. At Stations 1/I chlorophyll a was very low in summer when zooplankton values were among the highest of the year. In the monthly data from Transect II chlorophyll a values showed a progressive decline from Station 1 to Station 3 throughout the year. The data for zooplankton abundance showed the same trend in most months. During the annual cycle, changes in chlorophyll a data were poorly correlated to changes in zooplankton abundance at Stations 1 and 2. However, at Station 3, changes in chlorophyll a were directly related to changes in zooplankton abundances.

Linear correlation coefficients of the 1977 zooplankton data against the three physical and biological parameters considered above, generally supported the relationships discussed (Table 14.25). Correlation coefficients based on seasonal data were somewhat lower than those for the monthly data and probably reflected the inability of such widely-spaced samplings to properly accommodate natural lag periods between changes in physical parameters and the zooplankton community. Of the zooplankton data tested for linear relationships, the total number of zooplankton, numbers of Chaetognatha, and numbers of the *Paracalanus parvus* group showed strong but negative correlation to salinity. On the other hand, *Clausocalanus furcatus*, an oceanic species, displayed only a moderate, though positive correlation to salinity. Good positive correlations occurred between forms abundant near shore, such as the Mollusca and the

TABLE 14.25

CORRELATION COEFFICIENTS FOR CERTAIN BIOLOGICAL AND HYDROLOGICAL DATA

COLLECTED SEASONALLY FOR THE ENTIRE STUDY AREA AND MONTHLY ON TRANSECT II IN 1977

Zooplankton	Correlation Coefficient			
	Monthly		Seasonal	
	Salinity (ppt)	Chlorophyll a	Salinity (ppt)	Chlorophyll a
Dry Weight (mg/m^3)	-0.5512	0.1686	-0.5522	-0.0958
Number of Zooplankters per M^3	-0.5776	0.0877	-0.7631	0.4282
Number of Copepoda per M^3	-0.4244	0.0438	-0.6566	0.3966
Number of Copepod Species	0.2300	-0.4256	0.3175	-0.6108
Number of Cladocera per M^3	-0.5244	0.0228	-0.5853	0.0366
Number of Ostracoda per M^3	-0.1041	0.1467	-0.1884	0.0264
Number of Mollusca per M^3	-0.5441	-0.0328	-0.5675	0.6208
Number of Chaetognatha per M^3	-0.6669	-0.0582	-0.8341	0.1932
Number of Paracalanus parvus group per M^3	-0.5001	0.2599	-0.7228	0.5840
Number of Clausocalanus furcatus per M^3	-0.0611	-0.2689	0.3854	-0.3006

Paracalanus parvus group, and the chlorophyll a data. These results, expressed statistically, support many of those suggested by visual examination of the data. Strong correlations between certain zooplankton data and chlorophyll a and salinity values suggested that land drainage, by lowering salinities at nearshore stations, provided nutrients which supported phytoplankton blooms and ultimately increased zooplankton production.

Comparison of Recent BLM-OCS and Historical Zooplankton Studies

"Historical zooplankton" refers to samples collected from 1963 to 1965 from the Texas continental shelf. These samples were originally analyzed for larval penaeid shrimp; then stored until 1975 when samples from three transects (two with four stations and one with three stations), located within the BLM-STOCS study area, were analyzed for zooplankton taxonomic composition and abundance. Except for biomass weights, which were not measured, the historical samples were analyzed following the procedures described in the methods section above. Historical samples were collected one per station, at monthly intervals using a 0.4 meter, wire screen net (GULF-V); whereas the recent samples were collected both monthly (on Transect II) and seasonally (all four transects) using a 1-meter nylon net. Some differences in data from the two studies may be attributable to these differences in sample collection methods.

In general, more similarity than dissimilarity appeared in the results of the two studies. Viewed as the annual mean for each station, the range of numerical abundances (3595 to 909 per m^3) in the historical zooplankton, fell within the range of annual means (4122 to 844 per m^3) reported from Transect II monthly data collected in the recent study. Further, patterns of historical zooplankton abundance showed a seaward decline in numbers

and a seasonal increase during the spring months, in agreement with the results of the recent study. The major difference in data from the two studies was found in the results for the total zooplankton at the deepest stations. Seasonal fluctuations in historical zooplankton abundances at the deepest stations increased from winter to spring in conformity with the results from the shallower stations. In the recent study, however, abundances at the deepest stations decreased from winter to spring. This suggested that the zooplankton population at the deepest (73 m) historical stations was more like the zooplankton at the intermediate depth (45-90 m) stations, than at the deepest (90-135 m) stations in the recent study.

As was found in the recent BLM-OCS results, copepods accounted for 50-65% of the historical zooplankton numbers except in the spring months when other forms were more abundant. Further, the same groups which were abundant in the recent study (ostracods, mollusc larvae, chaetognaths, and larvaceans) were generally well represented in the historical samples. Patterns of temporal and spatial distribution among these taxa also were in close agreement between the two studies.

Among the copepods the relative abundances of calanoids (about 75%), cyclopoids (about 25%), and harpacticoids (less than 1%), together with seasonal and spatial variations in their relative abundances, were similar between the studies. Percentages of adult copepods and immatures also followed similar seasonal and spatial trends in both studies. Most of the species found in recent samples were also found in historical samples. The numerically abundant calanoids *Paracalanus indicus, Paracalanus quasimodo, Clausocalanus furcatus* and *Temora turbinata* were, in terms of abundance and distribution, very similar in both studies. However, the small estuarine species *Acartia tonsa* and *Paracalanus crassirostris* were more

abundant in the historical samples than in the recent study. Among the most abundant cyclopoids, *Oithona plumifera* produced similar patterns of abundance and distribution in both studies. The small estuarine species *Oithona nana* along with *Oncaea media*, a small form well represented throughout the area, were the most abundant cyclopoids in historical samples; whereas, the larger species *Corycaeus americanus*, *Oncaea venusta* and *Oncaea mediterranea* were usually the most abundant cyclopoids in the recent study.

In conformity with the findings in recent BLM-OCS results, the species diversity indices and coefficients of equitability increased seaward along with the numbers of copepod species. Differences in species composition between the two studies may, in part, be attributed to the differences in sampling gears and sampling depths which were discussed earlier.

CONCLUSIONS

1. Zooplankton abundances in terms of both biomass and number displayed a considerable degree of spatial and temporal variations and these variations were progressively extensive toward shore.

2. The zooplankton usually showed a seaward decrease, and this decrease was highly pronounced in spring and summer when the zooplankton generally increased to an annual maximum at Stations 1 and 2 and decreased to the lowest annual value at Station 3.

3. Copepods were the most abundant group, comprising approximately 50% of the zooplankton by number. When the zooplankton increased in spring and summer, the relative abundance of copepods decreased, indicating that other organisms were increasing faster than copepods.

4. Numerically important groups other than copepods were Ostracoda,

Amphipoda, Cnidaria, Mollusca, Chaetognatha, Cladocera and Larvacea. Ostracods were most abundant at the mid-depth and deep stations and Cladocera and Mollusca, near shore in the spring. Amphipoda, Cnidaria, Chaetognatha and Larvacea usually showed no discernible distributional patterns, spatially or temporally, throughout the area.

5. About 75% of the copepods were calanoids, 25% cyclopoids, and less than 1% harpacticoids. Percentages of calanoids were at their highest in the winter and summer, cyclopoids, in the spring. In copepods the adult females maintained a relative abundance of about 50% throughout the year. Developmental stages accounted for 40-60% of the copepods in winter and summer, but dropped to less than 25% in spring.

6. The most abundant calanoid species were *Paracalanus indicus, Paracalanus quasimodo, Clausocalanus furcatus* and *Clausocalanus jobei*. The first two species were abundant at shallow stations while the latter two were abundant at deep stations. The most abundant cyclopoid species were *Corycaeus americanus, Oncaea mediterranea* and *Oithona plumifera*. The first was abundant near shore and the latter two were abundant offshore.

7. Species diversity indices and coefficients of equitability, based on adult female copepods, generally increased seaward in conformity to the number of species.

8. Of the other biological and physical data obtained at the time of zooplankton collection, salinity and chlorophyll a values seemed to be most closely correlated with the zooplankton. This correlation was most readily discernible in spring when the zooplankton was highly productive in low-salinity water.

9. A comparison of data from historical samples with the three

years of BLM-OCS data show more similarity than dissimilarity in the abundance and taxonomic composition of the zooplankton. The fact that smaller forms and some estuarine species of copepods were more abundant in historical samples may be the result of the differences in sampling gear employed and location of stations sampled.

CHAPTER FIFTEEN

NEUSTON PROJECT

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ABSTRACT

Neuston samples were collected on nine cruises on the South Texas Outer Continental Shelf (STOCS) during 1977. The samples were analyzed taxonomically and for standing crop and tar values. All three of these attributes showed high variability. Seasonal trends in abundance for many groups, both invertebrates and vertebrates, showed good agreement with 1976 patterns. Species groupings for invertebrates also agreed well with 1976 data.

Average dry weights for all tows on a single cruise ranged from 9.37 gms per 1000 m^3 in December to 79.98 gms per 1000 m^3 in March. Tar values averaged along only Transect II ranged from 8.33 gms per 1000 m^3 in August to greater than 70 gms per 1000 m^3 in March.

A total of 77 decapod taxa were identified in the 1977 samples. The decapod larvae reached a peak in the spring and fall seasonal cruises. Concentrations were generally higher at night than during the day. Decapod species diversity was also generally higher at night.

The greatest abundances of fish eggs occurred in the spring. Fish larvae were most abundant during July. A total of 71 taxa of larval fishes were collected during 1977. In general, more fish eggs were captured during the day than during night tows, while the fish larvae showed the opposite trend.

INTRODUCTION

The purpose of this study was to perform a taxonomic analysis of the neuston community occupying the upper 15-20 cm of the water column at specified locations sampled on a regular basis over the STOCS. This taxonomic analysis, which included quantitative enumeration of species, dry weight and ash-free dry weight determinations and weight of tar, was designed to characterize existing environmental conditions prior to possible environmental perturbations which might occur in the future as a result of offshore drilling for oil and gas.

The neuston environment and its organisms are important to the water column ecosystem in that they occupy a relatively thin skin of the ocean surface where air-sea mixing initially occurs. Many potential pollutants are thought to enter the oceans through this route, and any biological impact might first manifest itself in changes in the neuston.

Although the neuston defies a strict biological definition in terms of species, there are certain taxonomic groups which are commonly found in the upper 15-20 cm of the water column during significant portions of each day. There is considerable variability not only in the abundance of neuston, either as total numbers of organisms or in terms of dry weight, but also in its taxonomic composition. This is due, in part, to diel vertical migration, but is also probably due to various types of environmental heterogeneity. Therefore, day-night sampling is done to minimize the former variation, but the latter source of variability is not generally monitored.

In this report, an attempt was made to identify the variations in numerical abundance of the various taxonomic categories of neuston in relation to diel, seasonal and geographic considerations as they existed during 1977 in the sampling area. In addition, an attempt was made to

analyze for relationships between species as co-occurring groups and to determine significant temporal patterns.

Literature Survey and Previous Work

It is only within the last 15 years that much has become known about marine neuston, although the neuston of freshwater ponds and pools has been studied since Naumann first applied the term to surface film organisms in 1917 (Zaitzev, 1970).

Marine neuston has been studied fairly extensively in the Black Sea and Sea of Azov (Zaitsev, 1961, 1968, 1970) and in the North Sea, Norwegian Sea, and subtropical Northeast Atlantic (Hempel and Weikert, 1972). Neuston studies in most other areas, however, have been limited, usually concentrating on specific taxonomic groups. These include various reports on aspects of Mediterranean neuston fauna, studies of pontellid copepods of the Pacific (Heinrich, 1969, 1971), and ichthyofauna of the subtropical Eastern Atlantic (Hartman, 1970).

No complete quantitative faunal analysis of neuston samples has been published. Although Weikert's (1972) study of the zooplankton of the subtropical Atlantic came close, it omitted several major zooplankton groups as coelenterates and tunicates, and did not provide identifications of species of calanoid copepods.

Two recent unpublished manuscripts presented the most complete quantitative and detailed analyses of neuston organisms to date. The first, a study of neuston of the Northwest Atlantic (Morris, 1975), compared the zooplankton in the neuston with the near-surface zooplankton and reported on definite seasonal and diel cycles of neuston biomass. The area of study included the southeastern Gulf of Mexico and Caribbean Sea as well as the northwestern Atlantic between Bermuda and Nova Scotia. The second was a

M.S. thesis by Berkowitz (1976). This study compared the neuston and near-surface zooplankton in the northwestern Gulf of Mexico in oceanic waters off Texas above the 1000-fathom bottom contour of the continental slope zone. The neuston in this area appeared to be relatively impoverished compared to plankton concentrations one meter below the surface. The above two studies did not, however, include detailed analyses of fish larvae and eggs or decapod larvae, as in the present BLM study.

Other neuston studies in the Gulf of Mexico have been sparse and incomplete. Zaitsev (1970) reported on neuston from the Gulf of Mexico, which he found to be poor in areas of upwelling, where biomass (wet fresh weight) did not exceed 100-200 mg/m^3, but where the water converges in the center of the Gulf the wet-weight biomass reached 410 mg/m^3.

Jeffrey *et al.* (1974) reported on relative abundance of pelagic tar in the Gulf of Mexico from neuston samples but did not report on the biotic aspects of the neuston. A cursory study of the latter was reported on briefly, however, in Pequegnat *et al.* (1976).

METHODS

Field

Field sampling was carried out under two different schemes. The winter seasonal cruise used the net from the 1976 program. This net had a 2 m x 1 m opening and yielded one sample per tow. Starting with the March monthly and for the remainder of 1977, a net 2 m x 0.5 m partitioned into four equal areas by vertical bars was used. Each section had a separate net so it was possible to collect four samples per tow. All four samples from each tow were analyzed for the March and April cruises. The agreement among the four "replicates" for all six tows was compared in detail for the March samples and the results were reported in the Second

Quarterly Report, 1977. No systematic bias was found in any of these comparisons and the agreement within the sets of four was very good. Starting with the spring seasonal samples two net chambers were randomly selected and analyzed. The values used for analysis represented averages of four samples for March and April and averages of two samples from Spring to December.

The mesh size of the four nets was 505 μm. After each tow the nets were rinsed down and each cod end was emptied into a separate jar. The jars were filled with 10% formaldehyde solution (4% formaldehyde) and buffered with sodium borate. Labels were added with the starting and final flowmeter readings. The flowmeter was suspended just below the middle of the net and recorded the distance traveled by the net. Assuming an average fishing depth of 15 cm the volume of water filtered could be estimated. It also was assumed each net filtered an equal volume of water. The validity of these last two assumptions remains untested.

Laboratory

Each sample was "rough sorted" initially to remove large organisms and non-living debris. This material was put in a separate jar and labeled as the large fraction. The remainder was put into a Folsom plankton splitter which mechanically divided the sample in half. The first split produced the "archive half" and the other half was resplit. This resplitting process continued until two final aliquots of approximately 1000 individuals were obtained. One of these final aliquots was used for a dry weight determination while the other was used for taxonomic identifications. Each tow resulted in at least four aliquots, five if there was a large fraction present. For example, if a sample was split four times and there was also a large fraction, there were the following aliquots: a large

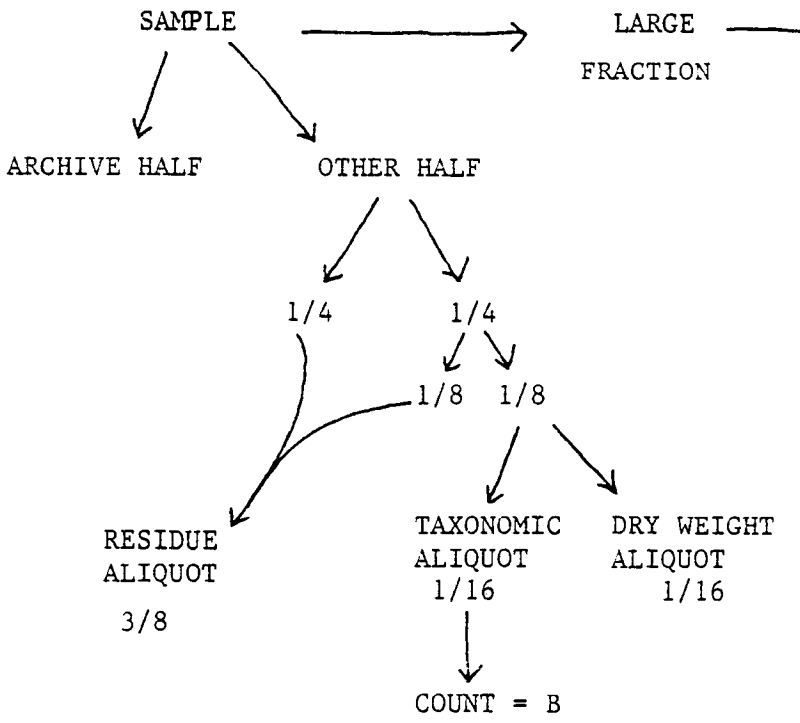
fraction, an archive half (1/2 of original sample), one final aliquot for taxonomy (1/16 of original sample), one final aliquot for dry weight and ash-free dry weight (1/16 of original sample) and a residue (1/2 - 1/16 - 1/16 or 3/8 of original sample)(Figure 15.1).

The archive half was permanently stored. The organisms and debris in the large fraction were enumerated. These counts were called "A". The organisms in one final aliquot were also identified and counted. These were called "B". Any tar in either of these samples was removed, dried at 60°C and weighed separately. Any tar in the other final aliquot was removed and added to that form from the other final aliquot before drying. This then represented the tar from 1/8 of the original sample.

The counts termed "B" were then multiplied by (1000/volume filtered) x 4 nets to give the numbers per 1000 m^3 per net per aliquot. If these numbers were multiplied by the inverse of the aliquot size (16) the number per 1000 m^3 per net was obtained. The large fraction counts ("A") were multiplied by "C", which was a correction factor to a constant volume (Figure 15.1) and added to the values of the number per 1000 m^3 per tow obtained from the "B" counts. Then the total sample was counted and corrected to a standard volume, 1000 m^3 in this case.

The other final aliquot was dried at 60°C to constant weight and weighed. It was then put in a muffle furnace at 500°C to combust all organics and weighed again. The difference between these two weights was the ash-free dry weight. The same corrections for aliquot size and volume filtered were made.

In the taxonomic sorting all decapods and decapod larvae were sorted out and sent to Dr. Linda Pequegnat for analysis. All fish and fish eggs were also removed and sent to Dr. John McEachran for analysis. These people also sorted through all the large fractions for their organisms.



$$\frac{1000m^3}{\frac{(\text{VOLUME FILTERED})}{4}} = C$$

$$\text{TOTALS} = (A \cdot C) + (B \cdot C \cdot 16) = \text{NUMBERS PER } 1000M^3$$

Figure 15.1 Schematic diagram of the analysis of a single sample.

In addition McEachran sorted all the residue aliquots for fish and fish eggs.

The results of the general taxonomic analyses will be discussed first, followed by a discussion of the decapod and decapod larvae results by Dr. Pequegnat and finally a discussion of the fish and fish eggs results by Dr. McEachran.

RESULTS

Dry Weight

An examination of the dry weight data for the entire year (Table 15.1) showed a considerable amount of variability. In Table 15.2 the averaged values along Transect II using both day and night values are presented. This was done since there were unequal numbers of day and night observations if all transects were used and diel differences were not consistent along a transect. Figure 15.2 shows these means and 95% confidence intervals. Considerable overlap of intervals was observed due to the high variability and a horizontal line could be drawn which intersected every month. This indicated that there were no significant seasonal changes which could be shown in our data.

Tar Weight

Figure 15.3 shows monthly and seasonal averages for all available data. With the exception of August which had small variability (and a small mean), all other values were indistinguishable at the 95% level.

Species Counts

The general philosphy of this report was not to present a lot of results which showed little. Examination of monthly changes of total numbers per unit volume provided little additional information and there-

TABLE 15.1

CRUISE AVERAGES FOR DRY WEIGHT OF NEUSTON TOWS

Cruise	Average ($gms/10^3m^3$)	Standard Deviation	N
Winter	12.85	15.74	15
March	79.78	94.39	6
April	16.44	12.37	6
Spring	20.42	26.74	15
July	9.96	6.45	6
August	57.02	131.24	6
Fall	10.96	13.60	15
November	17.59	10.80	6
December	9.37	5.00	6

TABLE 15.2

TRANSECT II AVERAGES ONLY FOR NEUSTON TOWS

Cruise	Average ($gms/10^3m^3$)	Standard Deviation	N
Winter	11.29	11.26	6
March	79.78	94.39	6
April	16.44	12.37	6
Spring	17.39	11.73	6
July	9.96	6.45	6
August	57.02	131.24	6
Fall	8.33	6.78	6
November	17.59	10.80	6
December	9.37	4.99	6

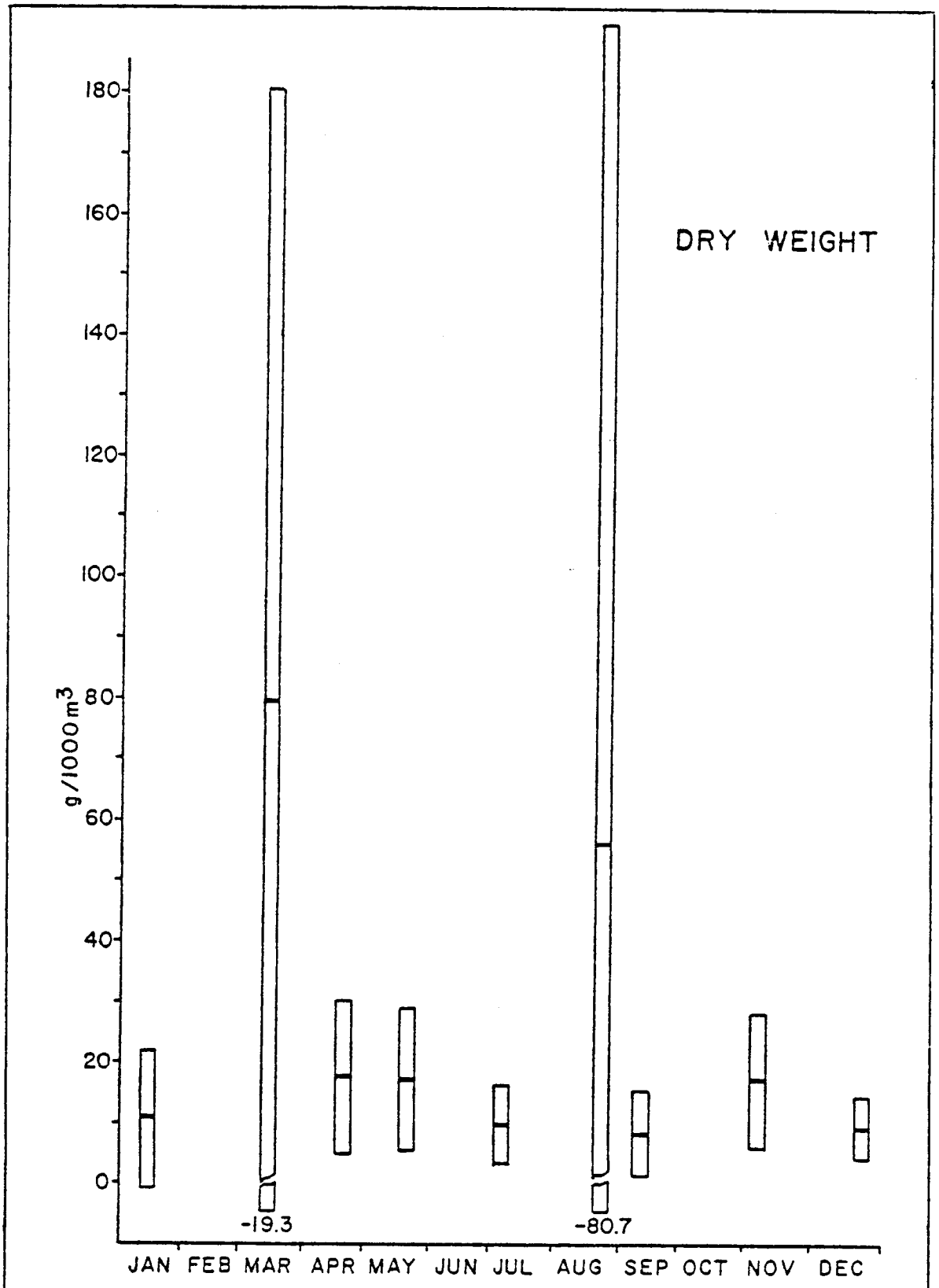
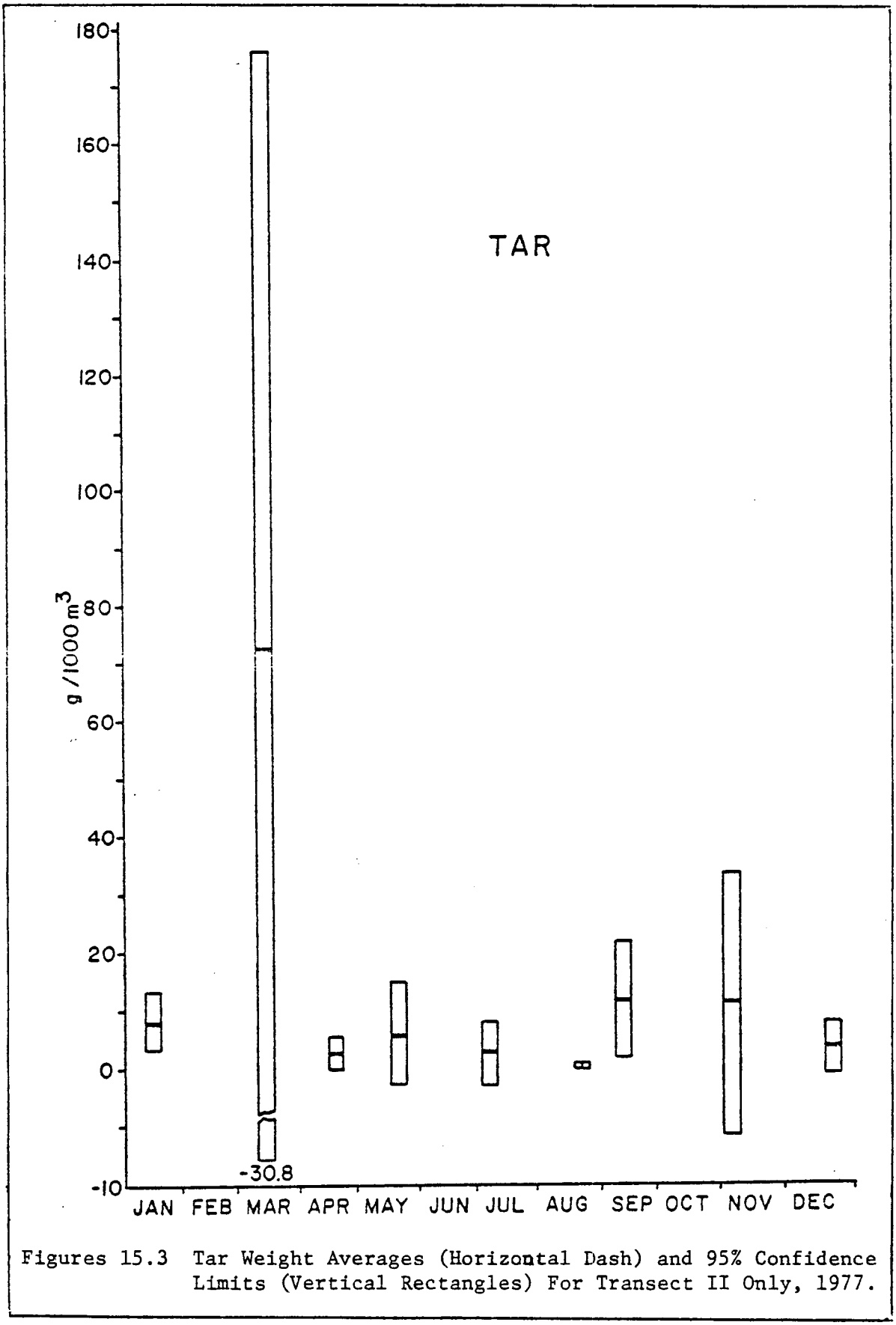


Figure 15.2 Dry Weight Averages (Horizontal Dash) and 95% Confidence Limits (Vertical Rectangles) for Transect II Only, 1977.



Figures 15.3 Tar Weight Averages (Horizontal Dash) and 95% Confidence Limits (Vertical Rectangles) For Transect II Only, 1977.

fore are presented in the summary tables in Appendix N, Table 1. A number of species or larger taxa were selected which were both frequent in occurence and/or abundant at times. These species or taxonomic groups were also analyzed in detail in the 1976 neuston data. The most encouraging generalization which could be made about these results was the high degree to which they followed the important trends seen in the 1976 data.

The most remarkable and most interesting of these patterns was that of *Anomalocera ornata*. Males, females and immature forms of this species showed the same trends (Figures 15.4 - 15.6). Immatures were found in their highest abundance in the winter sampling and showed a decline in March. The adults increased by about an order of magnitude in the winter and then peaked in March with the maturation of the immature forms (mostly Stage IV and V copepodites). This species completely disappeared from the sampling area from the April to the spring cruise. During this time interval the water temperature increased from an average of 21.94 to 25.28°C. Their reappearance in the December samples went along with a decrease in average temperature from 25.52 in November to 23.07°C in December. The similarities in "critical temperatures" was remarkable. The possibility of a resting egg in this species seemed very strong and warrants further work.

Centropages furcatus males and females showed very similar trends to 1976 values (Figures 15.7 and 15.8). Not only did the diel differences remain basically the same, but the gross trends in abundances were the same. During both years, *Pontellopsis villosa* males and females were low in abundance and quite variable early in the year followed by a strong increase in the late summer and fall (Figure 15.9 and 15.10).

Brachyuran zoeas (Figure 15.11) had a pronounced diel difference as in 1976 and showed high overall abundance with no pronounced seasonal

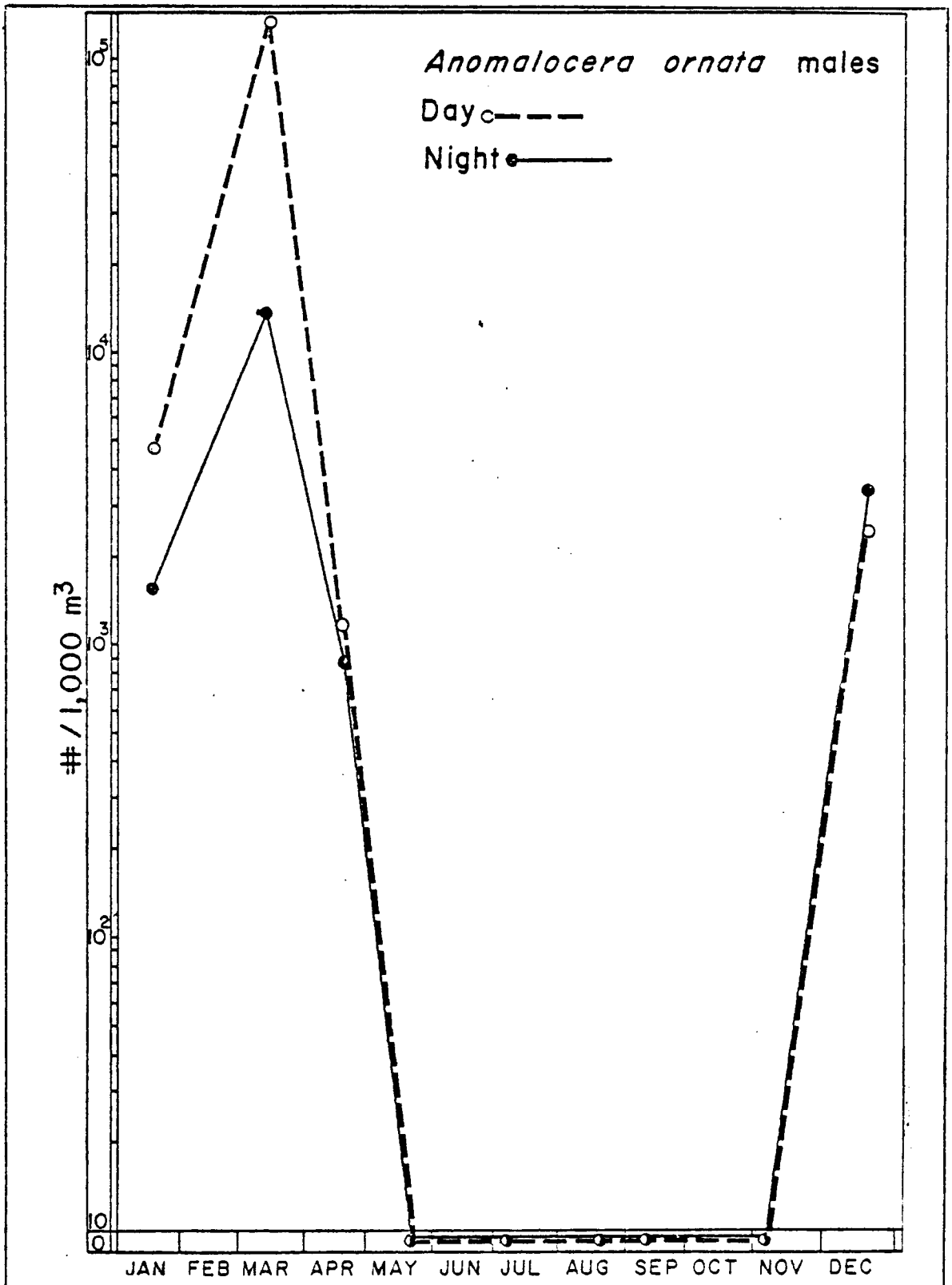


Figure 15.4 Annual Variation of Mean Day and Night Abundances Along Transect II for *Anomalocera ornata* Males.

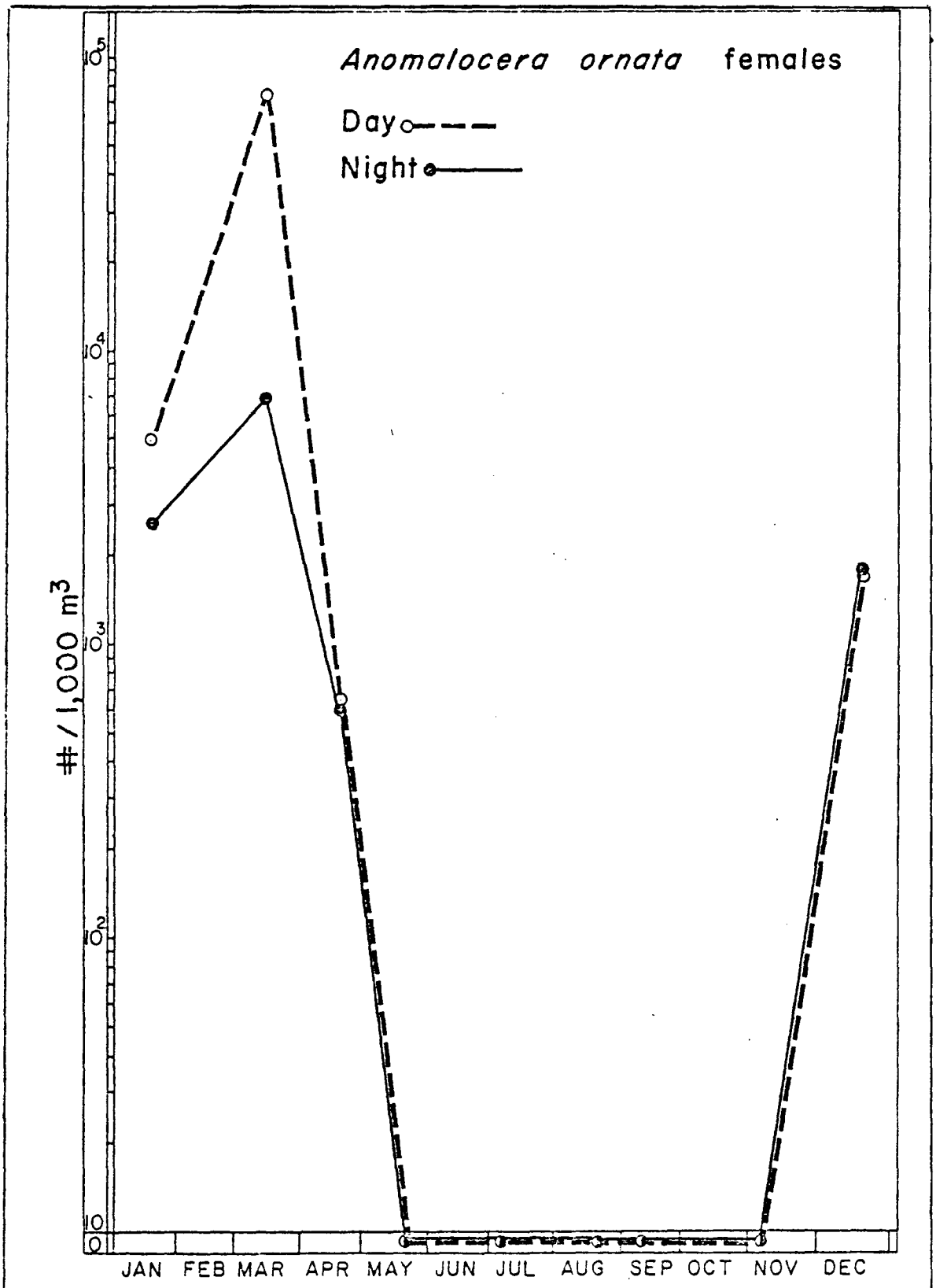


Figure 15.5 Annual Variation of Mean Day and Night Abundances Along Transect II for *Anomalocera ornata* Females.

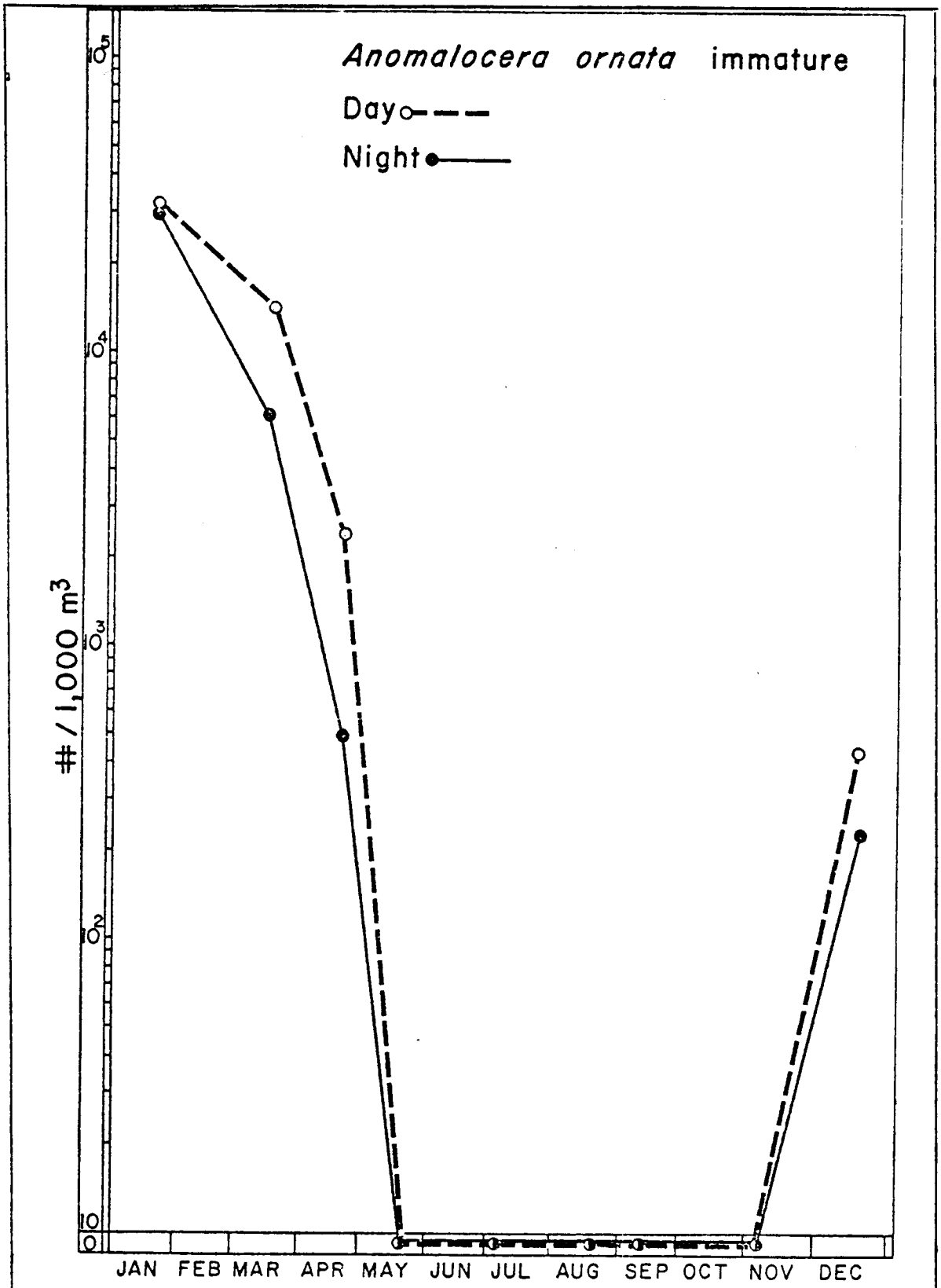


Figure 15.6 Annual Variation of Mean Day and Night Abundances Along Transect II for *Anomalocera ornata* Immature.

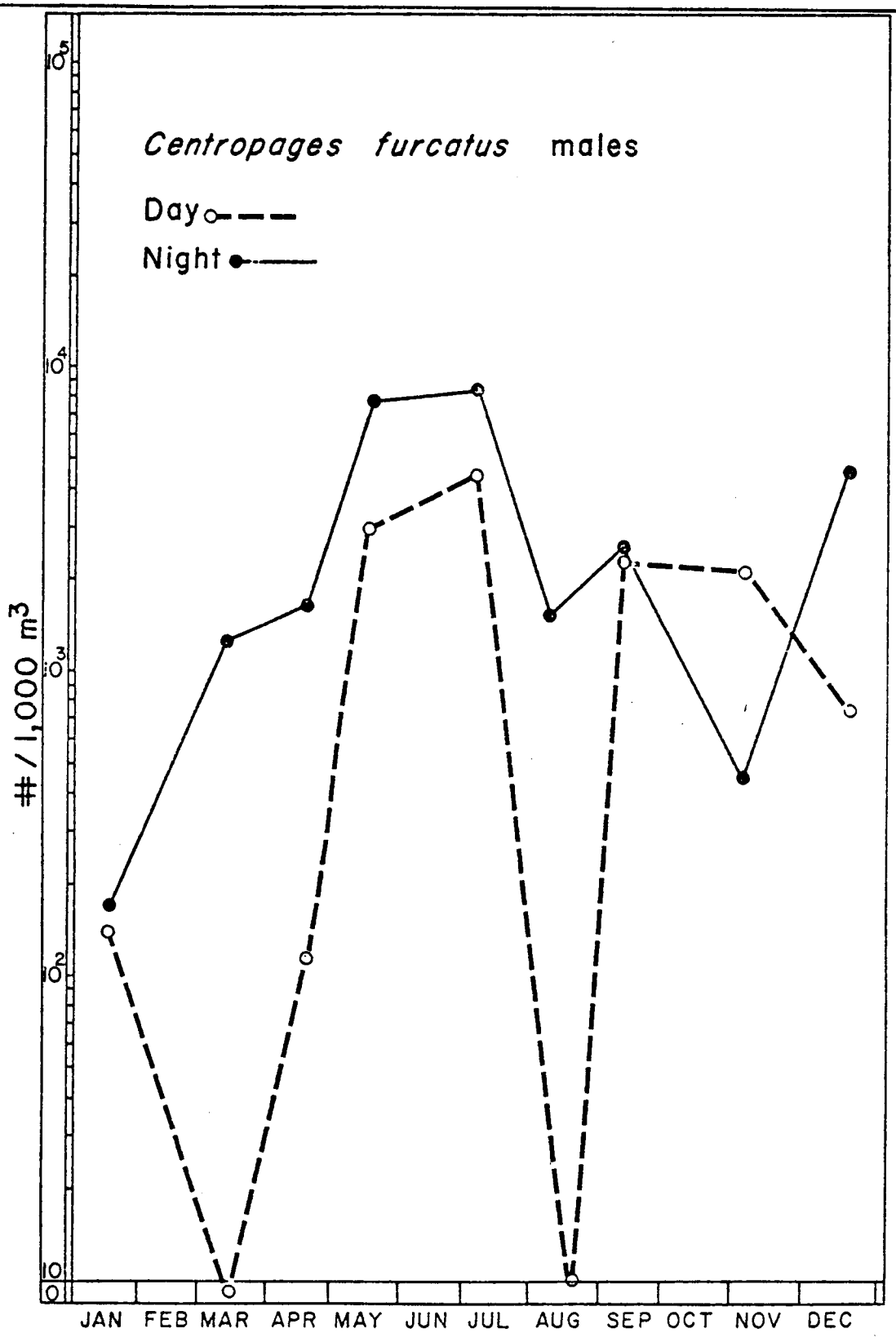


Figure 15.7 Annual Variation of Mean Day and Night Abundances Along Transect II for *Centropages furcatus* Males.

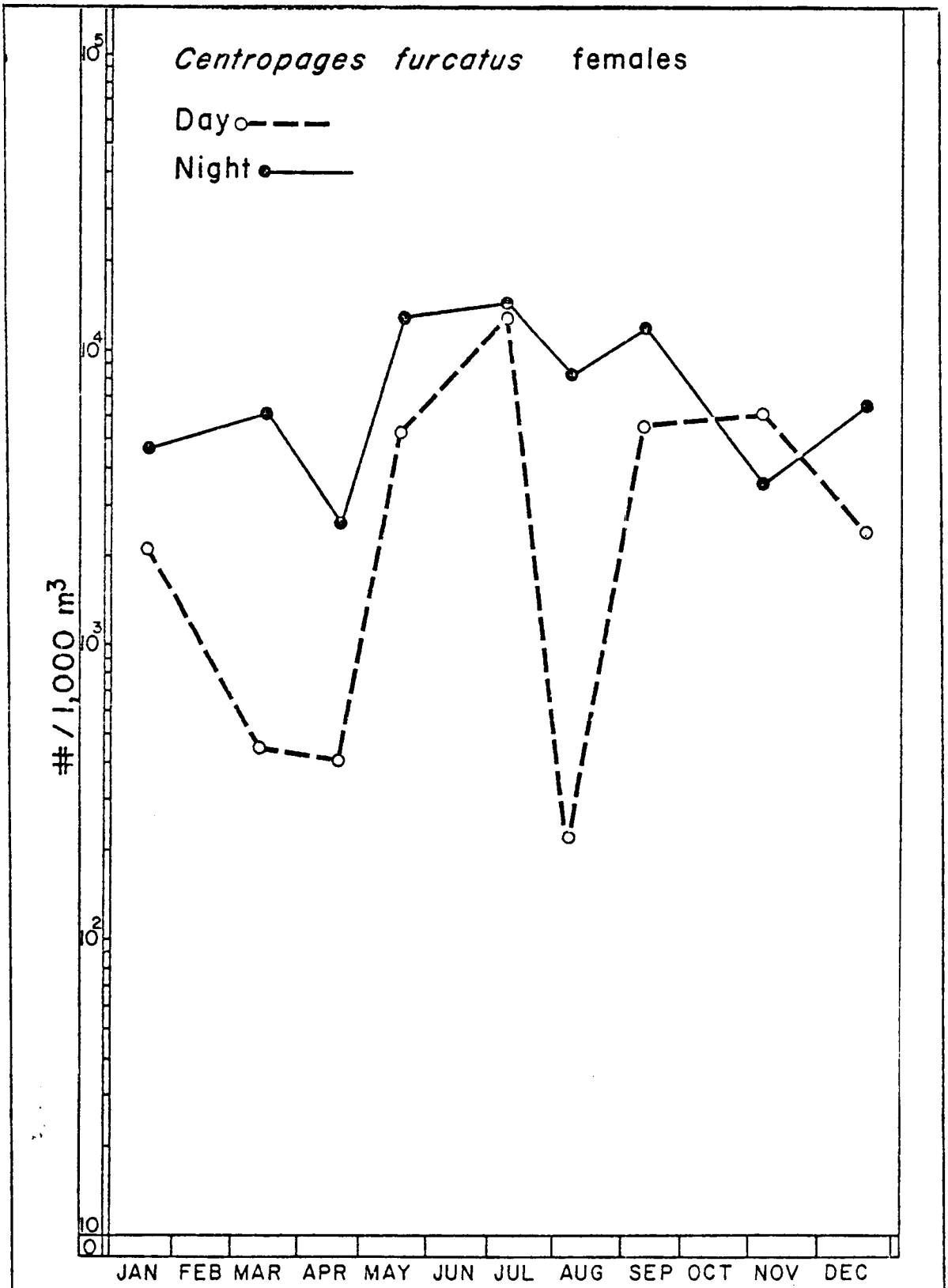


Figure 15.8 Annual Variation of Mean Day and Night Abundances Along Transect II for *Centropages furcatus* Females.

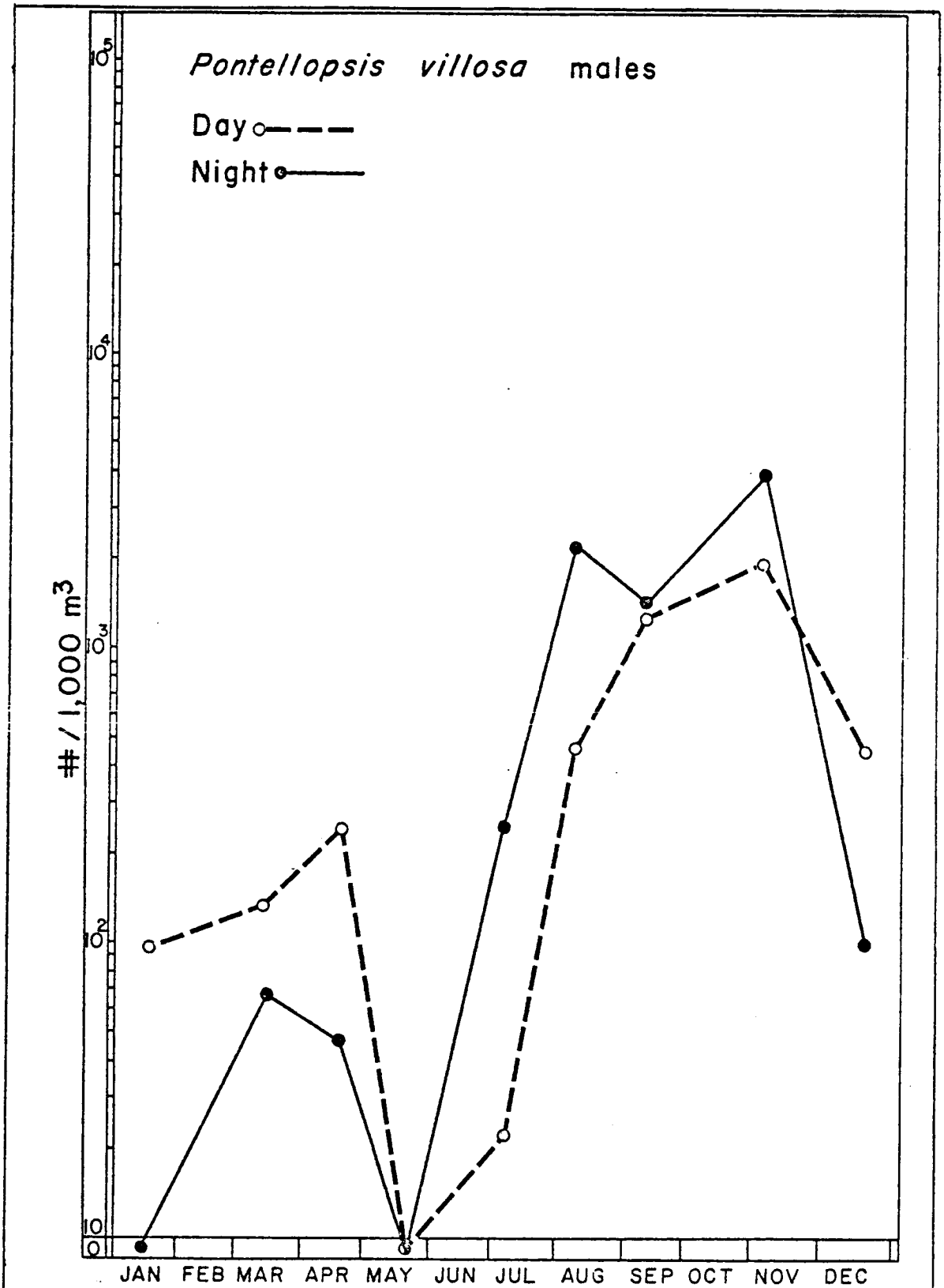


Figure 15.9 Annual Variation of Mean Day and Night Abundances Along Transect II for *Pontellopsis villosa* Males.

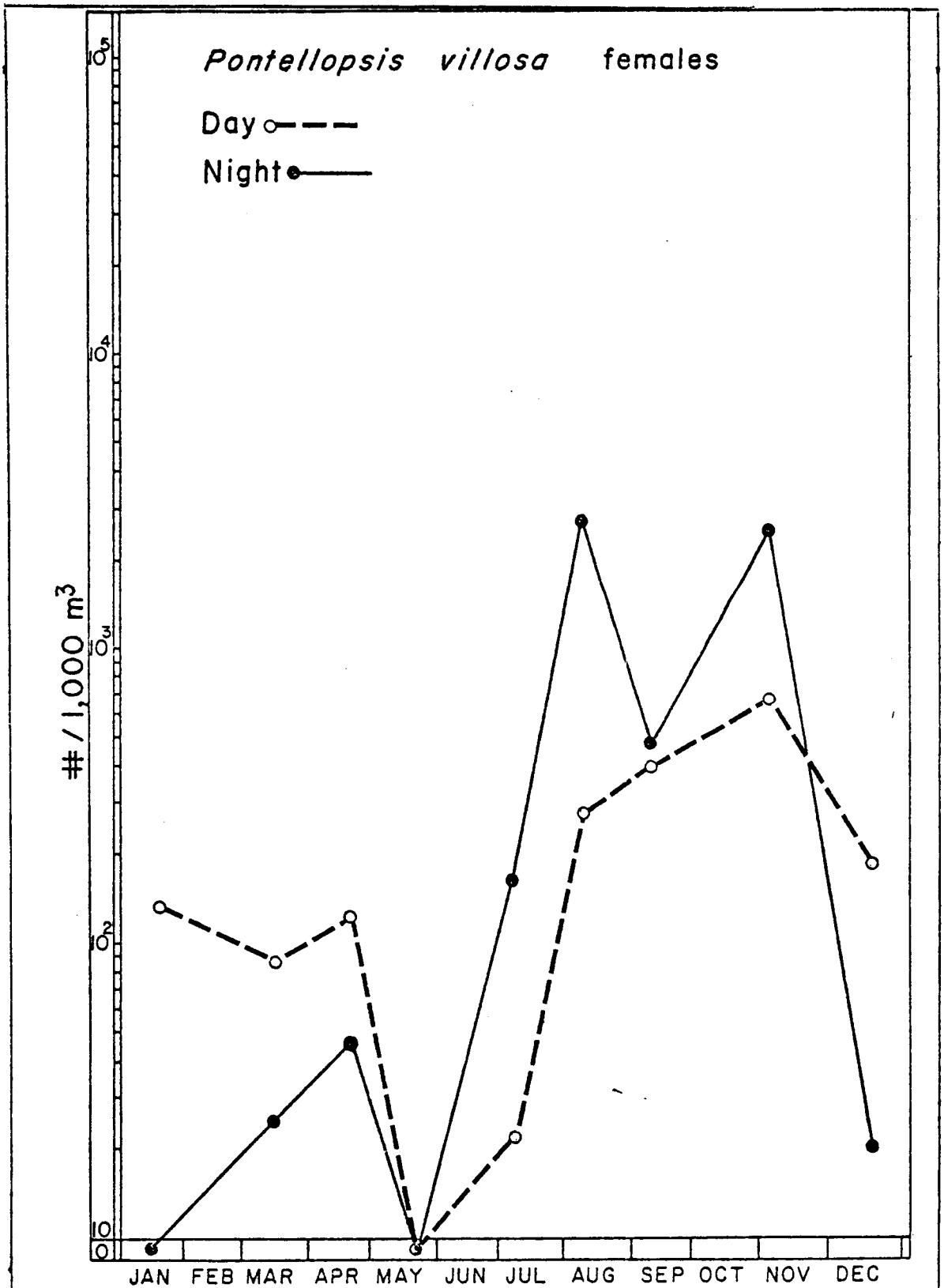


Figure 15.10 Annual Variation of Mean Day and Night Abundances Along Transect II for *Pontellopsis villosa* Females.

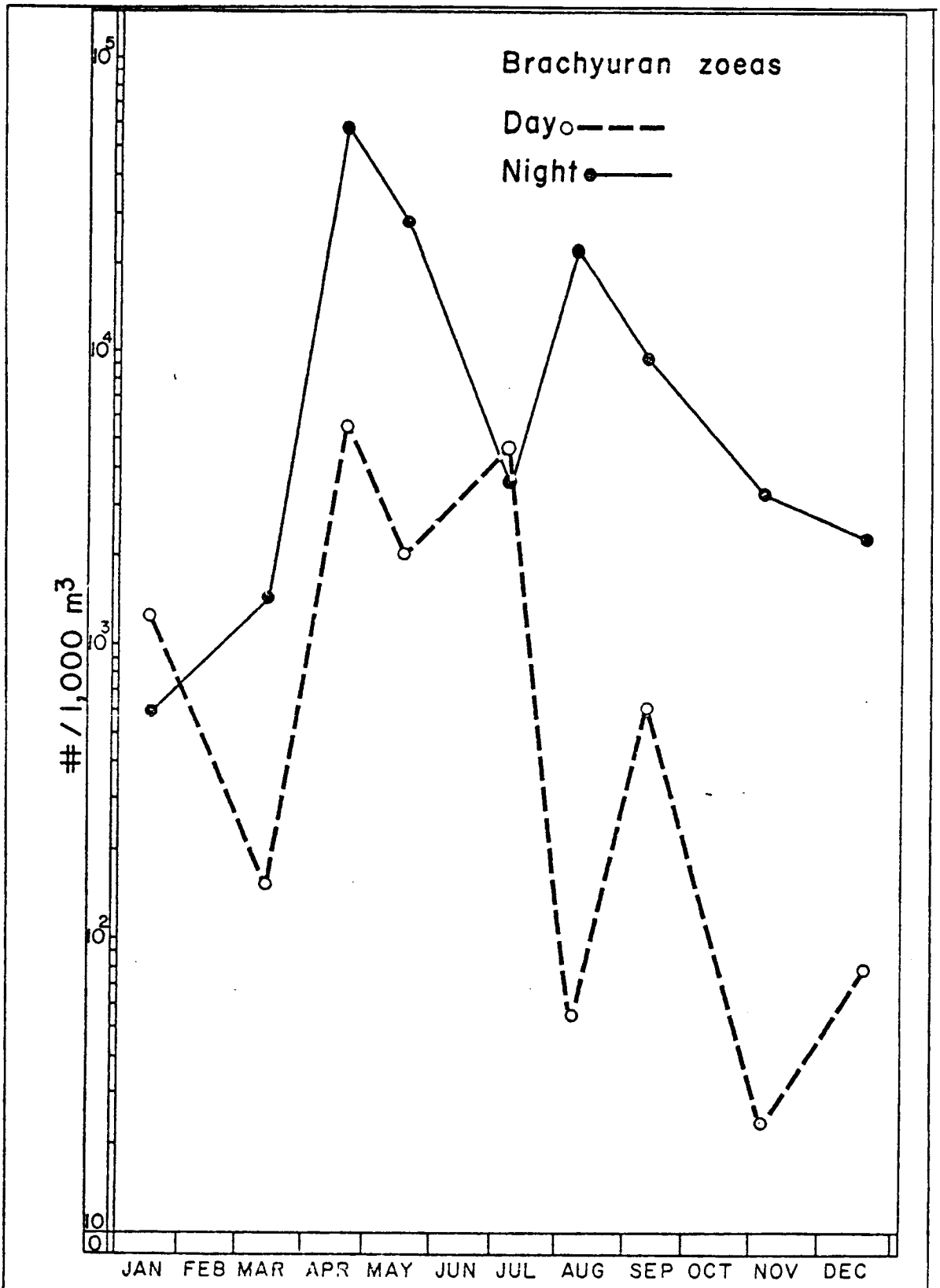


Figure 15.11 Annual Variation of Mean Day and Night Abundances Along Transect II for Brachyuran Zoeas.

changes. Brachyuran megalops (Figure 15.12) showed a very similar pattern. A number of other species groups are shown in Figures 15.13 - 15.24. A more complete interpretation of their changes will be made when all ancillary data are obtained.

Grouping Results

As in our analysis of the 1976 data the index of affinity and its associate recurrent group analysis was selected to look for species which frequently tended to be a part of each others environment. Groups of species were formed on the basis of co-occurrence in samples. This co-occurrence or level of affinity could be set at any level between 0 and 1 (total absence of affinity and complete affinity, respectively). The following formula was used:

$$\text{I.A.} = \frac{J_{ab}}{(N_a N_b)^{1/2}} - \frac{1}{2(N_b)^{1/2}}$$

where I.A. = index of affinity (0 - 1.0)

J_{ab} = joint occurrences of a, b

N_a = total occurrences of a

N_b = total occurrences of b

and $N_b \geq N_a$.

The 1977 data I.A. was set at 0.7 to be consistent with our treatment of the 1976 data. As before day (D) and night (N) were run separately. Seven day groups were obtained with the largest consisting of eight taxa (Figure 15.25). Four taxa in this group (Group 1D) were the same as for 1976 and an additional two showed associations with Group 1D of the 1976 data. Groups 2D, 3D and 5D were repeats from 1976 data.

In the night data (Figure 15.26) Group 1N had all the same taxa as Group 1N - 1976 with only one exception. It had four members which showed

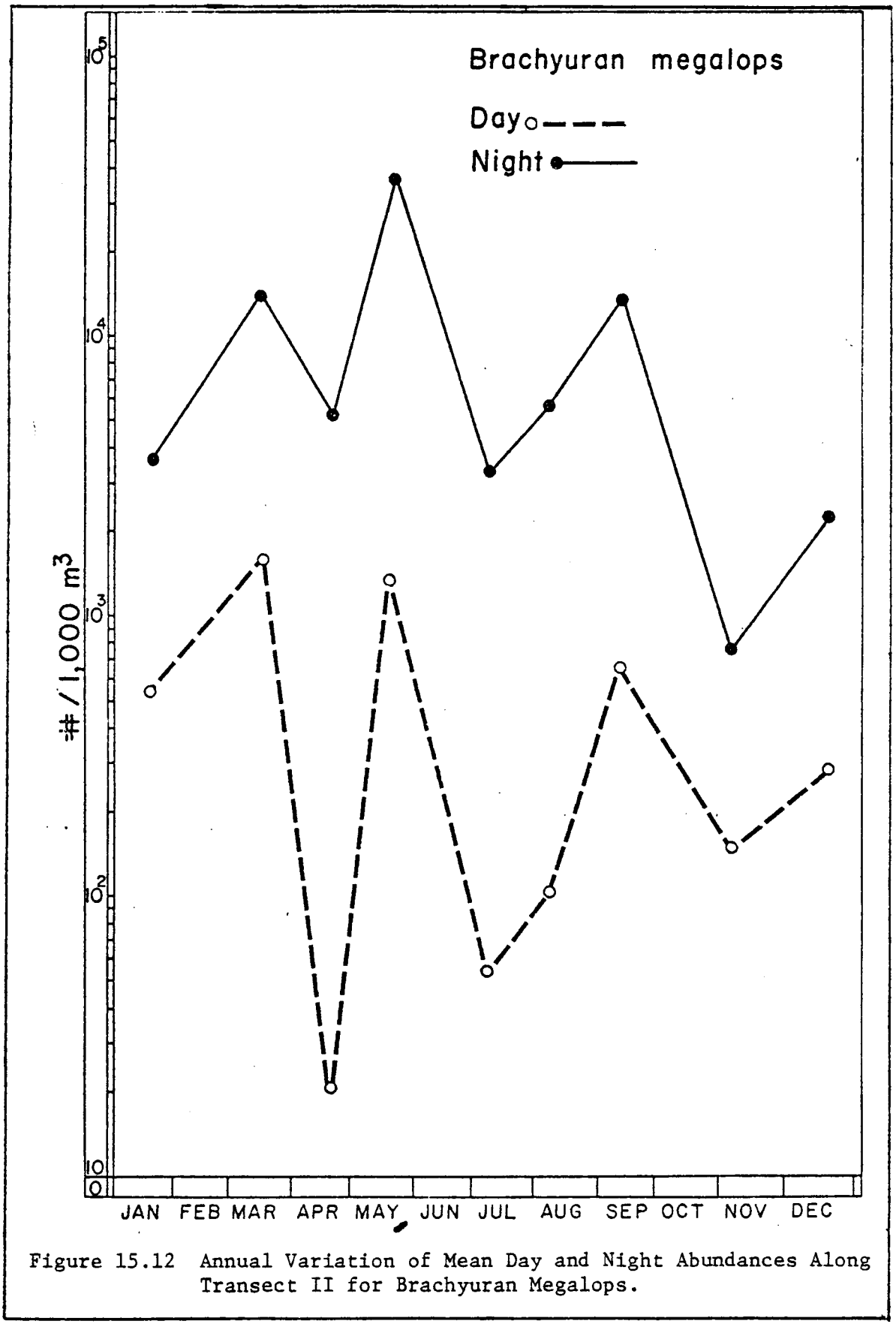


Figure 15.12 Annual Variation of Mean Day and Night Abundances Along Transect II for Brachyuran Megalops.

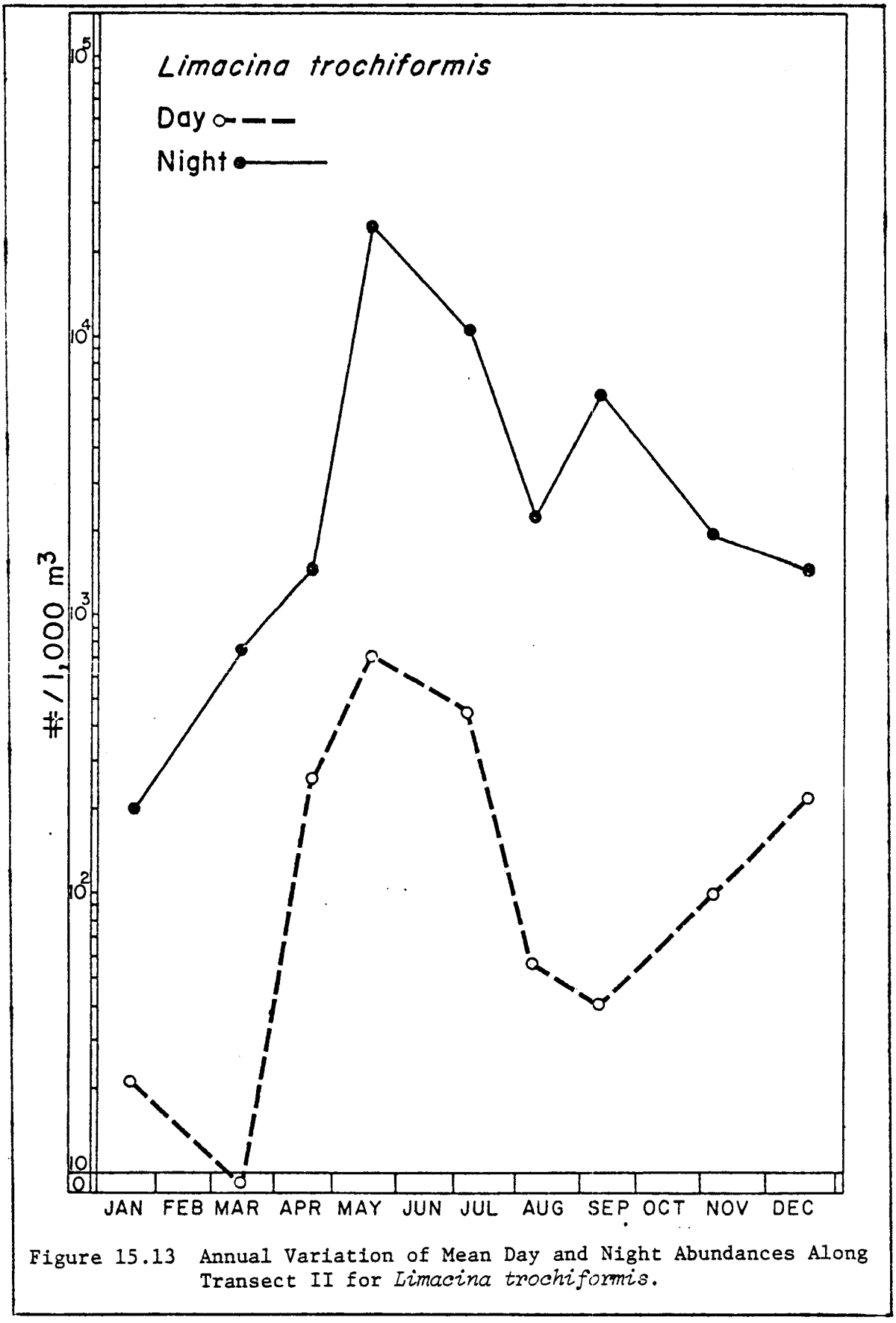


Figure 15.13 Annual Variation of Mean Day and Night Abundances Along Transect II for *Limacina trochiformis*.

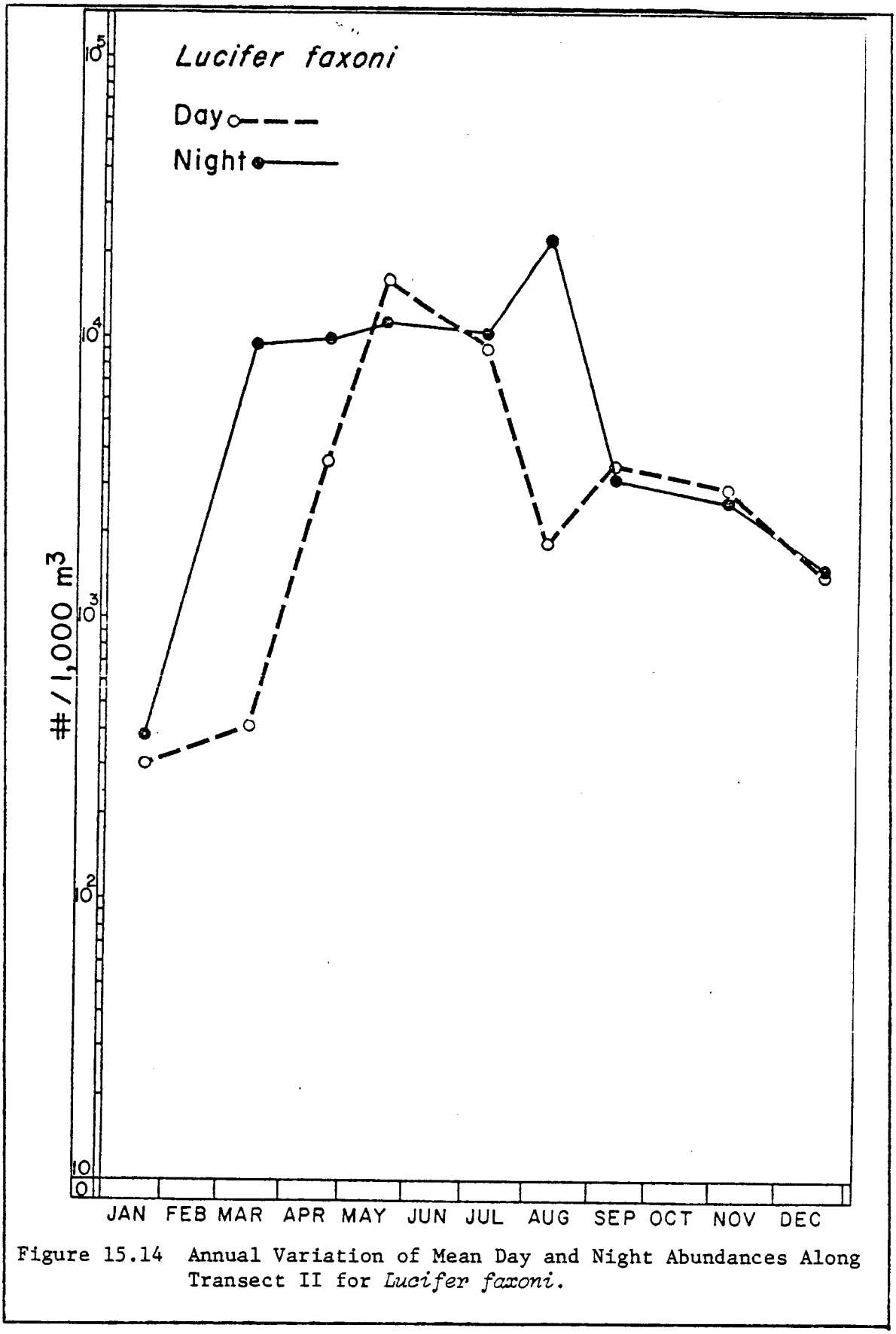


Figure 15.14 Annual Variation of Mean Day and Night Abundances Along Transect II for *Lucifer faxoni*.

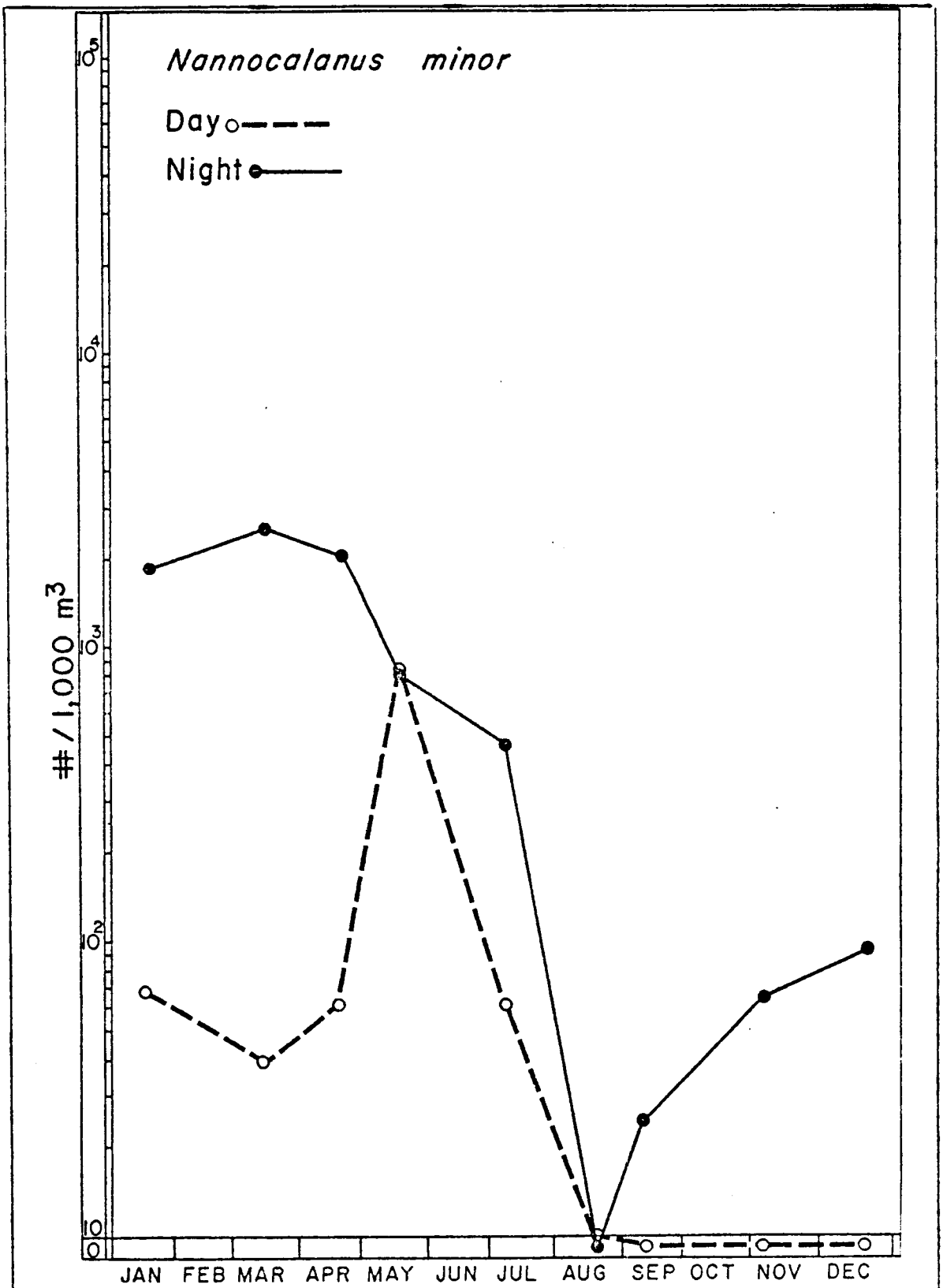


Figure 15.15 Annual Variation of Mean Day and Night Abundances Along Transect II for *Nannocalanus minor*.

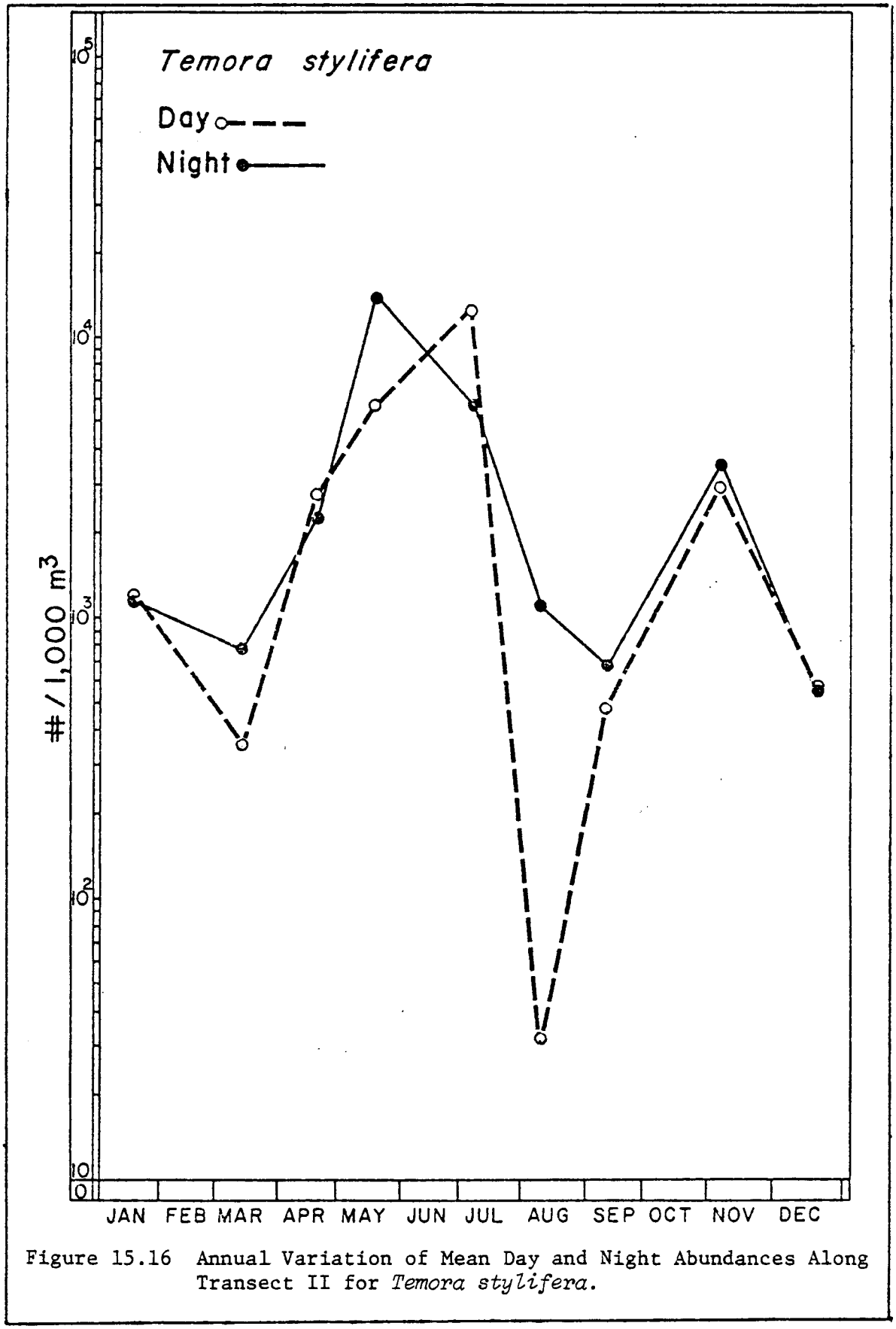


Figure 15.16 Annual Variation of Mean Day and Night Abundances Along Transect II for *Temora stylifera*.

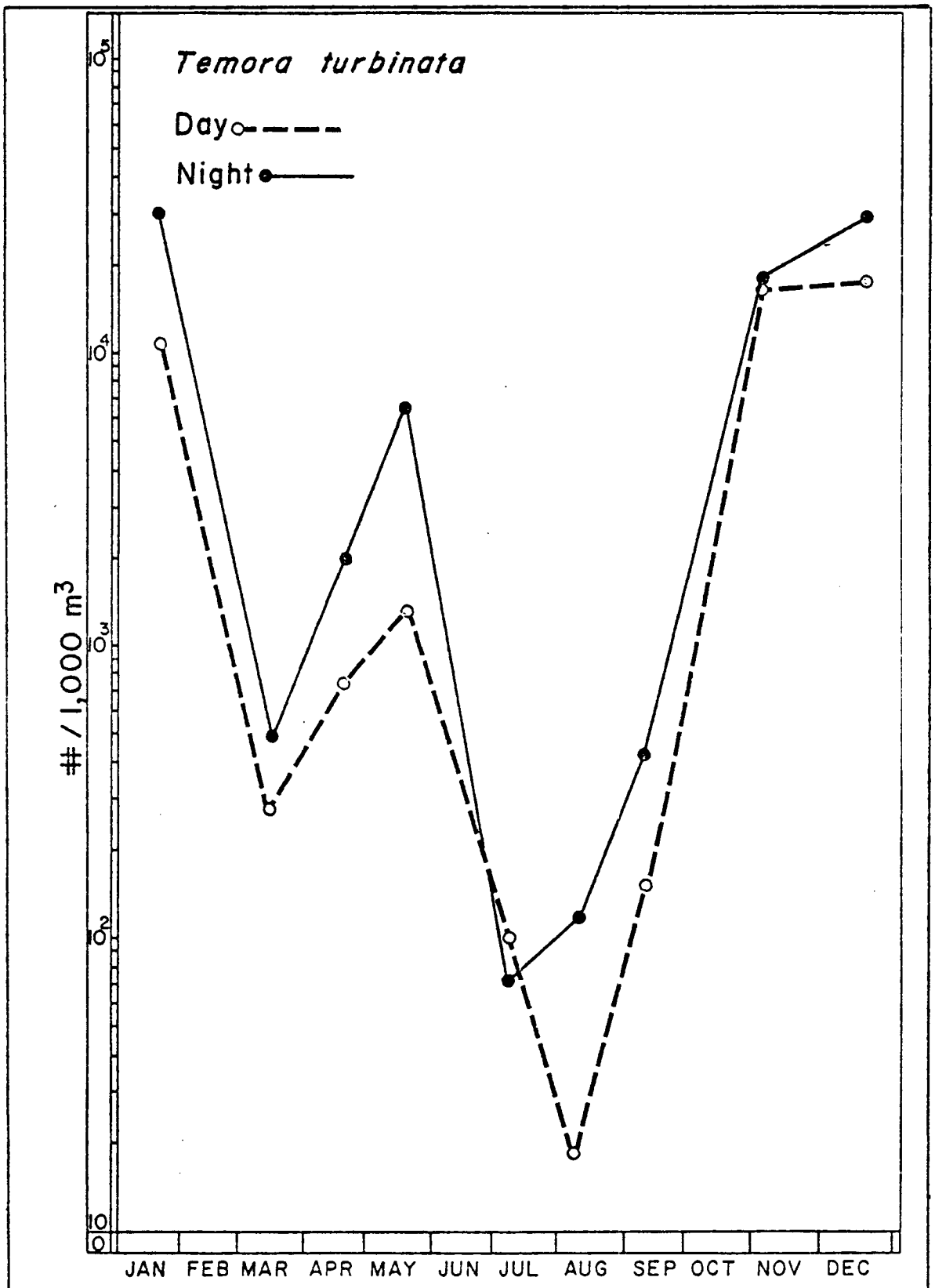


Figure 15.17 Annual Variation of Mean Day and Night Abundances Along Transect II for *Temora turbinata*.

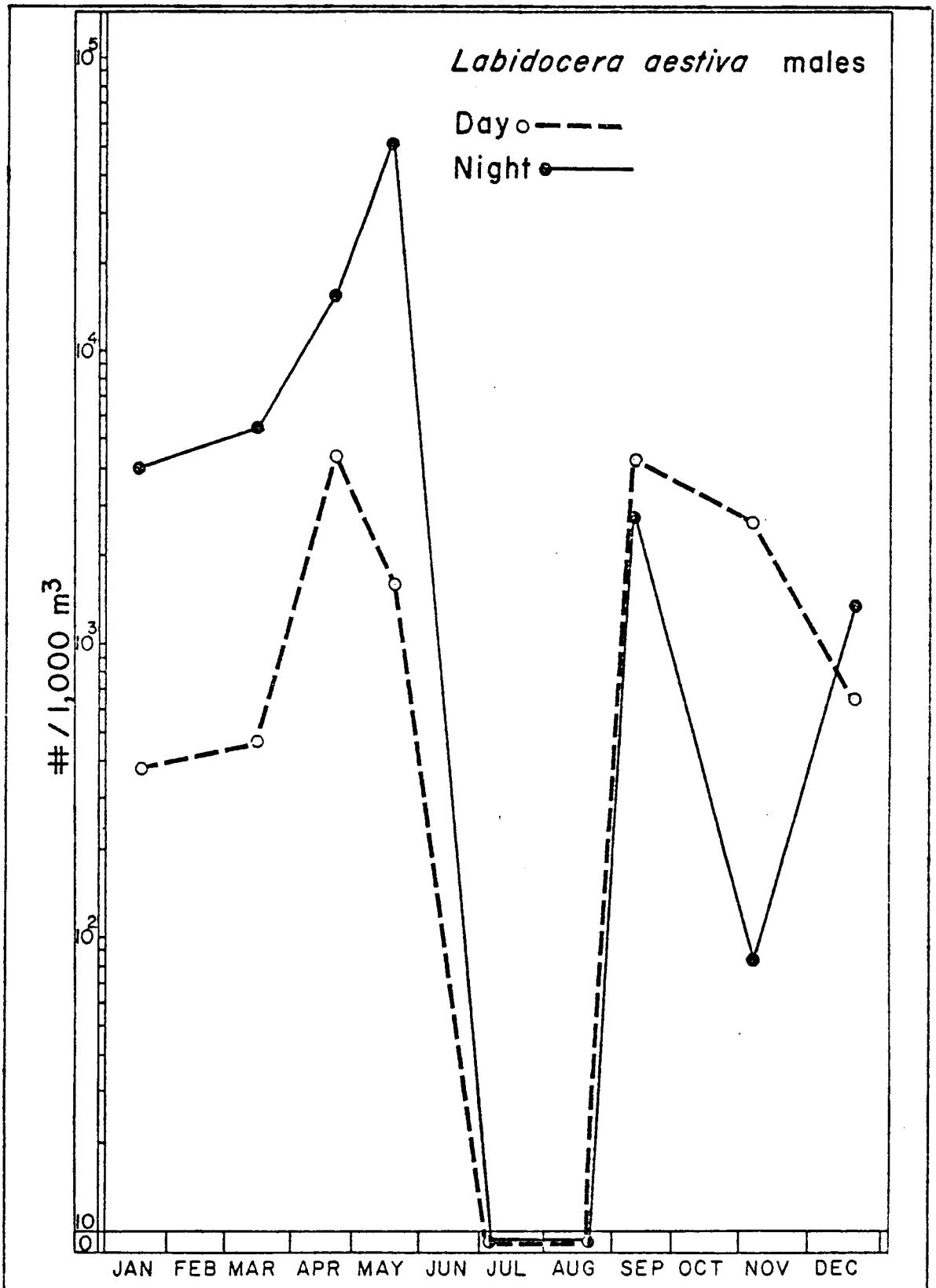


Figure 15.18 Annual Variation of Mean Day and Night Abundances Along Transect II for *Labidocera aestiva* Males.

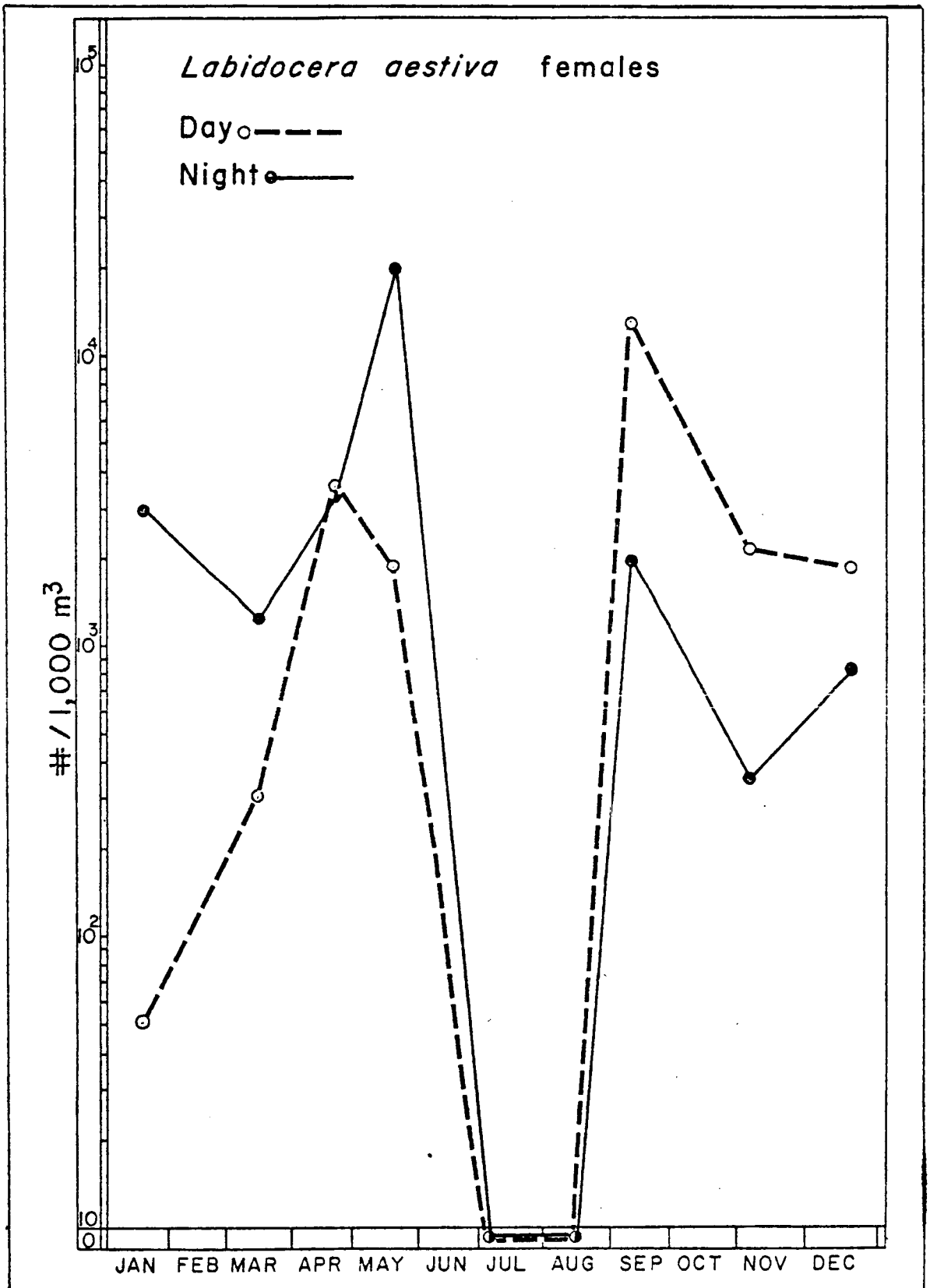


Figure 15.19 Annual Variation of Mean Day and Night Abundances Along Transect II for *Labidocera aestiva* Females.

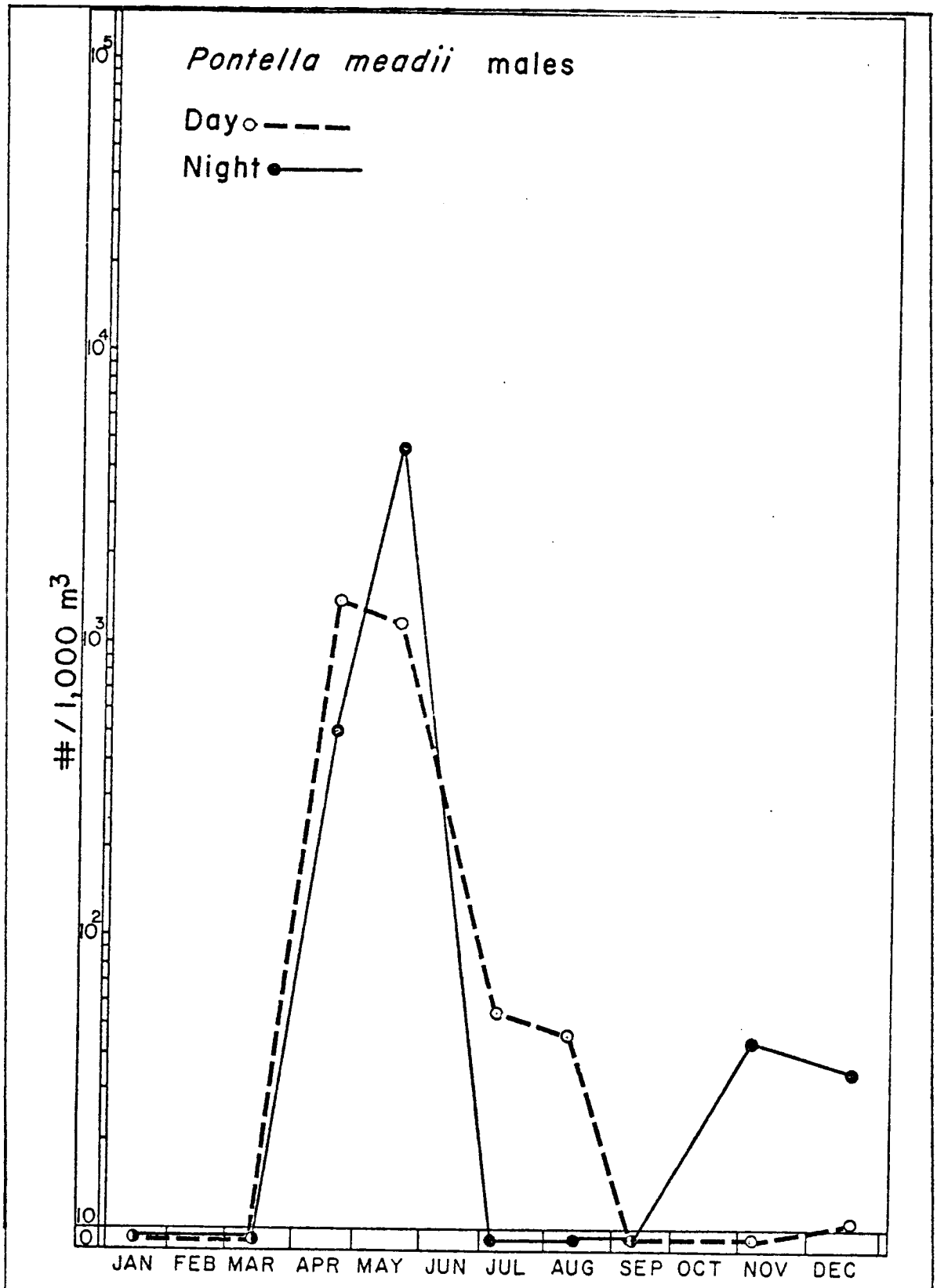


Figure 15.20 Annual Variation of Mean Day and Night Abundances Along Transect II for *Pontella meadii* Males.

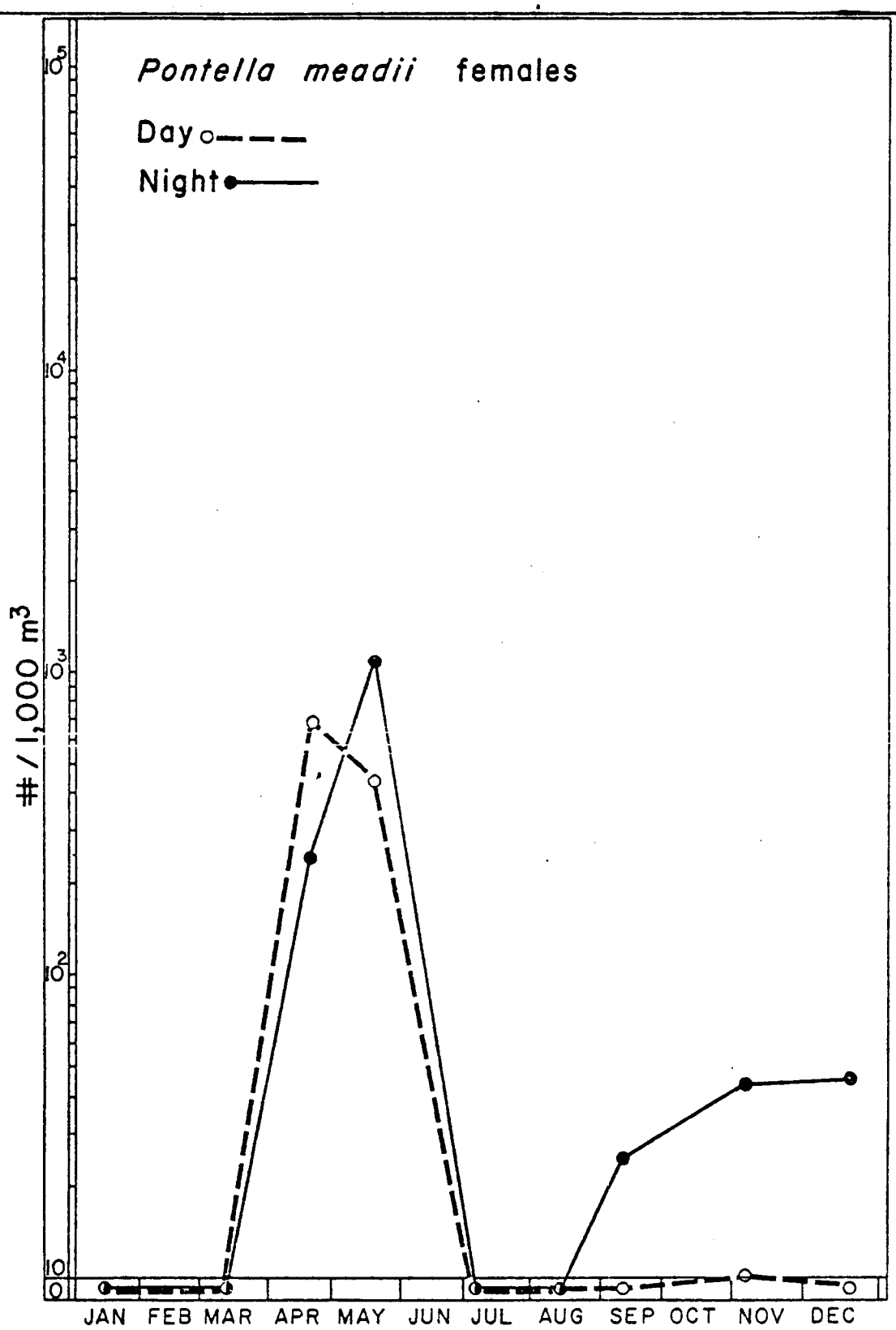


Figure 15.21 Annual Variation of Mean Day and Night Abundances Along Transect II for *Pontella meadii* Females.

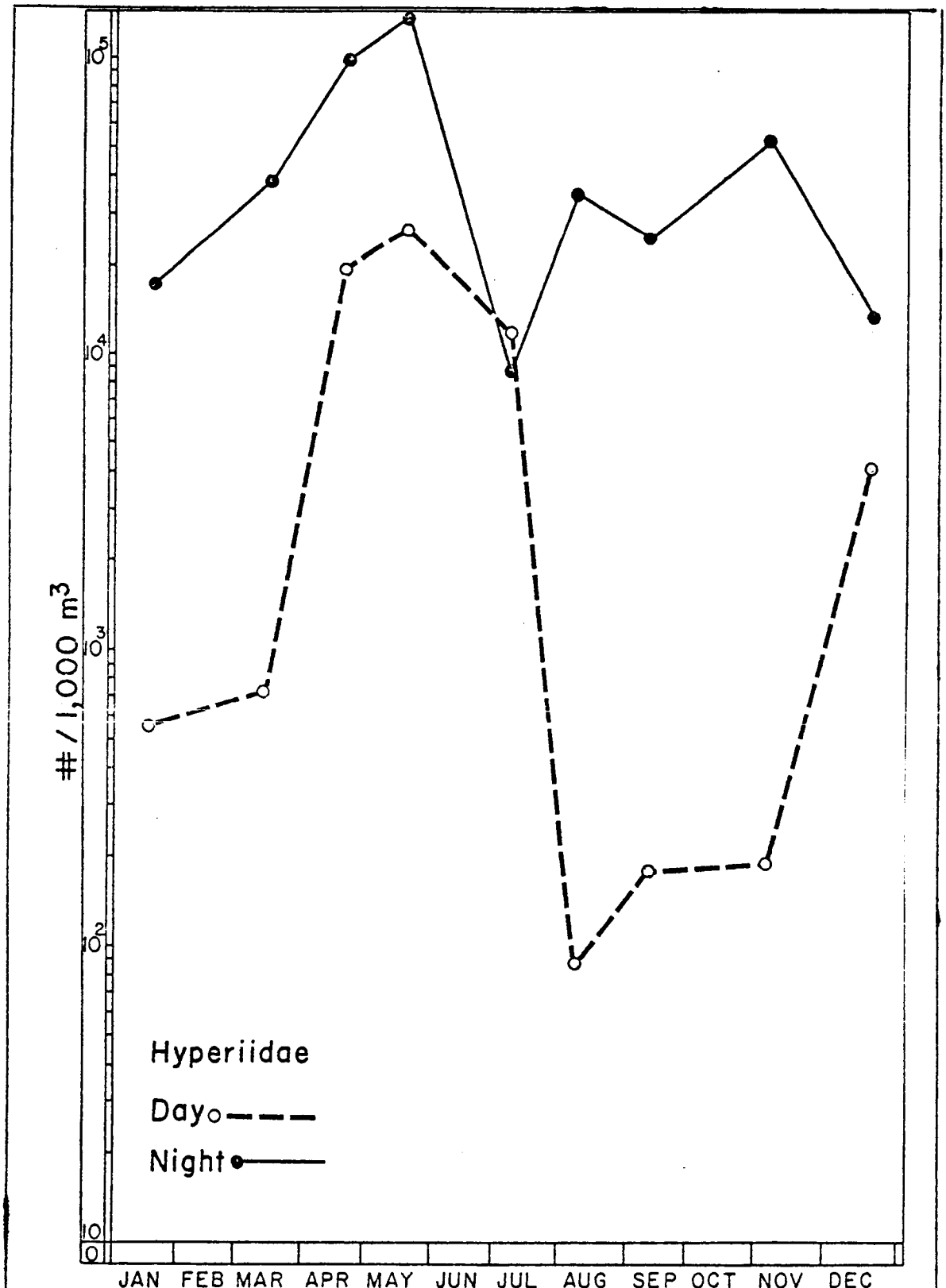


Figure 15.22 Annual Variation of Mean Day and Night Abundances Along Transect II for Hyperiidae.

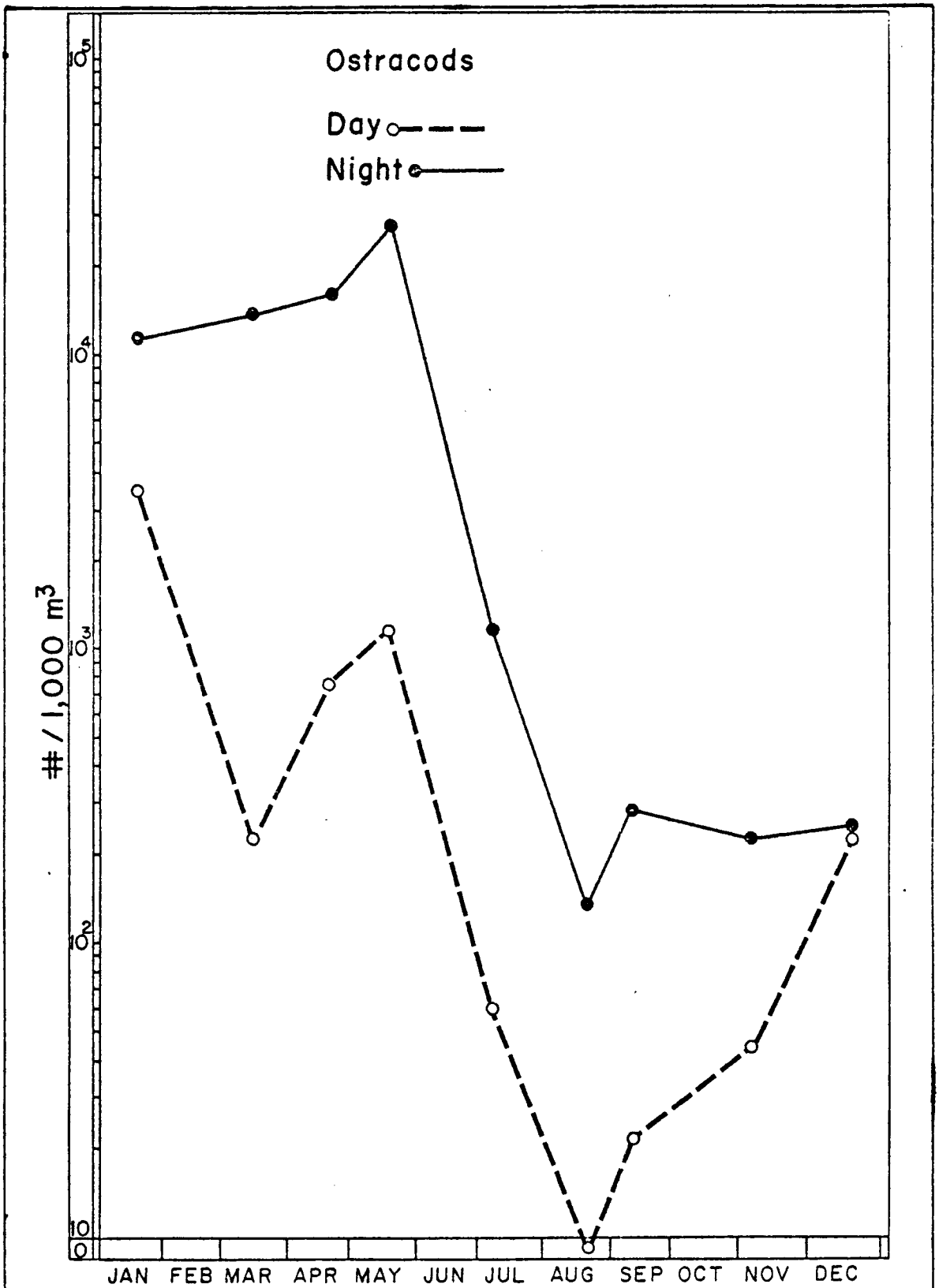


Figure 15.23 Annual Variation of Mean Day and Night Abundances Along Transect II for Ostracods.

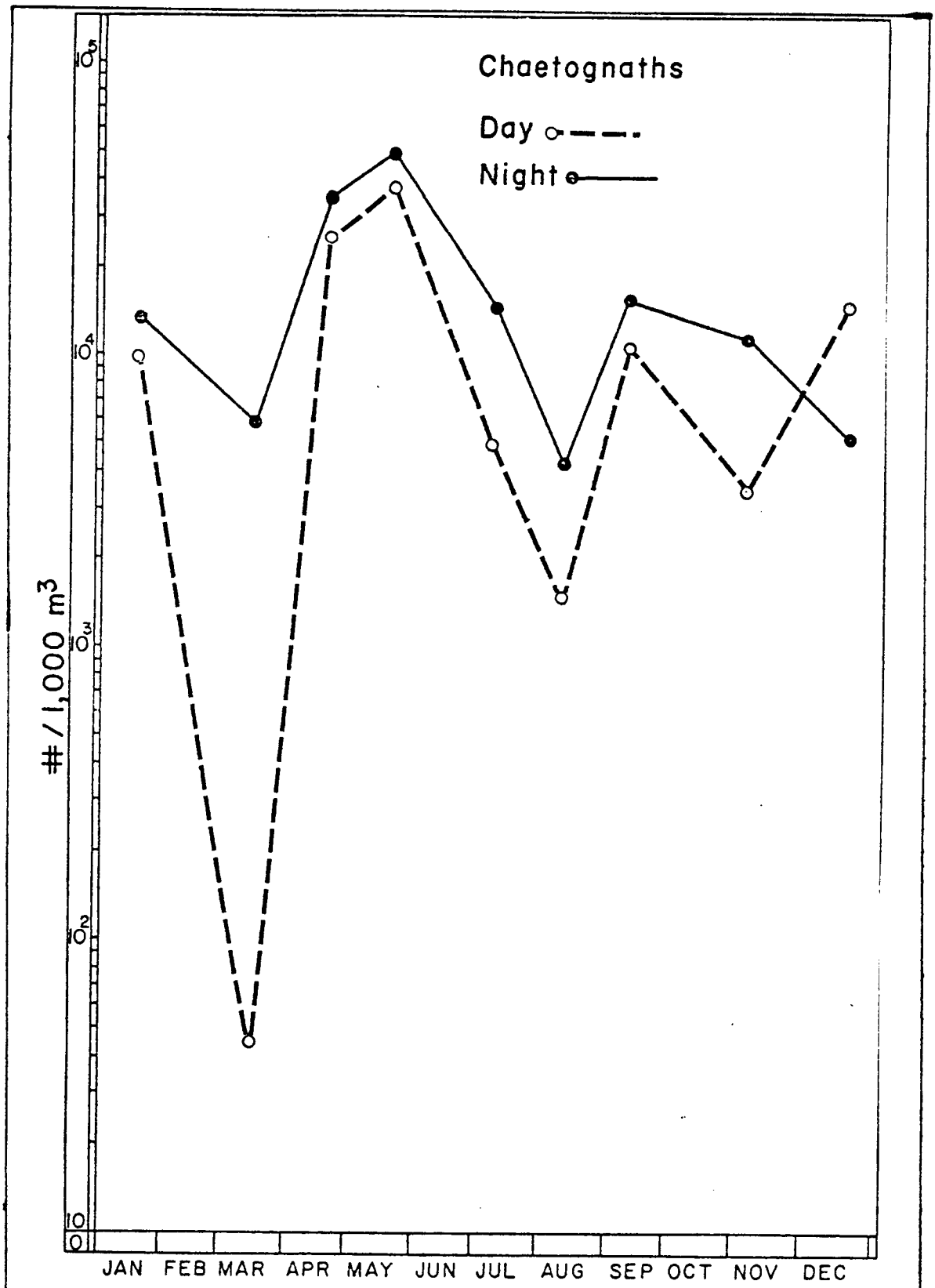


Figure 15.24 Annual Variation of Mean Day and Night Abundances Along Transect II for Chaetognaths.

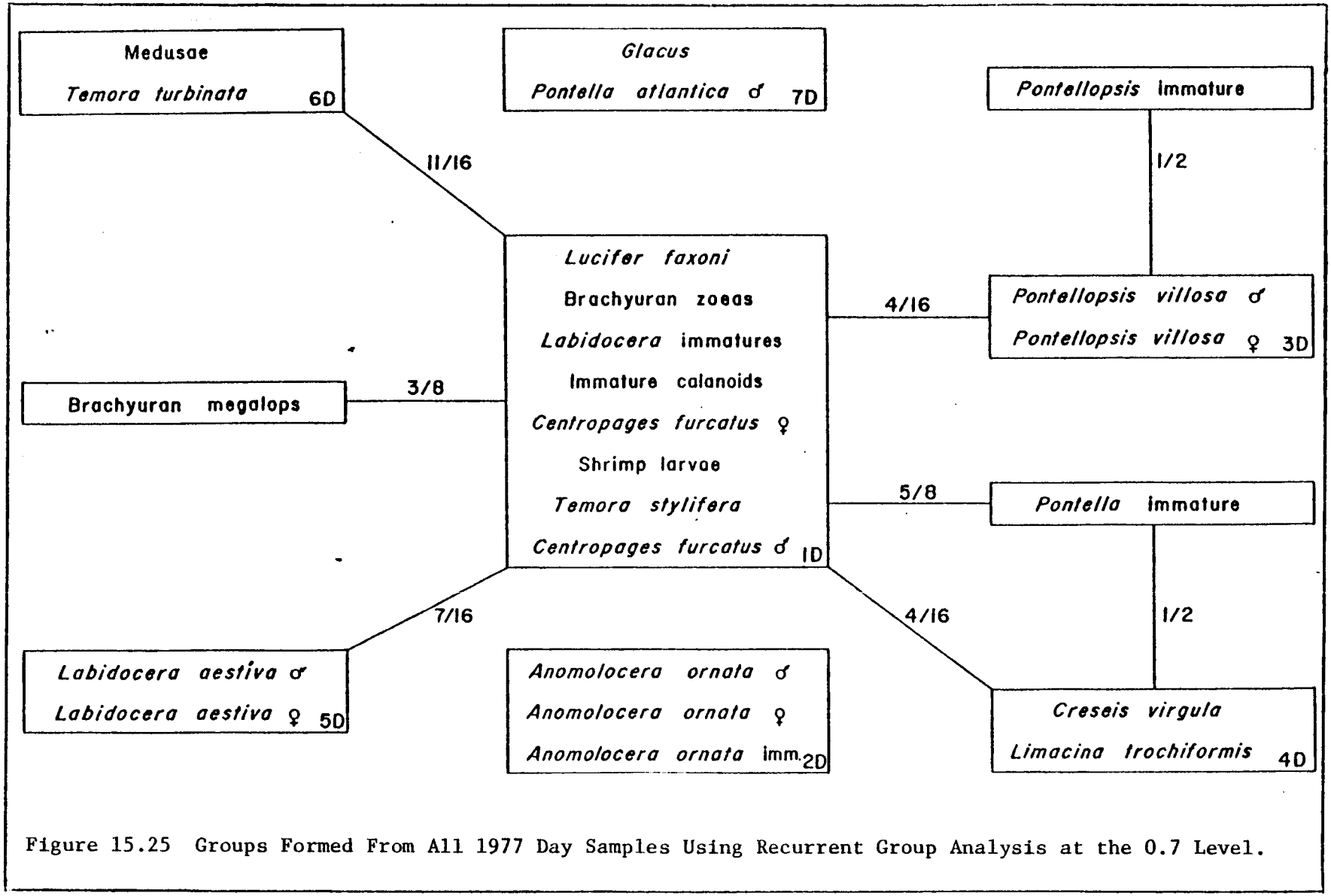


Figure 15.25 Groups Formed From All 1977 Day Samples Using Recurrent Group Analysis at the 0.7 Level.

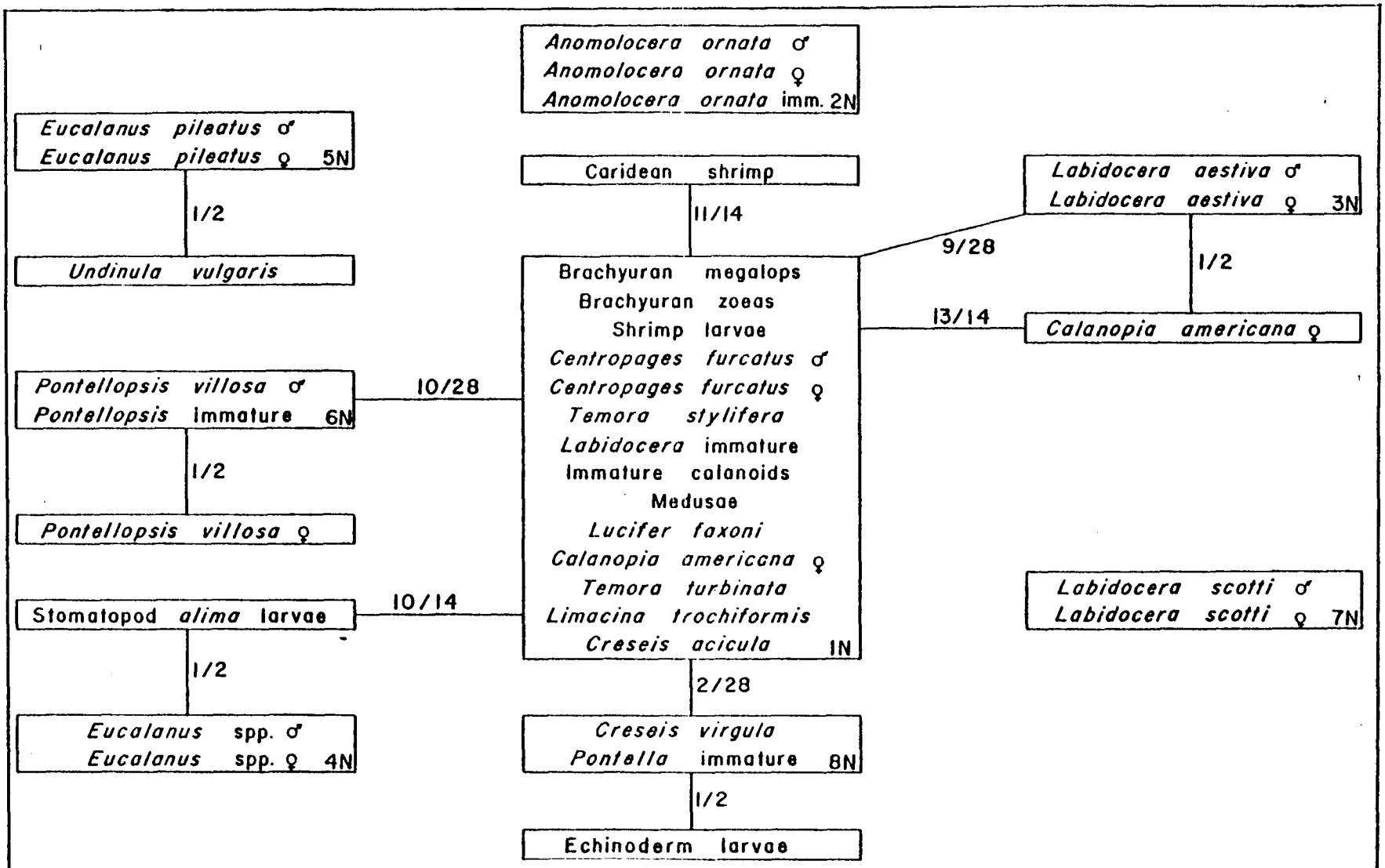


Figure 15.26 Groups Formed From All 1977 Night Samples Using Recurrent Group Analysis at the 0.7 Level.

associations with Group 1N - 1976. Groups 2N, 3N and 6N were repeats.

The similarities in the 1976 and 1977 Day and Night groups were very encouraging. More detailed analysis of quantitative aspects of these associations is now underway.

DISCUSSION

There are a number of findings in the 1977 data which, when taken together with the 1976 findings, represent significant results. These are:

1. The repetition of the cycle for *Anomalocera ornata* in 1976 and 1977 represents the strongest signal in the two years of data. This species should also receive special attention in the zooplankton program.

2. The similarities in the species groupings for the two years strongly suggest that there are groups of species that tend to be a fairly constant feature of the STOCS environment. More detailed examination of the seasonal occurrence and quantitative aspects of these groups should be done.

3. The large variability in the results of the dry weights indicates that this is a low return measurement and it is suggested that it be discontinued in future studies. It is presently impossible to determine the signal due to the high noise level.

Decapods and Decapod Larvae

A total of 77 decapod taxa, including the different larval stages, were identified from 1977 STOCS neuston samples. This compares to 85 decapod taxa from the 1976 samples.

Along Transect II (the only transect sampled monthly during 1977) (Figure 15.27), the decapod larvae reached peak concentrations in the

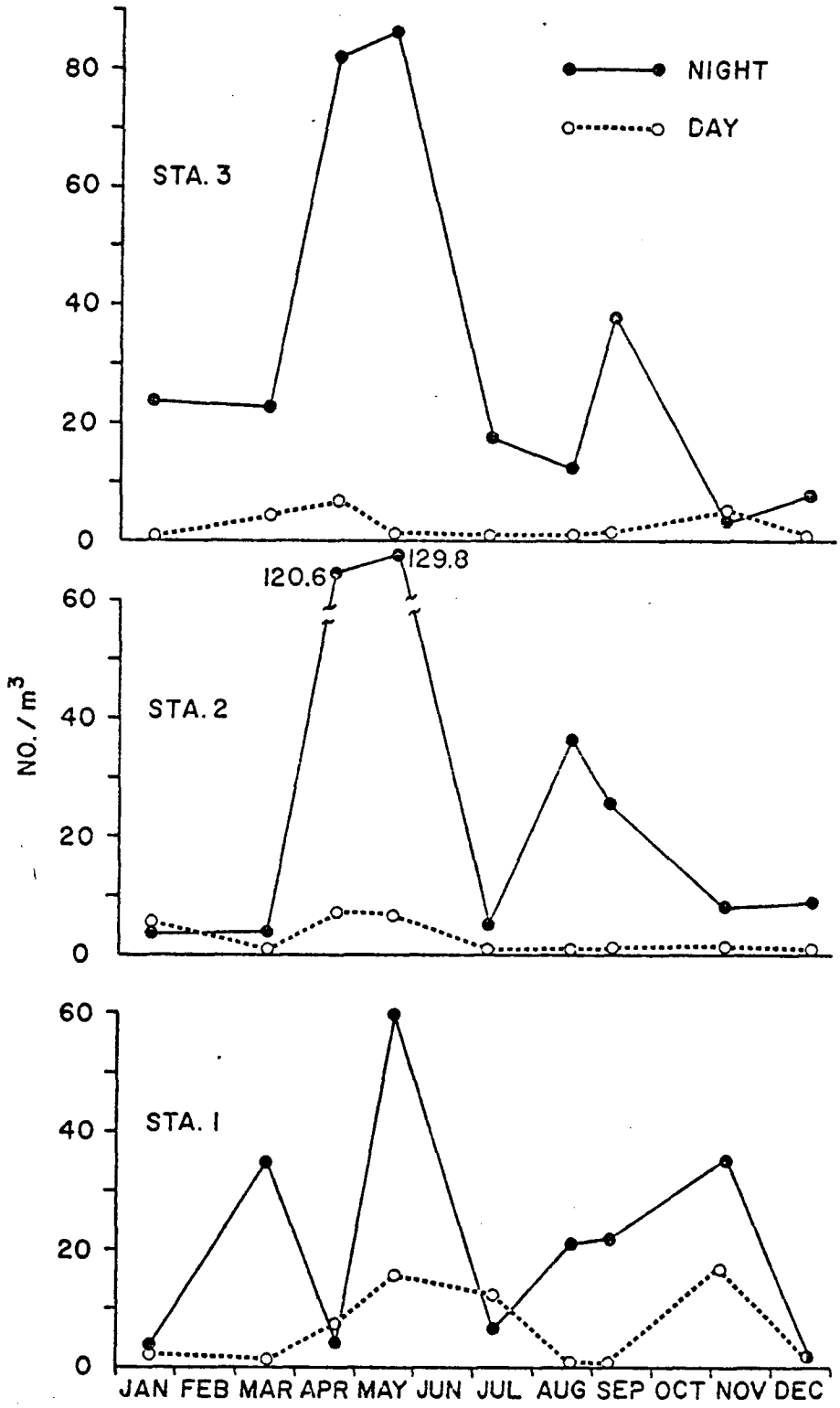


Figure 15.27 Annual Variation of Decapod Larvae at Transect II Stations for 1977.

spring (April and May) and again in the fall (August-November), especially in the night samples, which were nearly always higher in decapod larvae than the daytime samples. The 1976 neuston data showed similar spring and fall-winter peaks of decapod larvae with slight variations in onset or duration of peaks. For example, the Station 3 spring peak was confined to late March in 1976, while it spanned April and May in 1977. The Station 1 fall peak was confined to late August in 1976, while in 1977 it spanned September to November.

Maximum concentrations of decapod larvae occurred at Station 2/II in April and May night samples (120.6/m^3 and 129.8/m^3, respectively), but with completely different taxa accounting for the peaks during each month. The April sample from Station 2/II contained 14 decapod taxa and the dominant decapod larvae were portunid crab zoeas (*Callinectes* sp. and *Portunus* sp.) (76.7/m^3) and sp. E megalopa crab larvae (10/m^3). In May, at this station, the decapod species diversity was greater (25 taxa) and the dominant decapod larvae were penaeid shrimp zoeas of *Xiphopenaeus* (39/m^3), xanthid crab zoeas of *Menippe mercenaria* (12/m^3) and sp. I crab megalopas (11.7/m^3).

The April and May peaks in decapod larvae in the night samples from Station 2/II were also reflected in the night samples from Station 3/II, but at somewhat lower concentrations (82/m^3 for April and 85.8/m^3 for May). The dominant decapod larvae at Station 3/II in April were similar to those at Station 2/II for the same month (Portunid crab zoeas, 68.8/m^3), but the diversity was considerably less, with only six decapod taxa represented. At the same station in May, however, the dominant decapod larvae were Portunid crab megalopas (44.8/m^3), sp. E crab megalopas (19/m^3), and sp. B crab megalopas (12/m^3), and there were nine decapod taxa.

The smaller "fall" peaks occurred at Station 1/II in November (35.8/m^3, 11 taxa, with sergestid shrimp zoeas accounting for 27.7/m^3 and stenopodid

shrimp zoeas for 2/m^3), at Station 2/II in August (36.4/m^3, 14 taxa, with *Callinectes* crab zoeas dominant at 26.8/m^3), and at Station 3/II in September (37.8/m^3, 16 taxa, with portunid crab megalopas dominant at 15/m^3 and *Callinectes* zoeas at 8/m^3).

The nighttime samples were nearly always higher in decapod larval concentrations then the daytime samples. The daytime concentrations at Station 1 tended to be generally higher than at the two offshore stations, and tended to reflect the nighttime peaks in spring and fall, but on a lower level of concentration. This was also true of the 1976 samples. The levels of concentration of decapod larvae in 1977 during the spring peaks were greater than in 1976, *e.g.*., 219.8/m^3 for the 1977 spring peak at Station 2/II/N compared to 38.6/m^3 for the same station during the 1976 spring peak.

Figure 15.28 compares the numbers of decapod larvae in day samples from Transects I, II, III and IV during the seasonal sampling periods of winter (January), spring (May), and fall (September). Along Transect I there were peak concentrations of decapod larvae in September at Stations 1 and 3 (62.9/m^3 and 63.4/m^3, respectively). Both Stations were dominated by portunid crab megalopa (8.3/m^3 at Station 1 and 58.2/m^3 at Station 3). Pagurid (hermit crab) zoeas also accounted for 7.5/m^3 at Station 1. Station 1/I fall had a greater species diversity of decapods with 24 taxa while Station 3/I fall had only 10 decapod taxa. Why Station 2/I did not reach such high decapod larvae concentrations in September could not be explained, except it was noted that the dominant taxa (portunid crab megalopas) at Station 2 were the same as those at the other two stations, but in much lower concentrations (1.7/m^3).

Only one other major peak in decapod larvae numbers stood out among the seasonal day samples, and that was also in September from Station 1,

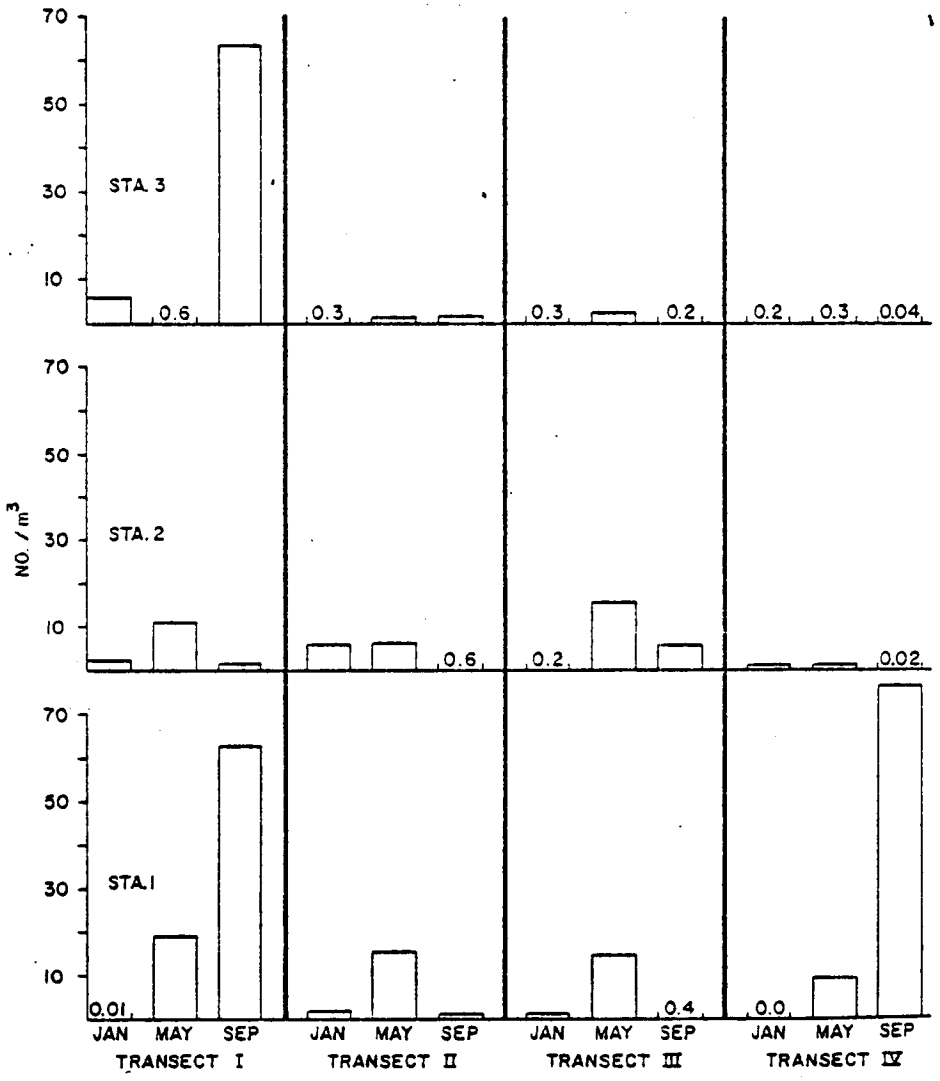


Figure 15.28 Decapod Larvae in Day Samples for Seasonal Cruises, All Stations.

Transect IV (76.8/m^3). There was a high species diversity of decapods (31 decapod taxa) and the dominant decapod larvae were pinnotherid crab larvae (17.7/m^3), sergestid shrimp zoeas (15.4/m^3) and portunid crab megalopas (13.8/m^3). These daytime high concentrations were considerably higher than the highest daytime concentrations from the 1976 samples, where the highest daytime concentration of decapod larvae reached only 16.2/m^3 (at Station 3/IID fall).

In most of the 1977 samples decapod species diversities were greater at night than in the day (see Tables 15.3 and 15.4). This was to be expected because of the known nocturnal migrations of many decapods, especially decapod larvae, toward the surface. Transect II was the only transect sampled at night during 1977. Looking at those night samples only, the decapod species diversity was found to range from a low of six taxa (at Station 1/II/N winter, Station 3/II/N April, and Station 2/II/N July) to a high of 32 taxa (at Station 1/II/N spring). The average species diversity for night samples was 15.1 decapod taxa while that for day samples was 6.4 taxa.

Table 15.3 presents decapod species diversity averages from Transect II showing nearshore-offshore differences, seasonal differences, and day-night differences. The nearshore station (Station 1) showed the highest average diversity of decapods in day and night samples combined (12.4 taxa) with the intermediate station (Station 2) next highest (10.8 taxa) and the offshore station (Station 3) the least diverse (8.8 taxa). Spring had the highest average species diversity (17.9 taxa), followed by fall (12.4 taxa), and winter had the lowest (8.7 taxa).

Considering the average species diversities for daytime samples from all four transects, Transect I had the greatest (9.4 decapod taxa), then Transect II (8.9 taxa), Transect III (8.7) and Transect IV (6.6)(Table 15.4).

TABLE 15.3

SPECIES DIVERSITY AVERAGES FOR DECAPOD CRUSTACEA
IN TRANSECT II NEUSTON SAMPLES FOR 1977

NEARSHORE-OFFSHORE DIFFERENCES:	NEARSHORE (STA. 1)	INTERMEDIATE (STA. 2)	OFFSHORE (STA. 3)
DAY	8.3	5.3	5.6
NIGHT	15.7	16.3	12.1
DAY & NIGHT	12.4	10.8	8.8

SEASONAL DIFFERENCES:	WINTER	SPRING	FALL
DAY	6.3	13.7	6.7
NIGHT	11.0	22.0	18.0
DAY & NIGHT	8.7	17.9	12.4

OVERALL DAY-NIGHT DIFFERENCES:	DAY	NIGHT
	6.4	15.1

TABLE 15.4

SPECIES DIVERSITY AVERAGES FOR DECAPOD CRUSTACEA
IN DAYTIME SEASONAL NEUSTON SAMPLES FOR 1977

GEOGRAPHICAL (TRANSECT) DIFFERENCES:	Tr. I	Tr. II	Tr. III	Tr. IV
	9.4	8.9	8.7	6.6

SEASONAL DIFFERENCES:	WINTER	SPRING	FALL
	4.6	10.4	10.2

NEARSHORE-OFFSHORE DIFFERENCES:	STA. 1	STA. 2	STA. 3
SEASONAL (DAY) SAMPLES:	11.3	7.3	6.5
ALL (DAY) SAMPLES:	9.9	5.9	6.1

Comparing seasonal differences in average species diversities for day samples from all transects, spring was the highest with 10.4 decapod taxa, followed by fall with 10.2 taxa, and then winter with only 4.6 taxa (Table 15.4).

The holoplanktonic sergestid shrimp, *Lucifer faxoni*, frequently occurred in very high numbers in south Texas neuston samples and ranked first in numerical dominance of decapod taxa in both 1976 and 1977 samples. Figure 15.29 shows the numerical concentrations of *Lucifer faxoni* in day and night samples throughout 1977 from Transect II. The greatest concentrations occurred at Station 1 with maxima of 44 and 47/m^3 in May (daytime) and August (nighttime) samples. These concentrations were low compared to the 1976 station 1 maxima of 147 and 186/m^3 in June and August. At Stations 2 and 3 the concentrations were generally lower than at Station 1, and the nighttime concentrations nearly always exceeded the daytime concentrations at these two offshore stations on Transect II.

The other transects, at which only day samples were taken (Figure 15.30), also showed generally higher concentrations of *Lucifer faxoni* at Stations 1, and the lowest concentrations at Stations 3. Stations 2 generally showed intermediate numbers of *L. faxoni*, except for the dramatically high concentration of 416/m^3 at Station 2/IV/D in May. Although *L. faxoni* tended to reach its highest concentrations in May at most stations, this was not consistently true for all stations. It is interesting to note that *Lucifer typus*, which is an indicator of open ocean water and occurred in 1976 only at the offshore stations (Station 3) between June and November, did not appear at all in 1977 samples.

Appendix N, Table 2 presents a listing of the numerically dominant decapod taxa at each station sampled during 1977, their concentration, and percentage of total decapods in the sample.

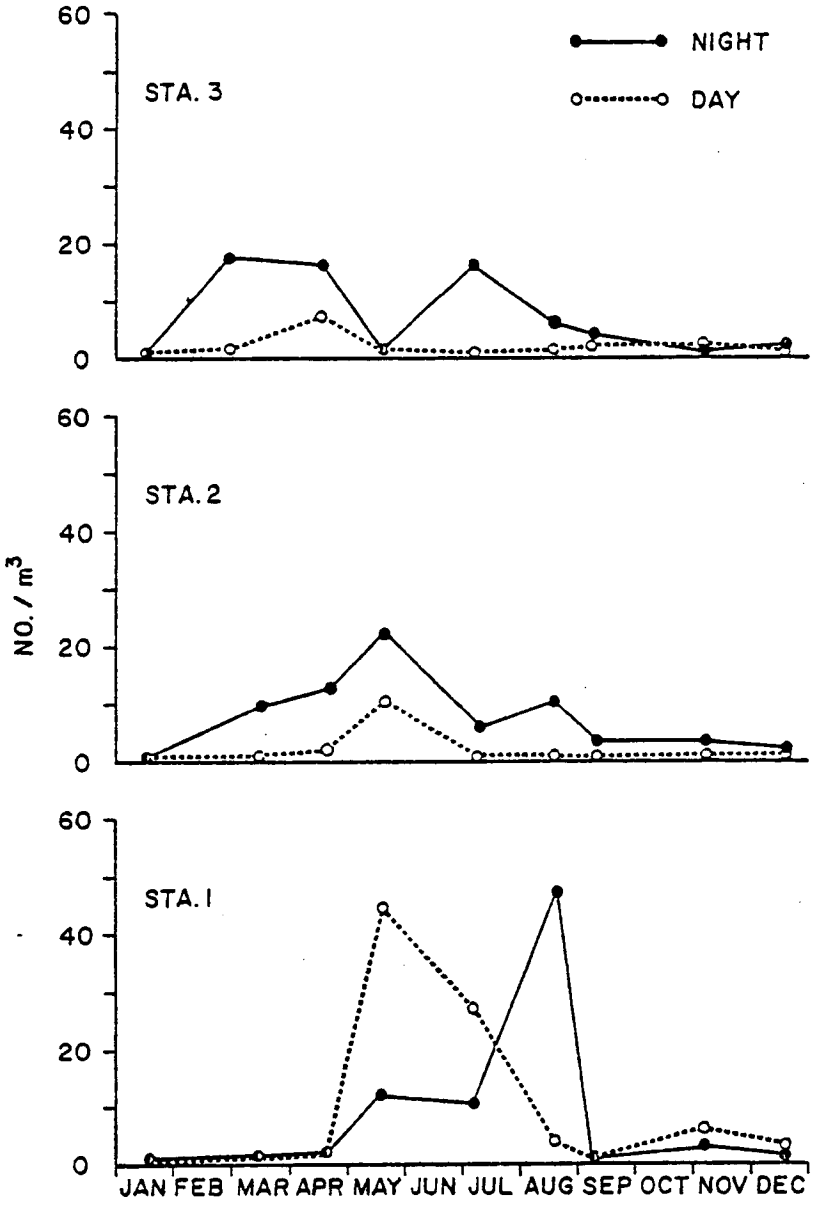


Figure 15.29 *Lucifer faxoni* at Transect II during 1977.

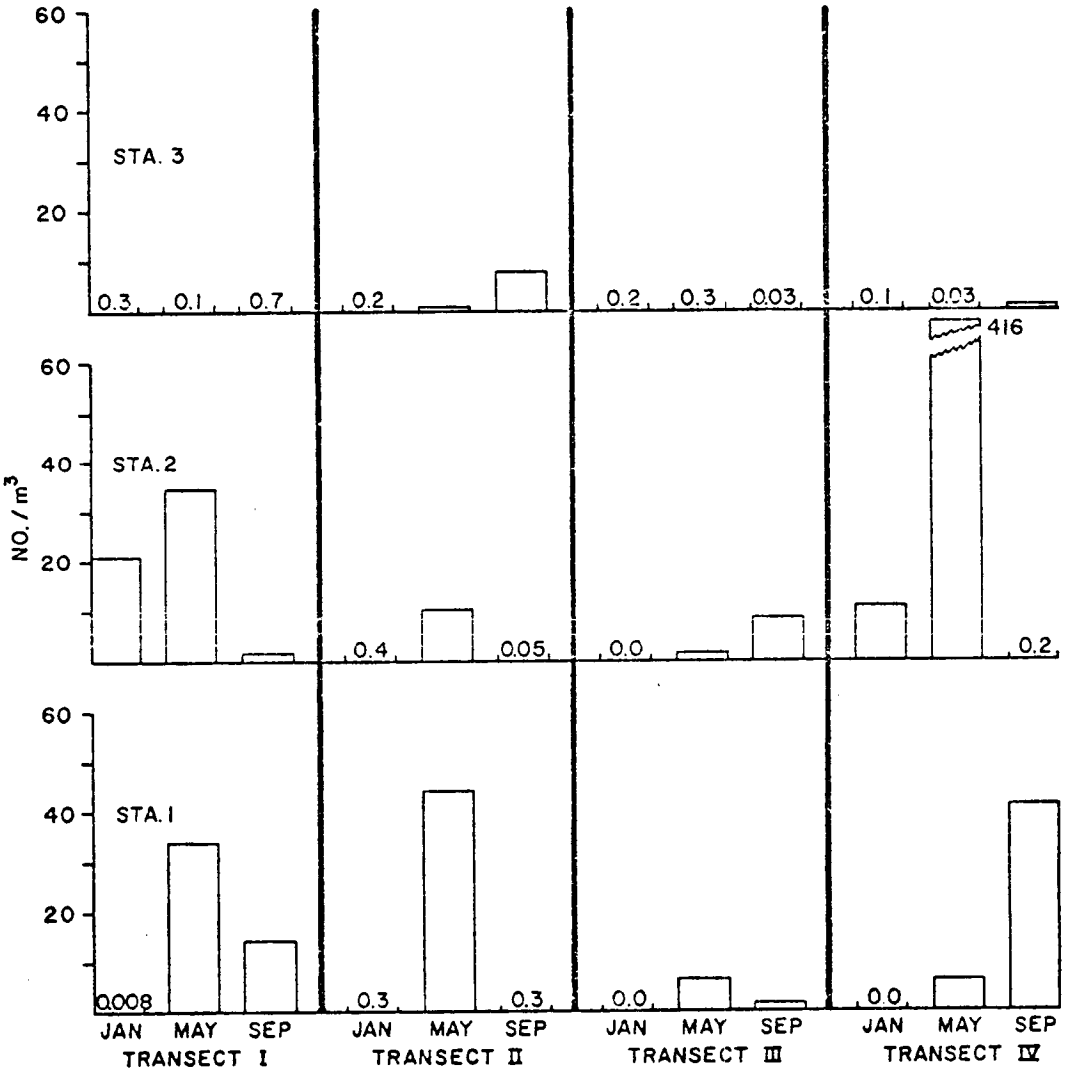


Figure 15.30 *Lucifer faxoni* from 1977 Daytime Seasonal Neuston Samples at Transects I, II, III and IV.

The dominant decapod taxa of the 1977 neuston samples may be ranked in order of dominance as follows: *Lucifer faxoni, Callinectes* zoeas, Portunid megalopas, *Portunus* zoeas, *Trachypenaeus* zoeas, Alpheid zoeas, Sergestid sp. A postlarvae, Sp. E megalopas.

Portunid crab larvae were frequently the dominant decapods, especially in night samples. The highest concentrations of portunid zoeas (*Callinectes* and *Portunus*) occurred in April samples from Transect II with concentrations of $77/m^3$ at Station 2/II/N and $69/m^3$ at Station 3/II/N.

Portunid megalopa larvae were most abundant at offshore stations in spring and fall with $58/m^3$ at Station 3/I/D fall and $45/m^3$ at 3/II/N spring. Portunid megalopa also occurred in greatest concentrations at offshore stations in 1976, but reached their highest peaks in the months of February and June.

Penaeid shrimp larvae were more abundant in 1977 than in 1976. They occurred primarily in spring samples and reached concentrations up to $39/m^3$ (*Xiphopenaeus*) and $7/m^3$(*Trachypenaeus*).

Pinnotherid crab zoeas were less abundant in 1977 than in 1976, and occurred primarily at the nearshore stations (Stations 1) as was the case in 1976. In 1977 they were most abundant from May through September with a maximum concentration of $19/m^3$ (Pinnotheridae sp. A) at Station 1/II/N August.

In general, it may be said that there were many similarities in geographical and seasonal occurrences of decapod taxa between 1976 and 1977. Unique peak occurrences of certain taxa at certain locations and times were difficult to explain, *e.g. Lucifer faxoni* at Station 2/IV/D spring in concentrations of $416/m^3$, nearly 10 times its concentration at any other 1977 neuston station. Possibly during the data synthesis phase of these studies, certain detailed correlations can be made with these drama-

tic peaks in concentrations and other biological, chemical or physical parameters. It is also expected that some of the brachyuran crab megalopa, designated in this report as sp. A, sp. B, etc., will be assigned to more specific taxa during the data synthesis so they can be related more specifically to their benthic adult stages.

Ichthyofauna

A total of 1,932,166 eggs and 280,683 larvae were captured during the 1977 neuston survey (Appendix N, Table 3). During the 1977 cruises the greatest abundance of eggs (62%) was captured in the spring. Larvae were also most abundant in July (37%) on the monthly cruises and in the spring (45%) on the seasonal cruises. The November cruise yielded the lowest number of eggs and larvae of the monthly cruises and the winter cruises yielded the lowest number of eggs and larvae of the seasonal cruises.

A total of 71 taxa of larval fishes were collected in nearly equal increments during the year. Number of taxa on the monthly cruises ranged from 27 and 24 during the winter and fall seasonal cruises to 12 taxa during the December monthly cruise. Thirty (30) taxa were collected on the winter and spring seasonal cruises and 28 taxa were captured on the fall seasonal cruise.

At stations where both day and night tows were made (Transect II, Stations 1, 2 and 3) during the three seasonal cruises more eggs were captured during the day then during the night and more larvae were captured during the night than during the day. Seventy-four percent (74%) of the eggs and 27% of the larvae were captured during the day and 26% of the eggs and 73% of the larvae were captured during the night. Daytime captures of larvae ranged from 3.1% on the March cruise to 71% on the April cruise. Night time captures of larvae ranged from 28.2% on the April

cruise to 96.9% on the March cruise.

The inshore and mid-depth stations along the four transects yielded the greatest number of eggs and larvae. On the three seasonal surveys 12.3% of the eggs and 31.4% of the larvae were captured at the four shallowest stations, 77.8% of the eggs and 41.9% of the larvae were captured at the four mid-depth stations and 9.6% of the eggs and 26.6% of the larvae were captured at the four deepest stations. On the monthly cruises 37.0% of the eggs and 43.9% of the larvae were captured at the shallowest station on Transect II (1/II), 47.9% of the eggs and 26.2% of the larvae were captured at the mid depth station (2/II) and 15.0% of the eggs and 29.9% of the larvae were captured at the deepest station (3/II).

The number of taxa did not appear to vary with the depth of the stations. A total of 28, 24 and 33 taxa were collected at the four inshore, mid-depth and deepest stations respectively during the three seasonal cruises. A total of 35, 34 and 33 taxa were taken at the inshore, mid-depth and deepest stations during the monthly cruises. On the three seasonal cruises eggs were more abundant along Transect I (79%) and larvae were more abundant along Transect II (53%).

Transect II was used to describe the distributions of the taxa of ichthyoplankton since this transect was sampled monthly and larvae collected along this transect were representative of those collected along the three other transects sampled during the seasonal surveys. The 10 most abundant families of fishes over the entire survey were: Clupeidae, Engraulidae, Sciaenidae, Mullidae, Bothidae, Triglidae, Mugilidae, Exocoetidae, Gerreidae and Gobiidae (Table 15.5). Engraulidae and Sciaenidae were more abundant during the fall than during the winter or spring surveys, while Exocoetidae and Mullidae were more abundant during the spring than during the winter or fall surveys (Figures 15.31 through 15.40).

TABLE 15.5

TEN MOST ABUNDANT FAMILIES CAPTURED ON TRANSECT II[1].

FAMILY	TOTAL NO./1000 M^3/YEAR	% OF TOTAL NO. LARVAE
Clupeidae	67,183	27.5%
Engraulidae	29,994	12.3%
Sciaenidae	17,065	7.0%
Mullidae	12,750	5.2%
Bothidae	2,979	1.2%
Triglidae	2,276	0.9%
Mugilidae	1,603	0.7%
Exocoetidae	906	0.4%
Gerreidae	672	0.3%
Gobiidae	496	0.2%
TOTAL	135924	55.7%

[1]A total of 244,550 fishes were captured on transect II over the survey.

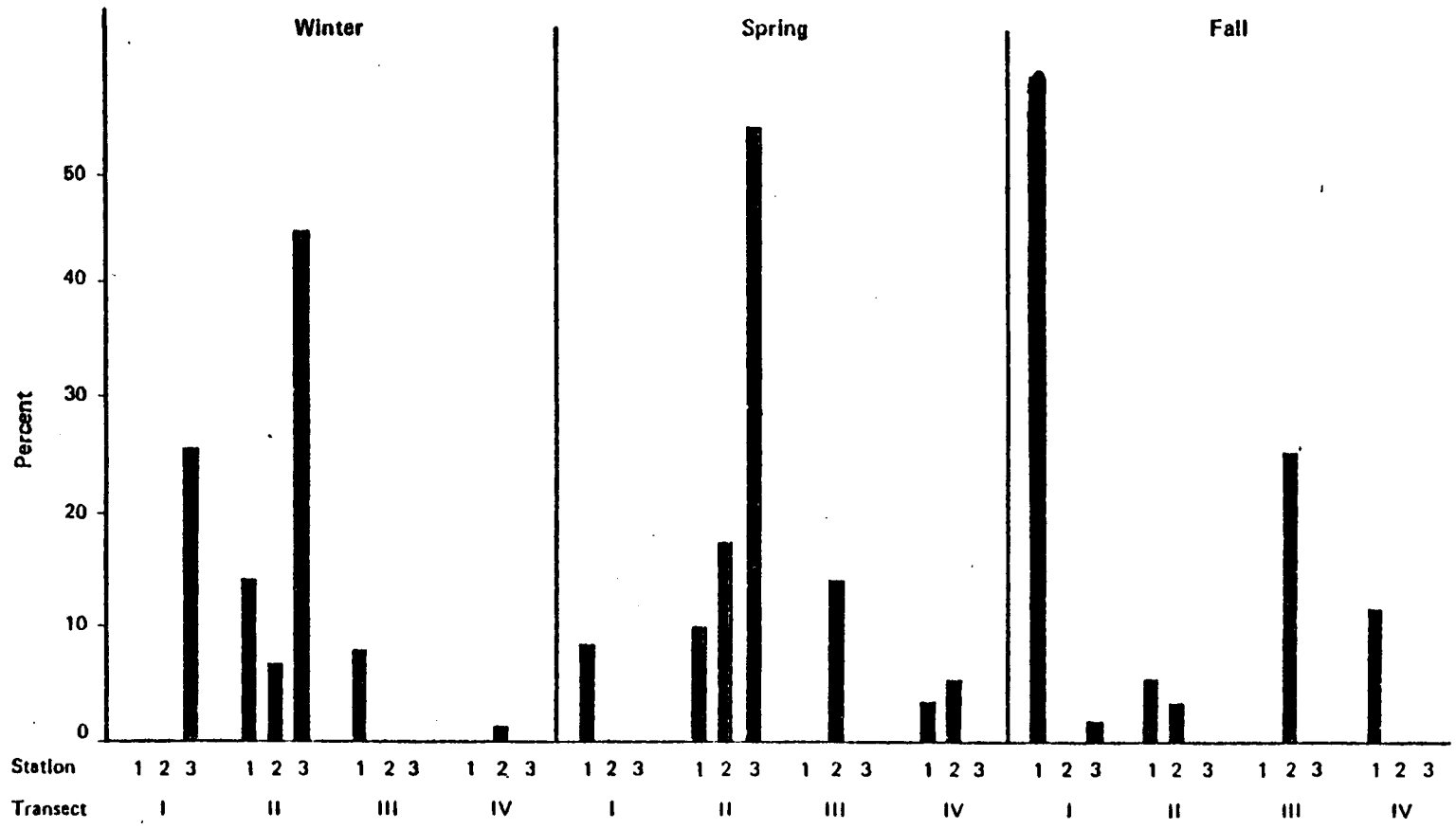


Figure 15.31 Relative Abundance of Clupeidae at Each of the Stations Along the Four Transects During the Three Seasonal Cruises.

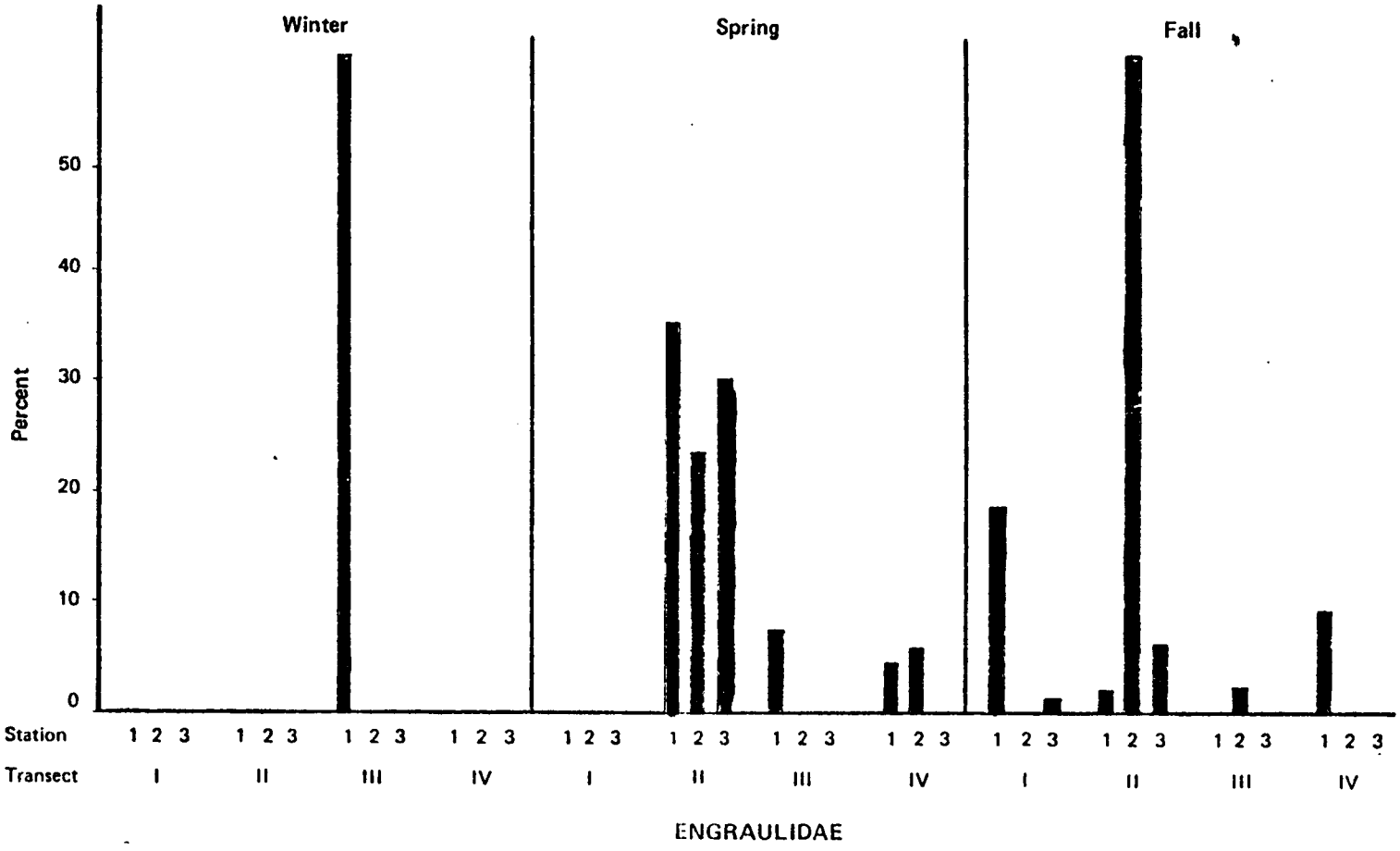


Figure 15.32 Relative Abundance of Engraulidae at Each of the Stations Along the Four Transects During the Three Seasonal Cruises.

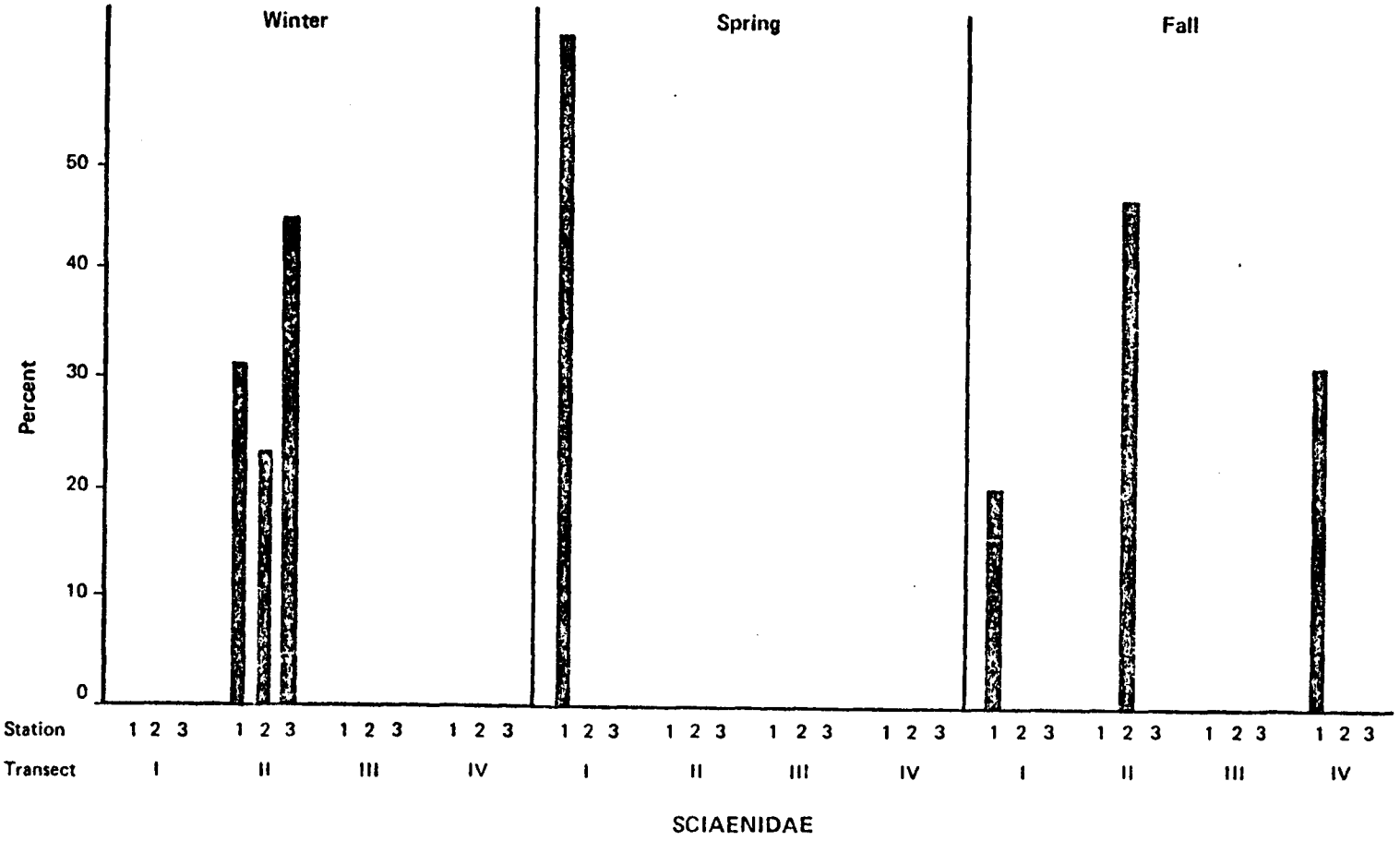


Figure 15.32 Relative Abundance of Sciaenidae at Each of the Stations Along the Four Transects During the Three Seasonal Cruises.

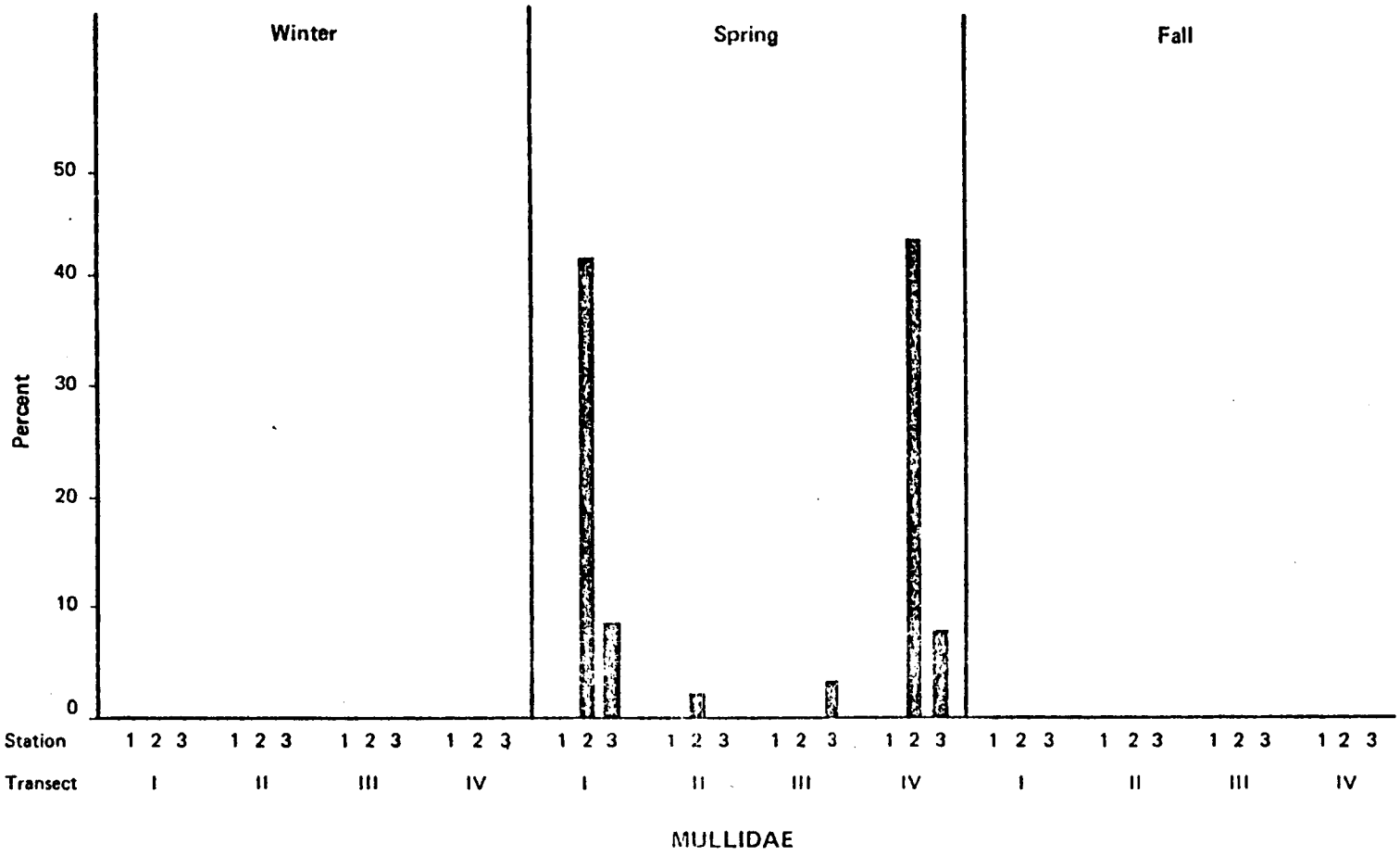


Figure 15.33 Relative Abundance of Mullidae at Each of the Stations Along the Four Transects During the Three Seasonal Cruises.

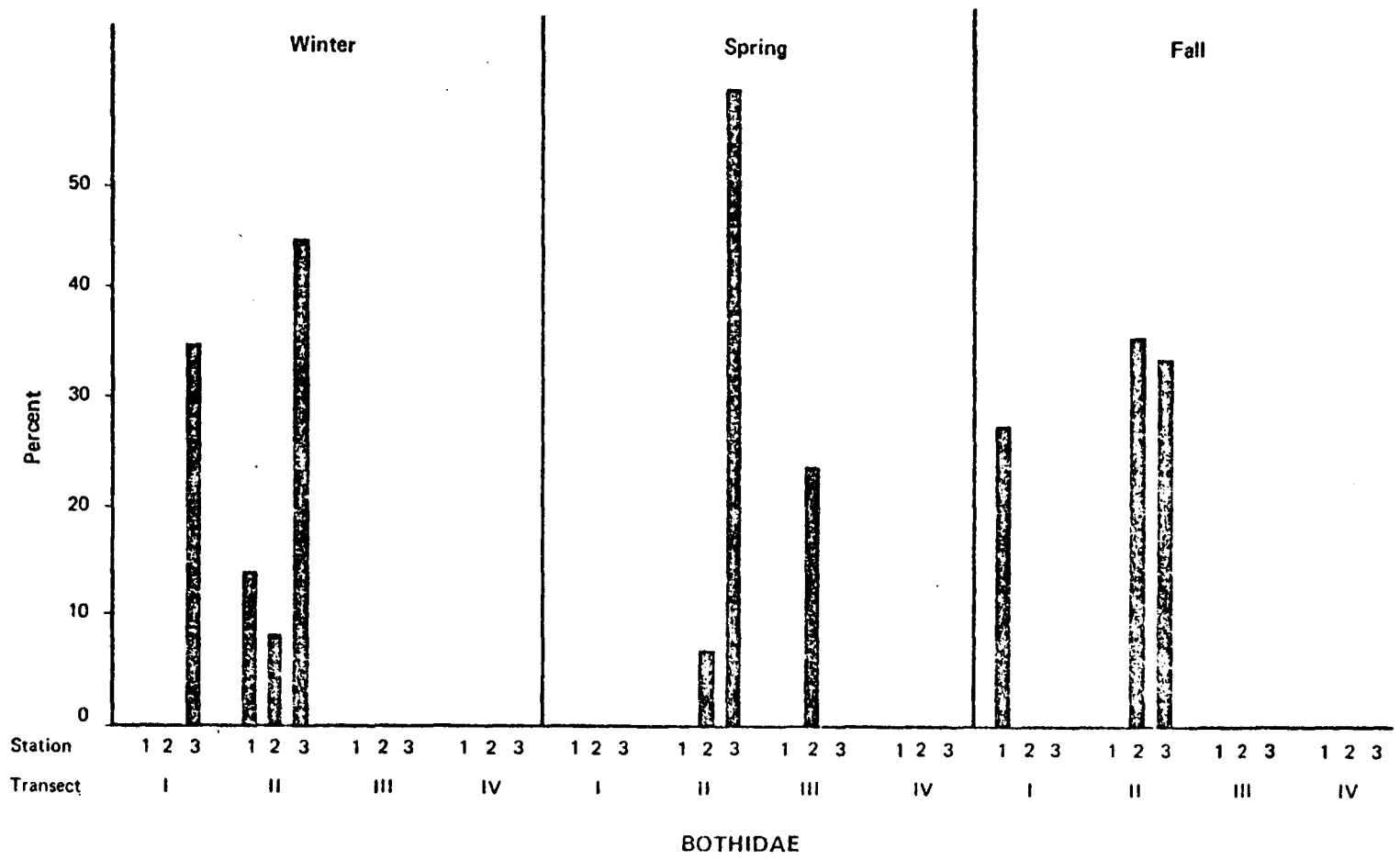


Figure 15.34 Relative Abundance of Bothidae at Each of the Stations Along the Four Transects During the Three Seasonal Cruises.

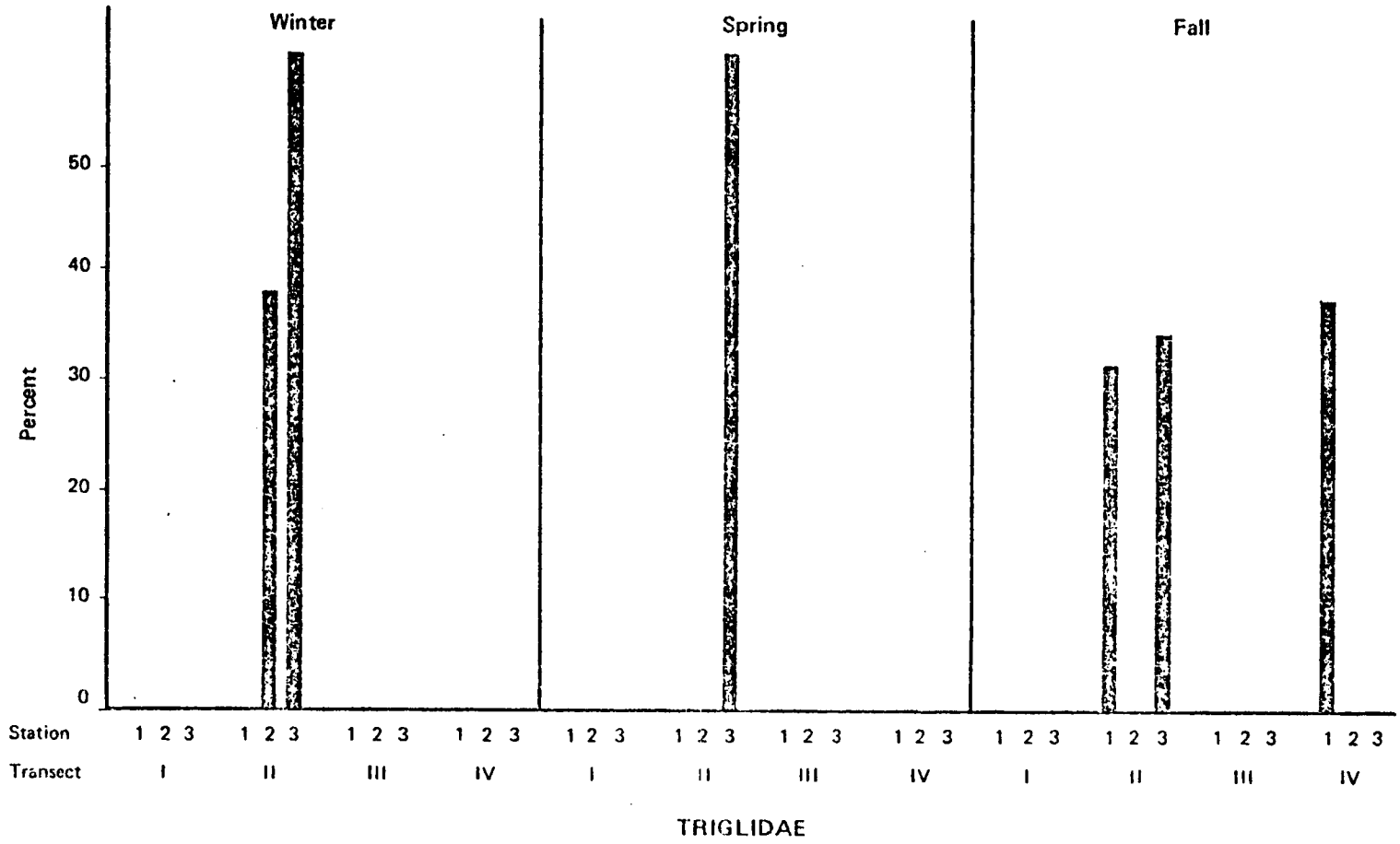


Figure 15.35 Relative Abundance of Triglidae at Each of the Stations Along the Four Transects During The Three Seasonal Cruises.

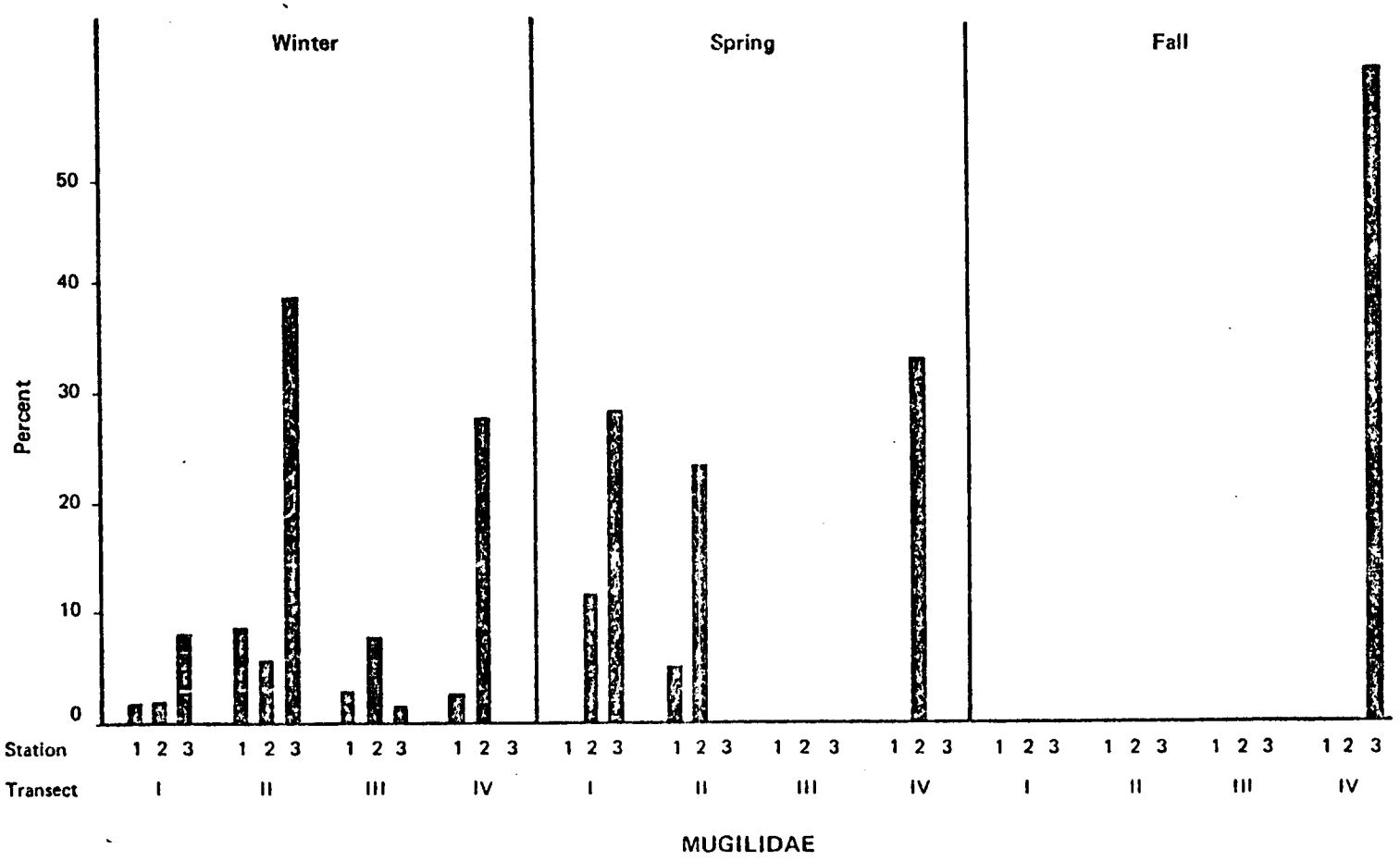


Figure 15.36 Relative Abundance of Mugilidae at Each of the Stations Along the Four Transects During the Three Seasonal Cruises.

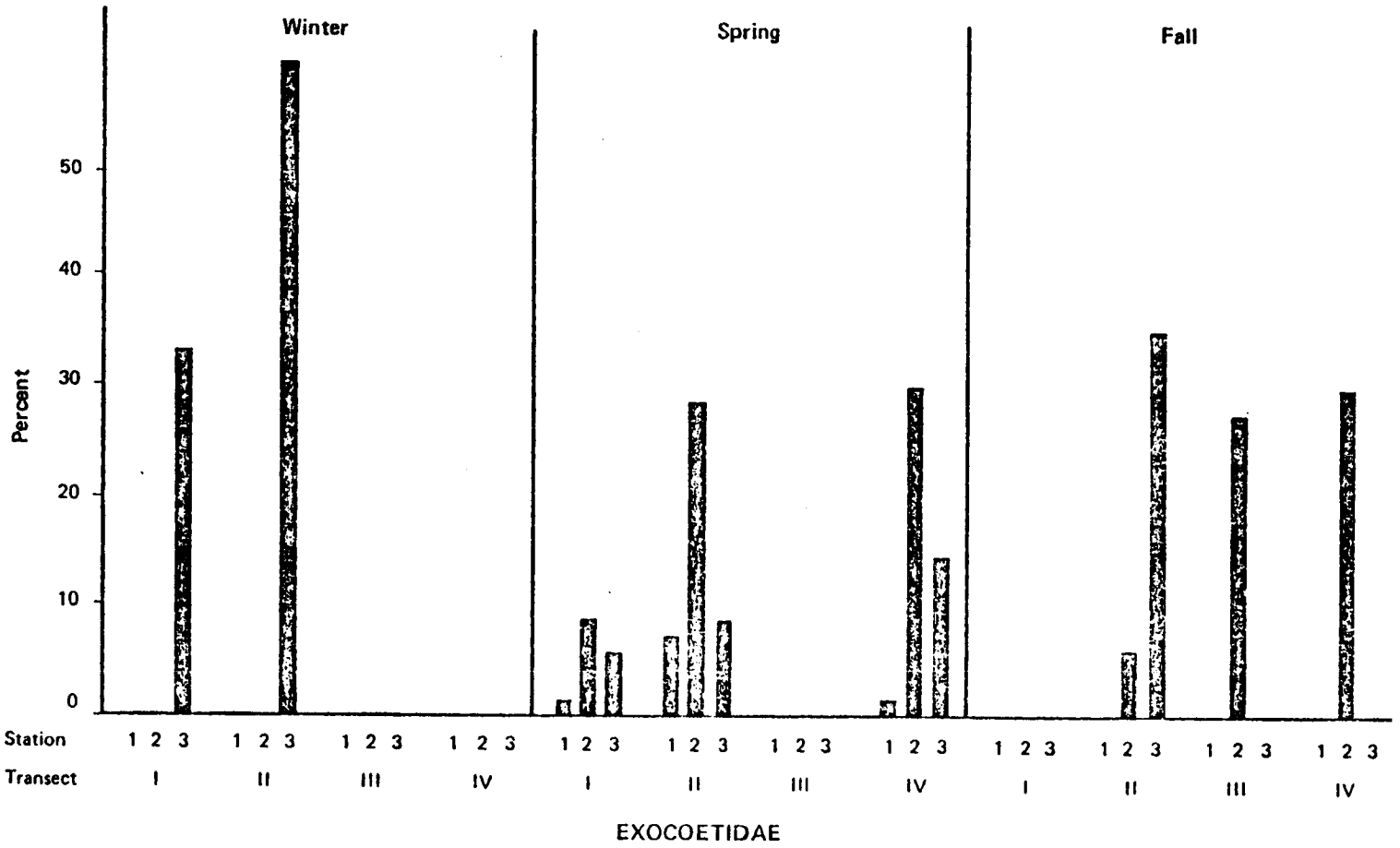


Figure 15.37 Relative Abundance of Exocoetidae at Each of the Stations Along the Four Transects During the Three Seasonal Cruises.

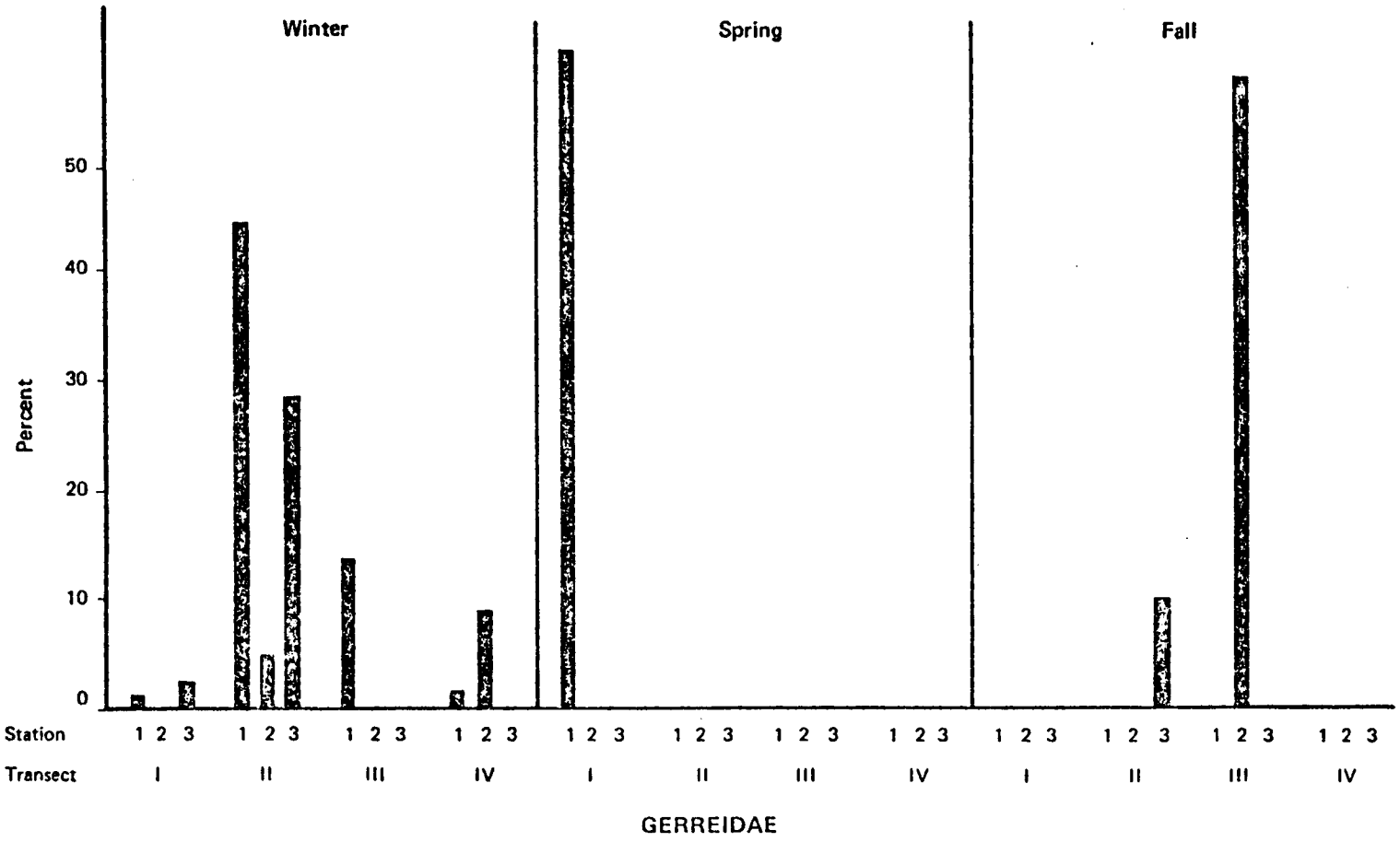


Figure 15.38 Relative Abundance of Gerreidae at Each of the Stations Along the Four Transects During the Three Seasonal Cruises.

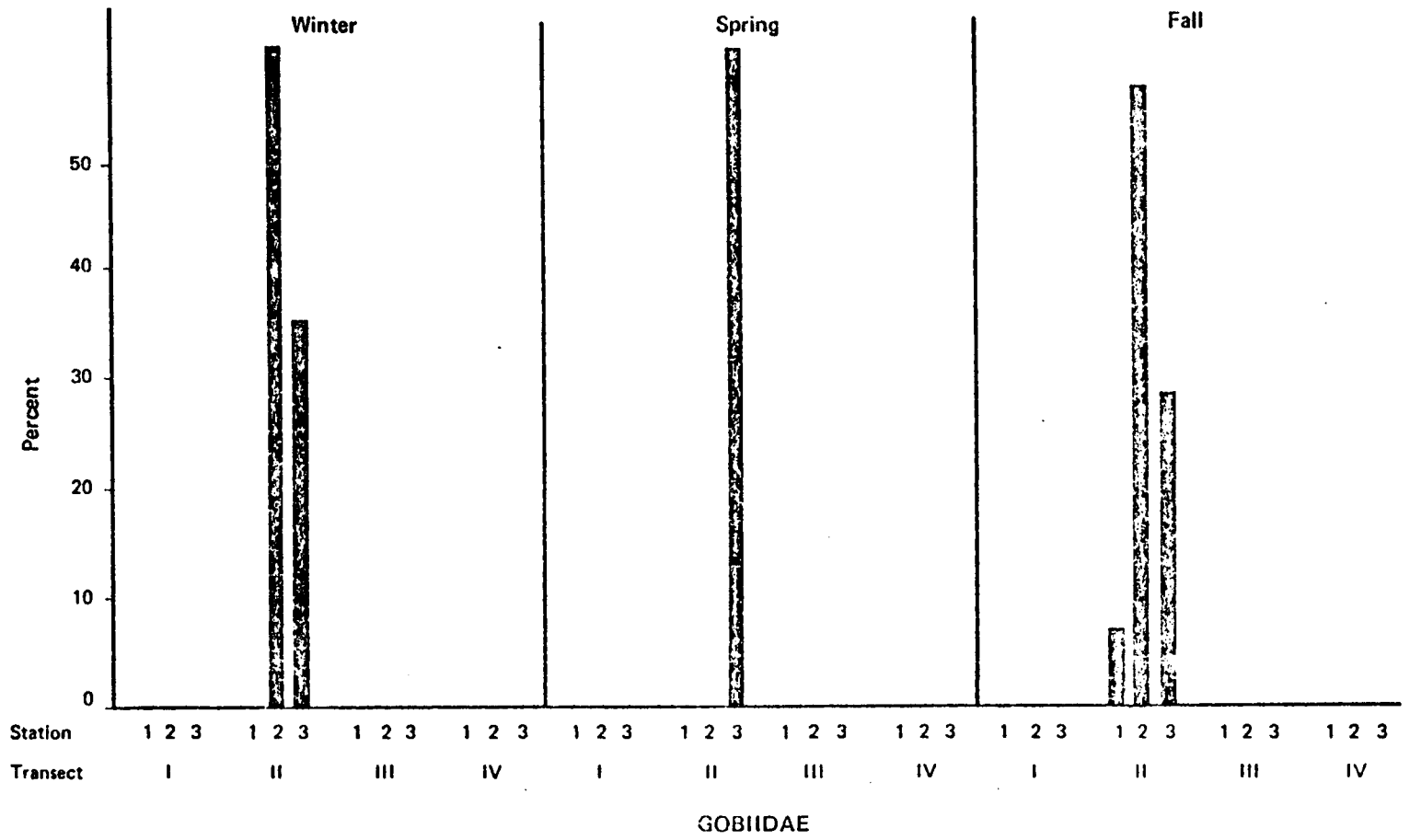


Figure 15.39 Relative Abundance of Gobiidae at Each of the Stations Along the Four Transects During the Three Seasonal Cruises.

Although more larvae were captured during the night and most taxa were more abundant during the night, some taxa were predominantly captured during the day. Clupeidae, Engraulidae and Bothidae predominated in the night samples and Exocoetidae, Mullidae and Mugilidae predominated in the day samples.

The ten most abundant species were *Etrumeus teres* (8.2%), *Mugil cephalus* (1.5%), *Harengula jaguana* (1.4%), *Prionotus* sp. (1.1%), *Eucinostomus* sp. (1.0%), *Bregmaceros atlanticus* (0.8%), *Trachurus lathami* (0.7%), *Micropogon undulatus* (0.4%), *Paralichthys* sp. (0.3%), and *Etropus* sp. (0.2%). The species of Sciaenidae and Clupeidae varied seasonally in their relative abundance during the seasonal surveys. The sciaenids *Leiostomus xanthurus* and *Micropogon undulatus* were captured during the winter and fall but were absent during the spring. *Menticirrhus* sp. was most abundant during the fall.

The clupeid *Brevoortia* sp. was captured during the winter but was absent during the spring and fall. The clupeid *Etrumeus teres* was captured during the winter and spring but was absent during the fall.

Ichthyofauna Conclusions

During the 1977 survey the greatest abundance of eggs was collected during the spring seasonal cruise and on the July monthly cruise indicating that spawning was most intense during the spring and early summer. Larvae were also most abundant during the spring and early summer with mullids, clupeids and engraulids making up the majority of the larvae. These three families were probably responsible for the high concentration of eggs during the spring and early summer. In 1976 the greatest abundance of eggs occurred in the winter and the greatest abundance of larvae occurred in the spring. Clupeids and engraulids were the most abundant larval forms.

Distribution of larvae along the transects indicated that most fishes, *i.e.* Sciaenidae and Gerreidae, spawn near shore while a few fishes, *i.e.* Mugilidae, spawn offshore. The majority of the larvae during 1977, as in 1976, were captured during the night, indicating either that larvae are more abundant in the neuston zone during the night or that larvae are less able to avoid the sampling gear during the night. However, larvae of the families Exocoetidae, Mullidae and Mugilidae were more abundant during the day than during the night indicating that either they sink below the neuston zone during the night or are less able, than other larvae, to avoid the sampling gear during the day.

During the 1976 neuston survey, Clupeidae was the most abundant family and nine of the 10 most abundant families were among the 10 most abundant families for 1977. However, in 1976 the families Sciaenidae, Mugilidae, Exocoetidae, Gobiidae and Carangidae were relatively more abundant and the families Engraulidae and Triglidae were relatively less abundant than during the 1977 survey.

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CHAPTER SIXTEEN

MEIOFAUNA PROJECT

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ABSTRACT

A total of 540 sediment samples collected between February and December 1977 from 25 transect stations and four bank stations on the South Texas Outer Continental Shelf (STOCS) were analyzed for establishment of meiofaunal populations and communities. The degree of similarity between 1976 and 1977 data indicated that reasonably stable meiofaunal populations exist on this shelf. In general, populations tended to decrease with increasing depth between 14 and 134 m. It was confirmed that the true meiofauna exhibited strong seasonal population increases in March-April, July-August, and November. These seasonal pulses were noted at even the deepest stations, albeit with lesser amplitudes. Nematodes were by far the predominant component of the true meiofauna.

Nematodes were highly correlated with sediment granulometry, increasing markedly in number when the sand component attained or exceeded 60%. Harpacticoid copepods did not respond to this factor, especially around some areas at the base of the banks. Calculations of the harpacticoid/nematode ratios, which averaged 0.04 for all transect stations, reflected this bank increase of harpacticoids in that the ratio increased to an average of 0.08. Significant differences among the ratios of the four transects appeared to have reasonable explanations, which suggested that the ratio could be used to predict, monitor, and evaluate environmental perturbations of either sedimental or chemical nature.

INTRODUCTION

Purpose

The major objective of this investigation was to determine in a relatively small geographical area of the South Texas Outer Continental Shelf (STOCS), including two hard banks, the distributions, abundances, and environment of the taxonomic components of the meiofauna. These findings will play a significant role in formulation of natural conditions from which it should be possible for environmental managers to determine whether or not man's activities on the shelf are having impacts of concern on the fauna. It is our belief that the meiofauna can provide data and concepts that will be useful in judging the impacts of sedimental and other environmental changes that will result from discovery and production of oil and gas.

Background

The term meiofauna generally refers to a taxonomically diverse and numerically abundant assemblage of animals that are further described by their small size. In early studies the meiofauna was separated from the macroinfauna by means of sieves having a mesh opening of 1.0 mm; more recently, however, the upper limit of size is taken as 0.5 mm (McIntyre, 1964; Tietjen, 1969, 1971; Coull, 1970; McIntyre and Murison, 1973; and Gettleson and Pequegnat, 1976). The lower limit has also been variable but 0.062 mm is now the usual mesh size employed for extraction. Accordingly, the meiofauna in this study was defined by passage through a 0.5 mm and retention on a 62 μm sieve, whereas all other organisms taken by the grab and retained on the 0.5 mm sieve were designated as macrofauna.

The meiofauna is composed of both a permanent and more numerically stable set of organisms as well as a temporary, numerically variable group

composed of juvenile macroinfaunal forms (McIntyre, 1961; Thorson, 1966). The permanent or true meiofauna differs from the macroinfauna not only in size, but also in regard to number, average generation time, and morphological adaptations to their environment. Some protozoans meet the size requirements of the meiofauna but, as Thiel (1975) pointed out, the Foraminifera have been excluded from most investigations on deep water meiofauna. Up to now, the Foraminifera have been grouped together with the multicellular meiofauna in only three publications (Wigley and McIntyre, 1964; Tietjen, 1971; and Thiel, 1975). There are several reasons for this deletion, among them being the difficulty of separating live from dead individuals because material in the tests other than protoplasm may stain red with rose bengal. On the basis of numbers alone, it would appear that they should be included in meiofaunal studies. The present study, as well as the work of others (Wigley and McIntyre, 1964; Tietjen, 1971; and Thiel, 1975), shows that the Foraminifera often are either the most numerous group or the second in abundance behind the nematodes.

Even so, for this report, the metazoan meiofauna were placed in the category of "true" meiofauna (all of which are permanent) and the Foraminifera and temporary meiofauna were lumped into a second category.

As Thiel (1975) noted, effective work on offshore meiofauna was started as late as 1964 when Wigley and McIntyre (loc.cit.) obtained quantitative samples from a transect on the North American Atlantic shelf and down the continental slope to about 600 m. In addition, quantitative samples were taken from slope to abyss by McIntyre from DISCOVERY (Warwick, 1973) and by Thiel from METEOR (Thiel, 1966) both in 1964/1965 in the Arabian Sea.

The meiofauna has received very little attention in the sublittoral

of the Gulf of Mexico. Pequegnat and Gettleson (1974) listed the number of individuals in major meiofaunal and macroinfaunal taxa from five stations in the vicinity of Stetson Bank. In 1976, they examined meiofaunal-sediment correlations from 25 stations located on the STOCS. Gettleson and Pequegnat (1976) reported on an intensive study of the wet weight and abundance of the meiofauna and macroinfauna taken from 10 stations on the outer continental shelf of east Texas. Prior to this report, there has been only a limited number of sublittoral studies in which the wet weight and/or abundance of the meiofauna and macroinfauna have been compared. Krogh and Spärck (1936) described the fauna contained within several cores taken in Copenhagen Harbor; Mare (1942) examined the flora and fauna of a small area in the English Channel; Sanders (1958) examined the macroinfauna and Wieser (1960) the meiofauna of three stations in Buzzards Bay, Massachusetts; McIntyre (1961, 1964) studied two areas off Scotland (Lock Nevis and Fladden Ground, North Sea); Wigley and McIntyre (1964) analyzed ten samples from a transect (40 to 567 m off Massachusetts); Guille and Soyer (1968, 1974) studied the fauna off the French Banyuls-sur-Mer coast (Meditteranean); Stripp (1969) examined samples from the Helgoland Bight (North Sea); Ankar and Jansson (1973), Elmgren (1972), Ankar and Elmgren (1975), and Jansson and Wulff (1977) analyzed samples from the Baltic Sea. Pequegnat *et al*. (1977) collected 294 sediment samples between February and December 1976 from 25 transect stations and eight bank stations on the STOCS and analyzed them for establishment of meiofaunal populations and communities.

Nematodes usually dominate the meiofauna; however, their systematics and ecology have been neglected to a great extent. Only six known papers have been published on Gulf of Mexico nematology, and all of the material was from the littoral zone (Chitwood, 1951; Chitwood and Timm, 1954;

Hopper, 1961a, 1961b, and 1963; King, 1962). Hulings (1967) reviewed previous papers dealing with the systematics and ecology of podocopid and platycopid ostracods in the Gulf of Mexico. Disregarding the foraminiferans, no other published reports on the components of the permanent meiofauna of the sublittoral Gulf are known. There are, however, a number of papers describing the living, soft-bottom foraminiferans of the Gulf. Phleger's (1951) study dealt with an area similar to that of the present study, but his total number of identified living forms was very low (16) due to the unreliable biuret test used to distinguish living from dead individuals. Phleger (1956) used the more accurate rose bengal method to detect living forams. Walton (1964) in a study of the central Texas coast and continental shelf was able to discriminate among four depth-related assemblages on the shelf. Other foraminiferal studies in the Gulf of Mexico have also resulted in depth-related biofacies. Phleger (1951) recognized six depth facies, Bandy (1954) three within water depths of 8 to 37 m, Parker (1954) six in the northeast Gulf, and Bandy (1956) described five major facies also in the northeast Gulf. Phleger (1960) reviewed much of the Gulf of Mexico foraminiferal work. Other studies of living, sublittoral, Gulf of Mexico foraminiferal distributions since 1960 include Walton (1964), Loep (1965), Lankford (1966), Greiner (1970), Poag and Sweet (1972), and Buzas (1967, 1972).

MATERIALS AND METHODS

Sampling Transects and Stations

The meiofaunal samples were collected with a Smith-McIntyre grab from all stations on the four transects and two stations of both Southern Bank and Hospital Rock during the three seasonal cruises. Additionally, Stations 1-6, Transect II were sampled during six monthly cruises. Four

replicate samples were taken from each grab for laboratory analysis, giving a total of 540 samples (Table 16.1). The 25 transect stations were divided into the five zones (A-E) shown in Figure 16.1. Hospital Rock (HR) and Southern Bank (SB) were located within zone C. More detailed information on specific depths of the zones is given in Figure 16.2. It should be noted that Transect II was located more or less in line with the channel entrance to Corpus Christi Bay and that Transect IV had seven stations, whereas the others had six. Also, Station 7, Transect IV was actually slightly beyond the shelfbreak which may have accounted for some of its unique faunal characteristics.

Sample Processing

On deck, all meiofauna samples were taken from the grab by means of a plexiglass core tube of 2.43 cm diameter (internal area = 9.187 cm^2) that was pushed into the sediment to a depth of 5 cm. Four such cores were taken and the enclosed sediment was extruded into 8 oz. glass jars. One sample was frozen immediately. The remaining three samples were anesthetized in isotonic $MgCl_2$ for 10 minutes and then placed in 10% buffered formalin. Only two of the three samples were to be sorted and these received rose bengal in the formalin. The remaining sample was archived.

In the laboratory, the stained meiofauna samples were sieved through 20.3 cm diameter 500 and 62 µm mesh sieves. The material retained on the smaller sieve was washed into 2 oz. squat jars with 10% buffered formalin, to which 10 ml of rose bengal in formalin (200 mg/ℓ) was added. After the sample had been allowed to stain for between 24 and 48 hours, it was washed in a 7.6 cm diameter, 62 µm sieve to remove excess stain and then aliquoted into an 80 x 40 mm rectangular sorting dish marked off in a 7 mm square grid. The whole sample was then examined microscopically and the sorted

TABLE 16.1

SOURCE AND TIME OF COLLECTION OF THE MEIOFAUNA SAMPLES COLLECTED AND ANALYZED IN 1977

SAMPLING PERIOD	TRANSECTS				HARD BANK	
1977	I	II	III	IV	SOUTHERN BANK	HOSPITAL ROCK
February	24	24	24	28	16	16
March		24				
April		24				
May-June	24	24	24	28	16	16
July		24				
August		24				
September-October	24	24	24	28	16	16
November		24				
December		24				
SUBTOTALS	72	216	72	84	48	48
GRAND TOTAL	540 samples analyzed					

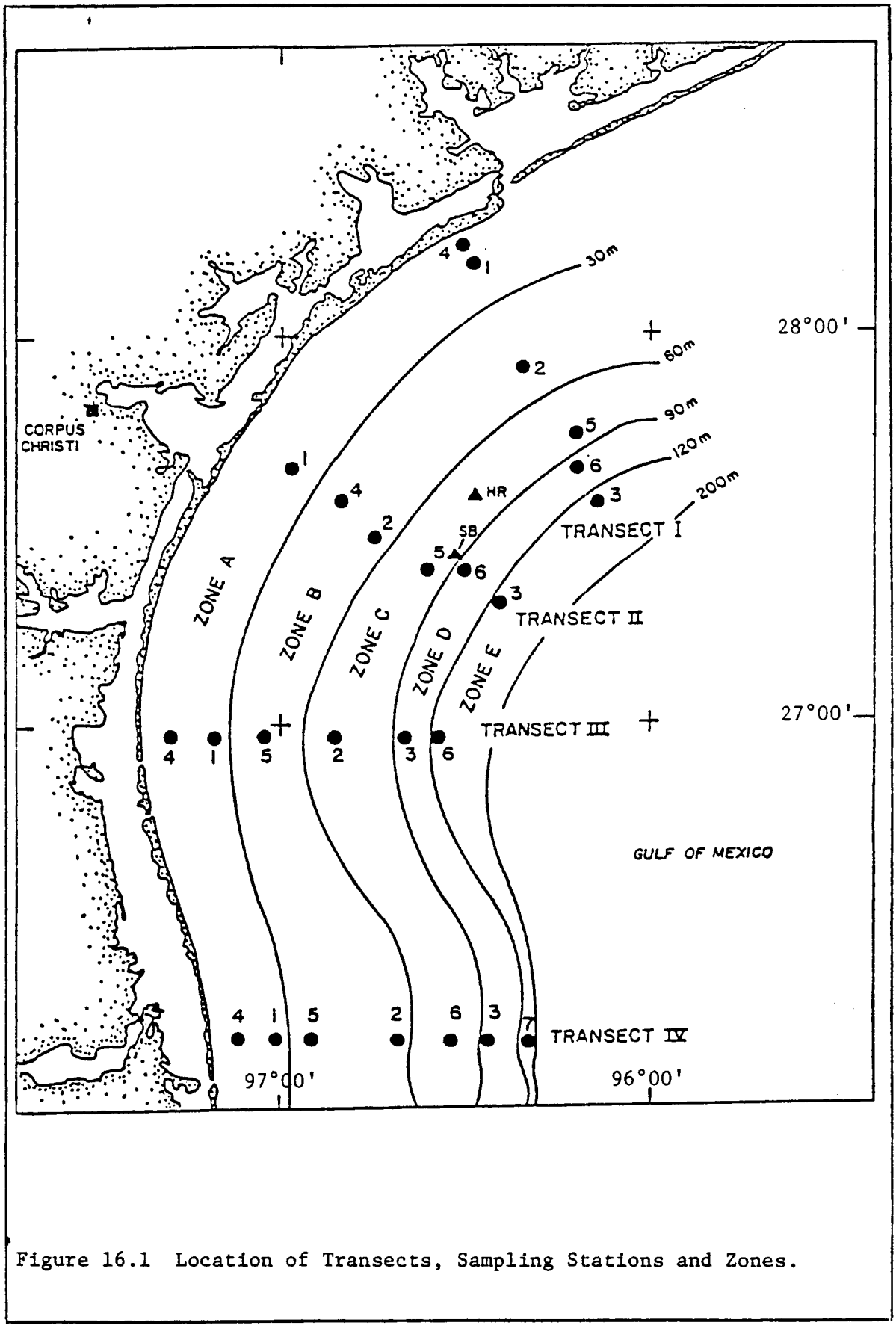

Figure 16.1 Location of Transects, Sampling Stations and Zones.

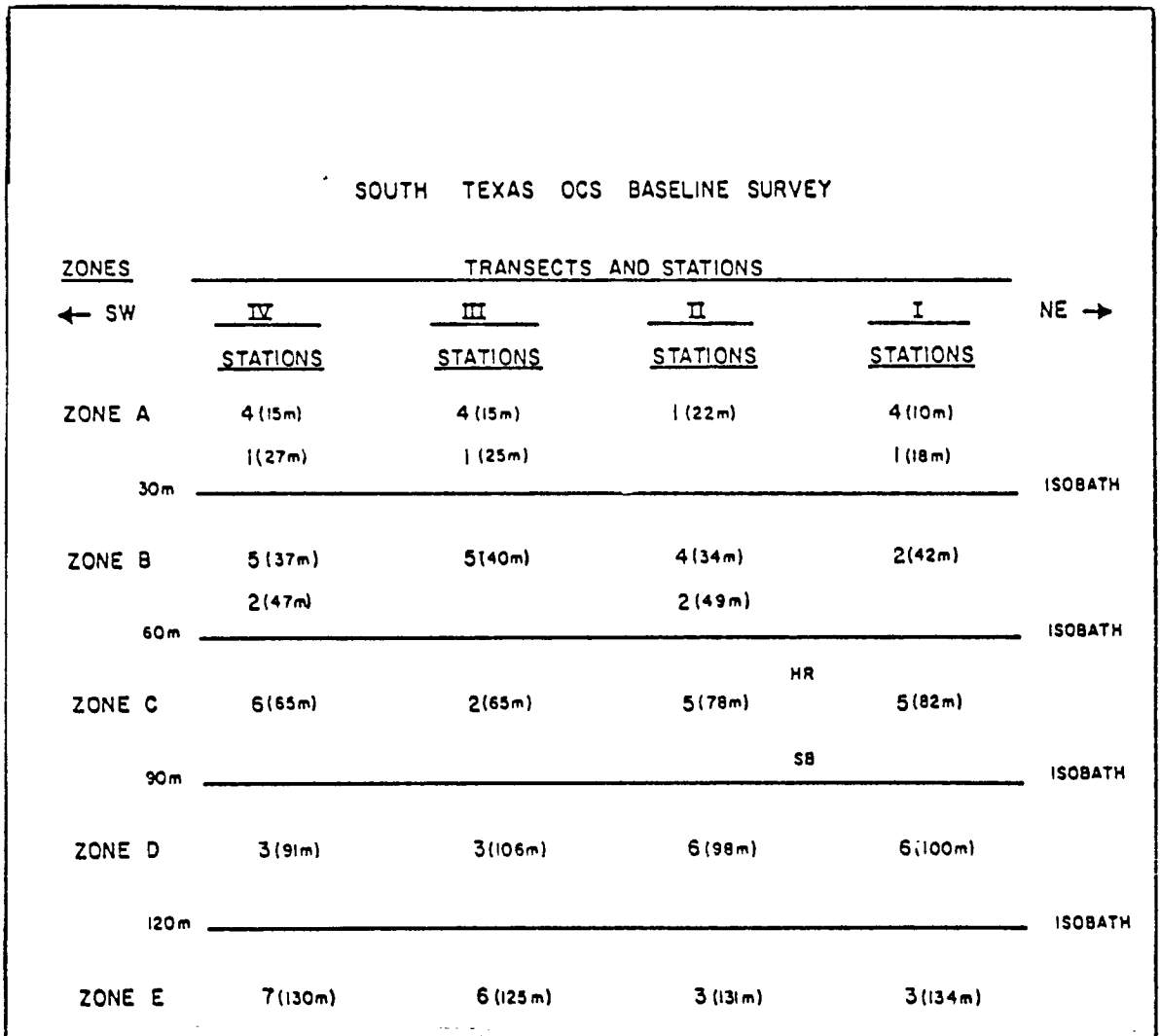

Figure 16.2 Zonal Distribution and Depths of the 25 Transect Stations and the Two Bank Stations on the South Texas Outer Continental Shelf. (Also see Figure 16.1).

animals placed in vials. When the number of nematodes exceeded 150, the 150 were vialed and the remainder were only counted and archived.

The meiofaunal samples were occasionally sugar floated with a saturated water-sugar solution in order to obtain the lighter organisms promptly. The sediment mixture was then stained with rose bengal and again sorted for bivalves and those animals not recovered during flotation. Finally, the remaining material was examined microscopically for extraction of the smallest organisms.

RESULTS

Transect Populations

As was demonstrated previously (Pequegnat and Sikora, *In* Groover, 1977), the highest number of individuals of the true meiofauna was found on Transect IV and the smallest number on Transect II. Second and third positions were held by Transects III and I, respectively, as was also true in 1976 (Table 16.2).

These differences between transects were statistically significant. On the other hand, the totals between years were remarkably close, with the possible exception of Transect IV, which alone accounted for the smaller 1977 total (see Appendix O for a summary of 1977 populations).

As noted previously, Transect II appeared to be the aberrant sampling line. Since populations increased in both directions from this transect, it may be that the low populations were somehow related to the fact that the stations were in line with the entrance to Corpus Christi Harbor and the effluent therefrom. There was also the possibility that the monthly trawling for epifauna along this transect could have accounted for at least part of the difference. Still, an analysis of the populations of the individual stations did not wholly support such a contention. Moreover,

TABLE 16.2

SUMS OF THE MEANS OF INDIVIDUALS OF TRUE MEIOFAUNA TAKEN AT ALL STATIONS OF TRANSECTS I THROUGH IV DURING THE THREE SEASONAL SAMPLING PERIODS OF 1977. 1976 NUMBERS ARE IN PARENTHESES.

SAMPLING PERIOD	TRANSECT			
	I	II	III	IV
WINTER	284(241)	97(35)	287(176)	297(303)
SPRING	100(111)	43(52)	209(234)	351(275)
FALL	163(183)	42(58)	170(270)	179(421)
	547(535)	182(145)	666(680)	827(999)

1976 TOTAL = 2359 1977 TOTAL = 2222

the station pattern was nearly the same along Transect II in both 1976 and 1977.

Population Trends by Station

As shown in Figure 16.3, populations of true meiofauna tended to decrease along the transects as distance from shore and depth increased. The major exception was on Transect II, where the shallow station not only supported low populations but also differed most from the conditions along other transects. It was interesting to note, however, that whereas the populations of true meiofauna at the outermost stations of Transects I, III and IV averaged only 6% of those of their respective shallowest stations, the population of the outermost station of Transect II was 57% of that of the shallow station. This again pointed to the aberrancy of the shallow station of Transect II.

Population Trends by Season

Populations of the meiofauna appeared to reach three definitive peaks (Table 16.3). After two years of sampling, it seemed best to designate these as March-April, July-August and November. It is interesting to note (Table 16.4) that the peaks in 1976 appeared to be more decisive in March, July, and November, whereas in 1977, with the exception of the nematodes, they were in April. There was, however, little difference in time between the two sampling periods. When data from 1976 and 1977 were combined (Table 16.5), the picture became clearer.

Figure 16.4 shows that monthly sampling gave a much more reliable picture of meiofauna standing crop than did the seasonal sampling, at least as it was carried out in this study. Examining the depth-related population response to season (Figure 16.5), it was evident that such responses occurred at all station depths sampled in this study (up to 134 m). This

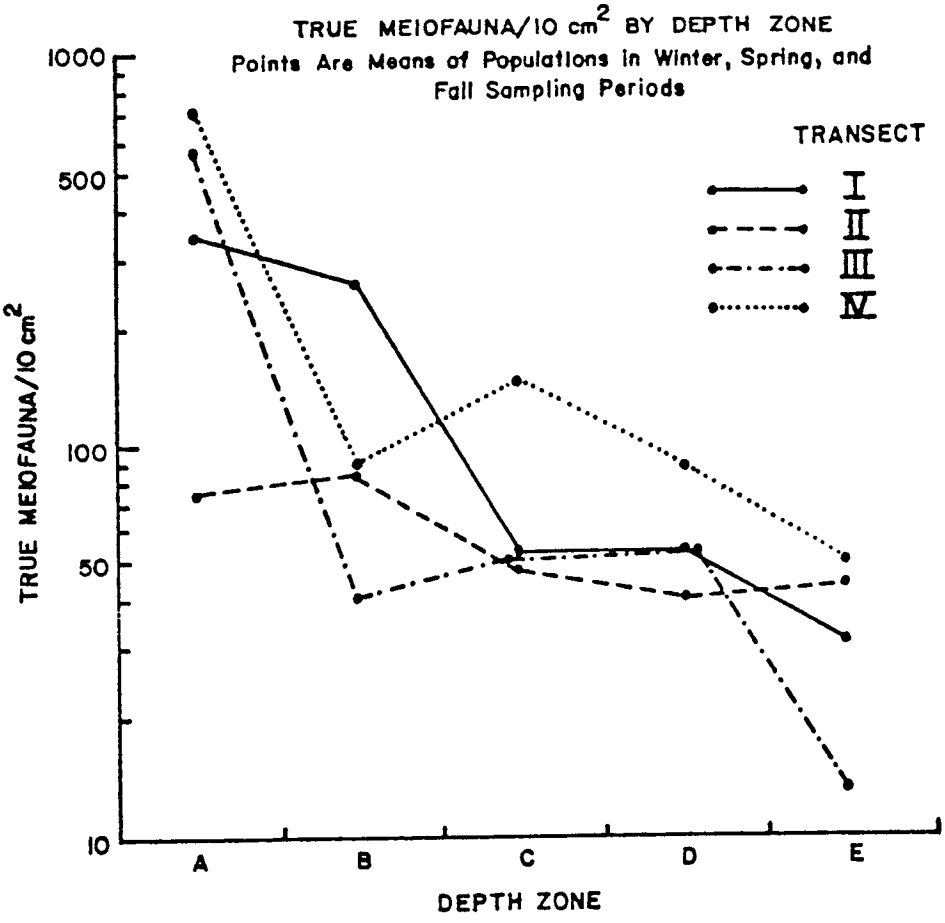

Figure 16.3 Distribution of True Meiofauna During the Winter, Spring and Fall Sampling Periods by Depth Zone (Also See Figures 16.1 and 16.2).

TABLE 16.3

POPULATION TOTALS OF VARIOUS MEIOFAUNAL GROUPS FROM ALL STATIONS OF TRANSECT II IN 1977 BY SAMPLING PERIOD (Highest Underlined).

TAXON	SAMPLING PERIODS								
	JAN-FEB	MAR	APRIL	MAY-JUNE	JULY	AUG	SEPT-OCT	NOV	DEC
NEMATODES	1950	2358	1664	797	1134	2198	736	978	761
HARPACTICOIDS	89	107	126	52	51	103	49	19	8
KINORHYNCHS	10	26	33	25	9	11	8	3	5
FORAMINIFERS	445	355	801	421	183	381	230	150	80
POLYCHAETES	62	59	69	29	52	91	35	36	28

TABLE 16.4

POPULATION TOTALS OF VARIOUS MEIOFAUNAL GROUPS FROM ALL STATIONS OF TRANSECT II IN 1976 BY SAMPLING PERIOD (Highest Underlined).

TAXON	SAMPLING PERIODS								
	JAN-FEB	MAR	APRIL	MAY-JUNE	JULY	AUG	SEPT-OCT	NOV	DEC
NEMATODES	379	433	422	568	1716	1193	594	1254	849
HARPACTICOIDS	9	14	8	7	59	89	27	198	39
KINORHYNCHS	0	5	7	1	30	19	3	13	1
FORAMINIFERS	19	111	21	285	882	783	358	227	579
POLYCHAETES	14	51	11	23	99	45	24	51	38

TABLE 16.5

COMBINED POPULATION TOTALS OF VARIOUS MEIOFAUNAL GROUPS FROM ALL STATIONS OF TRANSECT II IN 1976 AND 1977 BY SAMPLING PERIOD (Highest Underlined).

TAXON	SAMPLING PERIOD								
	JAN-FEB	MAR	APRIL	MAY-JUNE	JULY	AUG	SEPT-OCT	NOV	DEC
NEMATODES	2329	2791	2086	1365	2850	3391	1330	2232	1610
HARPACTICOIDS	98	121	134	59	110	192	138	217	47
KINORHYNCHS	10	31	40	26	39	30	11	16	6
FORAMINIFERS	464	466	822	706	1065	1164	588	377	659
POLYCHAETES	76	110	80	52	151	136	59	87	66

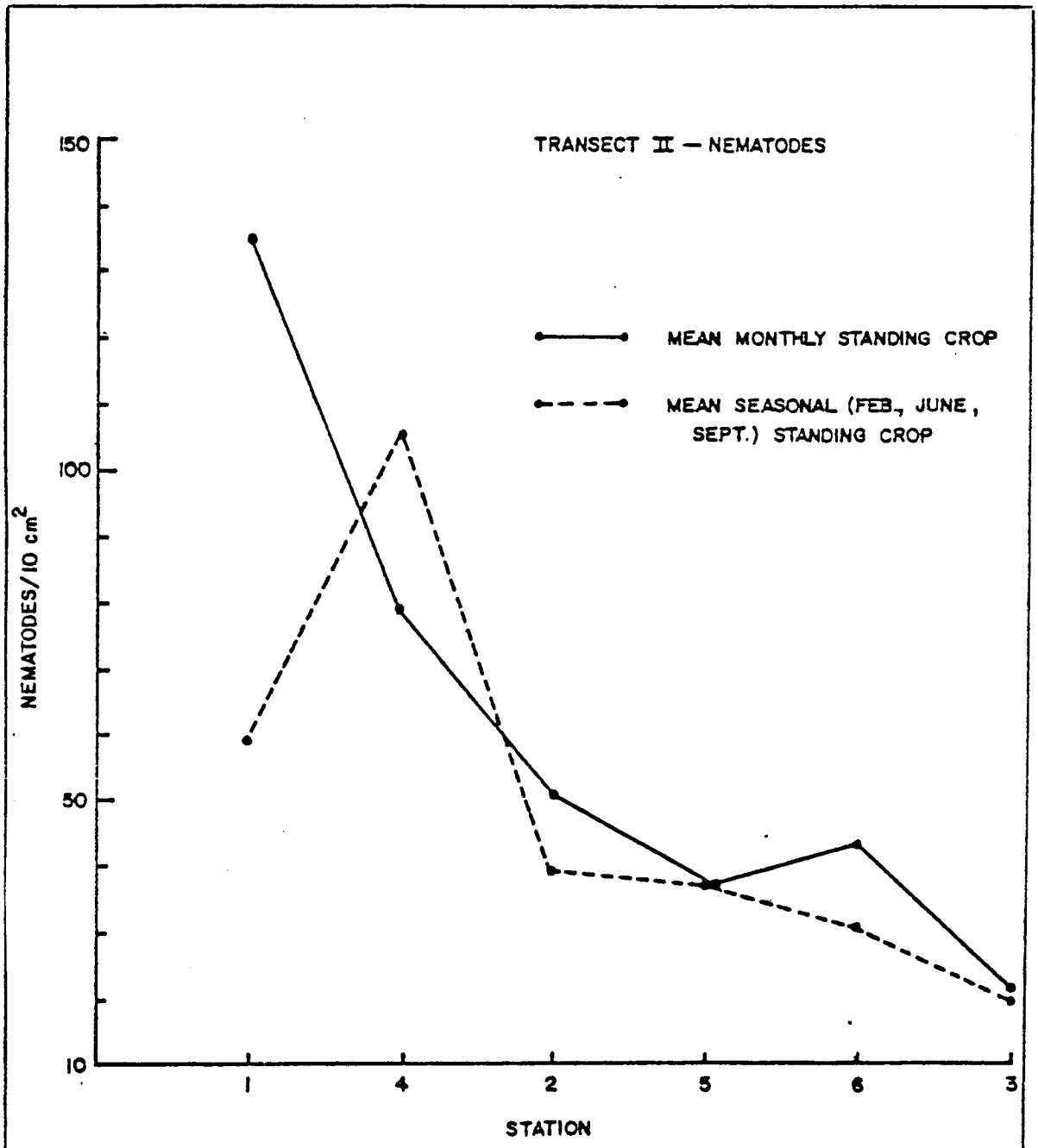

Figure 16.4 Transect II Mean Annual Nematode Standing Crop by Station (Offshore to Right) Calculated for the Six Monthly Sampling Periods and for the Three Seasonal Sampling Periods. One Nematode = 6.93 µg, Wet Weight.

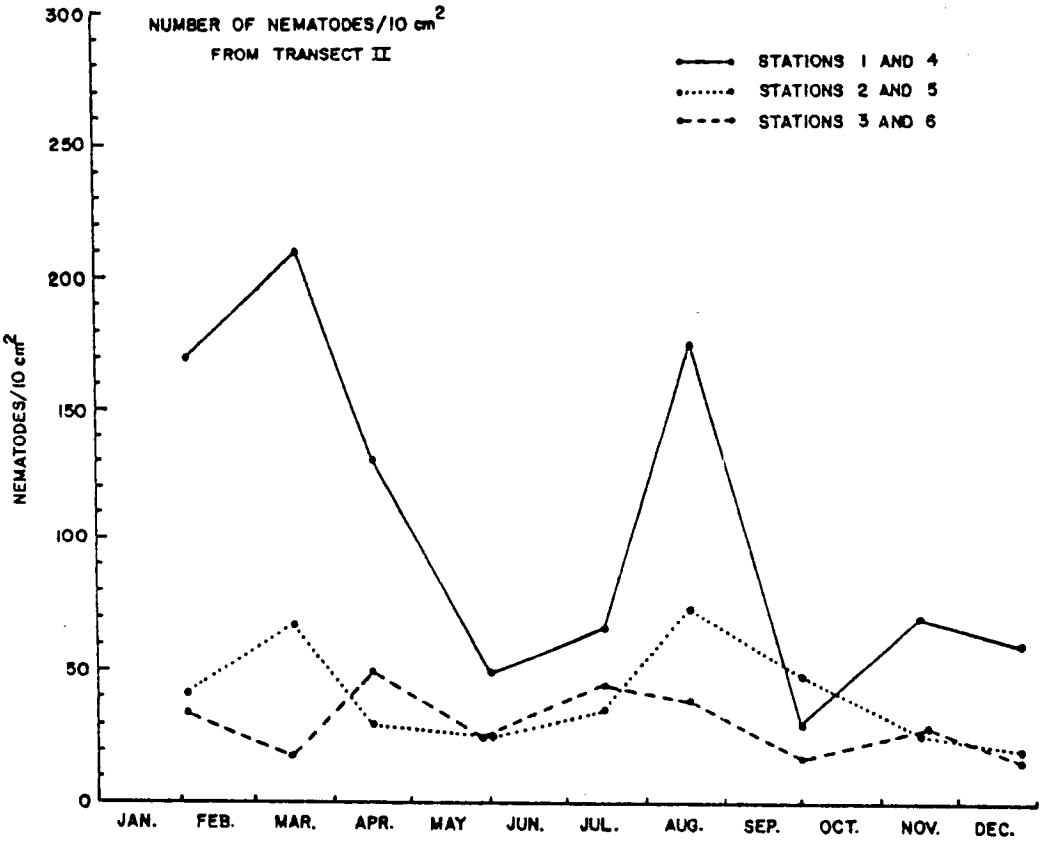

Figure 16.5 **Monthly Distribution of** Nematoda at Inshore Stations (1 and 4), Mid-way Stations (2 and 5) and Offshore Stations (6 and 3) of Transect II.

observation agreed with the 1976 findings, even to the extent that more pronounced seasonal population changes occurred at the shallow stations than at the deepest stations (Figure 16.5). This same seasonal result was shown for nematodes from Transect II considered as a whole (Table 16.6). The remarkable population differences between the shallowest stations of Transects II and IV and also between the shallow and deep stations on Transect II were also apparent (Table 16.6).

Bank Populations

The meiofaunal populations of Southern Bank and Hospital Rock were similar to those of the transect stations. Compared on the basis of seasonal sampling, Hospital Rock supported somewhat larger populations of meiofaunal groups than did Southern Bank (Table 16.7).

Population data from the banks could be compared to that from the transects provided only those transect stations of zone C, where the banks were located were used for comparison. The comparison showed that the banks and transects supported similar populations. It was very interesting to note that whereas the true meiofaunal populations of both banks were larger than those of the homologous station (5) of Transect II, the populations of Southern Bank were smaller than those of all other transects and Hospital Rock's populations were larger than all but Transect IV (Table 15.8). This same situation was observed in 1976. Reference to Figure 16.1 showed that Southern Bank was much closer to Transect II than was Hospital Rock, and possibly reflected a response to those environmental factors that were depressing the populations of the shallower stations of Transect II.

The bank populations of foraminiferans and temporary meiofauna exhibited a mixed pattern. As above, the populations of Hospital Rock were larger than those of Southern Bank (Table 16.9). However, they proved to exceed those of all homologous transect stations, including

TABLE 16.6

MEAN NUMBER OF NEMATODES PER CORE SAMPLE FROM TRANSECT II AND TOTAL NEMATODE POPULATIONS FOR TRANSECT II AND STATIONS 1/II, 2/II, 3/II

	FEBRUARY	MARCH	APRIL	JUNE	JULY	AUGUST	SEPTEMBER-OCTOBER	NOVEMBER	DECEMBER
NEMATODES Mean/Core Transect II	88.5	106.9	75.5	36.1	51.4	104.0	33.4	44.4	34.5
NEMATODES Total Transect II	1950	2358	1664	797	1134	2198	736	978	761
NEMATODES Total Station 1/II	452	1051	940	224	502	1274	31	90	261
NEMATODES Total Station 4/IV	3970			1461			3584		
NEMATODES Total Station 3/II	139	63	31	18	96	48	78	145	41

TABLE 16.7

SUM OF THE MEANS OF INDIVIDUALS PER 10 cm^2
OF FOUR IMPORTANT MEIOFAUNAL TAXA COLLECTED DURING THE THREE
SEASONAL SAMPLING PERIODS FROM SOUTHERN BANK AND HOSPITAL ROCK

	Southern Bank	Hospital Rock
Nematodes	111	234
Harpacticoids	13	17
Foraminifers	27	133
Polychaetes	6	12

TABLE 16.8

MEAN NUMBER OF INDIVIDUALS PER 10 cm^2 OF ALL TRUE MEIOFAUNA TAKEN FROM SOUTHERN BANK (SB) AND HOSPITAL ROCK (HR) AND THE HOMOLOGOUS TRANSECT STATIONS

	5/I	5/II	5/III	5/IV	SB	HR
Winter	102	60	23	262	56	133
Spring	40	44	94	145	58	94
Fall	10	41	32	54	33	49
Total	152	145	149	461	147	276

TABLE 16.9

MEAN NUMBER OF INDIVIDUALS PER 10 cm^2 OF FORAMINIFERS AND TEMPORARY MEIOFAUNA TAKEN FROM SOUTHERN BANK (SB) AND HOSPITAL ROCK (HR) AND THE HOMOLOGOUS TRANSECT STATIONS

	5/I	5/II	5/III	5/IV	SB	HR
Winter	29	10	1	107	10	101
Spring	3	22	10	11	18	36
Fall	2	22	4	17	4	15
Total	34	54	15	135	32	152

Transect IV. For this and other reasons, such as the fact that forams are not metazoans, it seemed wise to place major emphasis on the true meiofauna in this and future studies.

Specific Populations

As was noted in the 1976 study, approximately 90 nematode taxa at the genus level and above have been collected from the transect and bank stations. Those of 1977 were remarkably close to the taxa found in the previous year, as was reflected by the fact that the predominant genera of nematodes in the two years were the same. These in numerical order were as follows: *Sabatieria; Theristus; Halalaimus; Dorylaimposis; Neotonchus; Terschellingia; Synonchiella; Viscosia; Laimella;* and, *Ptycholaimellus.* The dominant position of nematodes in the meiofaunal community is shown in Table 16.10; they accounted for from 50 to 93% of the individuals of the true meiofauna.

Additional meiofaunal organisms observed during the study period included the following. Five genera of kinorhynchs were collected from the transect and bank stations: *Pycnophyes; Echinoderes; Trachydemus; Semnoderes;* and, *Centroderes.* Approximately 65 species of polychaetes appeared regularly in the meiofaunal samples but less than ten of these predominated. Chief among these were: *Paraonis gracilis, Mediomastus californiensis; Tharyx setigera; Prionospio cirrobranchiata; Sigambra tentaculata; Exogone dispar; Dorvillea sociabilis; Protodorvillea* sp. A; and, *Aedicidea cerruti.*

DISCUSSION

As was found in the 1976 study, ANOVA analyses demonstrated that the total meiofauna, true meiofauna, nematodes alone, and temporary meiofauna were significantly different (< 0.01) with respect to: 1) transect; 2)

TABLE 16.10

MEAN PERCENT OF TRUE MEIOFAUNA REPRESENTED BY NEMATODES AND HARPACTICOIDS BY TRANSECT, STATION, AND MONTH

TRANSECT I						
STATION NUMBER	4	1	2	5	6	3
February						
Nematodes	87	83	87	90	85	88
Harpacticoids	3	6	3	0.1	4	2
June						
Nematodes	90	80	76	85	60	50
Harpacticoids	1	7	3	3	9	9
September-October						
Nematodes	91	88	85	82	85	84
Harpacticoids	0.1	2	3	0.0	5	3
TRANSECT II						
STATION NUMBER	4	1	2	5	6	3
February						
Nematodes	90	87	80	80	76	65
Harpacticoids	1	4	7	10	9	6
June						
Nematodes	84	72	67	83	85	45
Harpacticoids	3	10	9	0.0	2	10
September-October						
Nematodes	87	51	81	61	56	67
Harpacticoids	1	10	3	5	13	6
TRANSECT III						
STATION NUMBER	4	1	2	5	6	3
February						
Nematodes	91	88	77	88	87	85
Harpacticoids	1	2	9	3	4	3
June						
Nematodes	88	75	90	82	72	75
Harpacticoids	3	8	1	8	3	3
September-October						
Nematodes	82	73	90	85	82	92
Harpacticoids	7	5	0.0	2	3	0.0

TABLE 16.10 CONT.'D

TRANSECT IV STATION NUMBER	4	1	2	5	6	3	7
February							
Nematodes	89	93	77	85	91	77	80
Harpacticoids	3	3	11	6	1	9	4
June							
Nematodes	90	90	97	80	88	87	85
Harpacticoids	1	5	2	2	1	3	4
September-October							
Nematodes	89	91	90	87	88	88	85
Harpacticoids	1	0.0	2	2	1	1	3

TRANSECT II STATION NUMBER	1	4	2	5	6	3
March						
Nematodes	83	84	89	90	90	91
Harpacticoids	5	4	3	0.0	0.0	0.0
April						
Nematodes	78	93	80	70	80	61
Harpacticoids	5	0.0	5	16	9	4
July						
Nematodes	85	77	84	90	88	82
Harpacticoids	5	8	6	1	1	7
August						
Nematodes	87	87	83	89	87	74
Harpacticoids	4	5	7	3	1	9
November						
Nematodes	86	91	90	82	85	81
Harpacticoids	3	0.0	1	3	1	6
December						
Nematodes	90	91	85	79	75	66
Harpacticoids	1	0.0	2	1	1	2

depth zones within transects; and 3) depth zones among transects.

Correlations were calculated between meiofaunal populations and nine physical parameters measured during the study. The results were essentially the same as those presented in the 1976 study. For instance, sediment texture gave the best correlations with nematodes, harpacticoids, true meiofauna and temporary meiofauna, whereas temperature gave the best correlation with the forams.

Although the harpacticoid/nematode ratio was not a prime consideration in this study, it was still considered as a potential way of estimating the degree of environmental perturbation, whether such impacts were more likely physical or chemical in nature, and possibly the degree of recovery. In essence the underlying basis for interpreting the values of the ratio is the fact that nematodes are very responsive to changes in sediment granulometry whereas harpacticoids are more likely sensitive to chemical factors in the sediment (Pequegnat *et al.*, 1977). It is also to be expected that biological factors such as reproductive cycles can affect the ratio to a certain extent.

The harpacticoid/nematode ratio calculated for all sampling stations in 1977 averaged 0.04. It was interesting to note that the ratio for the bank stations had a value twice (0.08) that of the transect stations. Although at individual stations the range may have been as high as 0.19, whole transect ratios ranged only from 0.01 to 0.08. Taking only the values for the seasonal samples, Table 16.11 shows that Transect II had the highest average ratio (0.06), whereas Transect IV had the lowest (0.02). This situation, of course, was just the reverse of population totals, where Transect IV was the highest and Transect II the lowest. Examination of the harpacticoid and nematode population totals in Table 16.11 gave a clue to the explanation for this situation. For instance,

comparing Transects II to IV, it could be seen that the harpacticoid populations of the latter were about 2.5 times those of Transect II, whereas the nematodes increased by a factor of about six. Sediment characteristics may have been the principal controlling factor recalling that nematode populations are low when clay fractions are high and are high when the sand fraction approaches or exceeds 60%. Located opposite the mouth of Corpus Christi Harbor, Transect II had high clay levels, whereas the location of Transect IV favored increased sand levels. Looking again at Table 16.11, it was apparent that 5 of the 12 ratios were above the mean value of 0.04, 5 were below and 2 were equal to it. All of the above data provided a base from which to estimate what basic kind of stress was being applied to the marine environment by man's activities in a given area.

CONCLUSIONS

The following conclusions are in agreement with data obtained in 1976 and 1977:

1. The meiofaunal populations of the STOCS exhibited seasonally related population peaks in March-April, July-August, and November. The lowest peak was in spring and the largest in summer, but the seasonal amplitude was far greater at shallow locations. Nevertheless, even at depths of 134 m seasonal fluctuations were clearly evident.

2. The meiofaunal populations on the shelf and upper slope decreased substantially with increasing depth down to 134 m. The decrease, however, was not wholly uniform. Local factors could modify the shape of the trend but not the overall trend of reduction. It was not known with certainty what happened to meiofaunal populations below the 134 m isobath in this region.

TABLE 16.11

MEANS OF POPULATIONS OF HARPACTICOIDS AND NEMATODES
FROM ALL TRANSECT STATIONS IN 1977 AND THE CORRESPONDING RATIO FOR EACH.

	TRANSECT I	TRANSECT II	TRANSECT III	TRANSECT IV
WINTER				
Harpacticoids	282	89	89	259
Nematodes	5848	1950	6192	7284
Harpacticoid/ Nematode Ratio	0.05	0.05	0.01	0.04
SPRING				
Harpacticoids	49	52	157	144
Nematodes	2076	797	4393	8752
Harpacticoid/ Nematode Ratio	0.02	0.07	0.04	0.02
FALL				
Harpacticoids	53	49	245	56
Nematodes	3441	736	3372	4489
Harpacticoid/ Nematode Ratio	0.02	0.07	0.07	0.01
AVERAGE RATIO	0.03	0.06	0.04	0.02

3. Comparing 1977 results to the 1976 findings seemed to support the conclusion that a reasonably good conception of the nature of the meiofauna over this shelf has been obtained.

4. Nematodes were strongly influenced by sediment grain size, increasing markedly when sand constituted as much as 60% of the bed.

5. Harpacticoid copepods found were not strongly influenced by grain size. Indirect evidence suggested that they responded more to labile organic inputs. Such evidence came from work on and around hard banks and from the fact that harpacticoids were more abundant at locations where one might expect inputs of detrital material.

6. Development of the harpacticoid/nematode ratio indicated that it was reasonably stable from year to year and that at least some of its departure from the all-station mean of 0.04 could be accounted for by either chemical or biological factors.

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CHAPTER SEVENTEEN

BENTHIC INVERTEBRATES: MACROINFAUNA AND EPIFAUNA

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ABSTRACT

The third year of data collection on the South Texas Outer Continental Shelf (STOCS) benthic invertebrate study consisted of 450 samples of benthic infauna and 186 epifaunal samples collected seasonally on four transects.

Infaunal data was analyzed for community structural parameters, for station and species groupings and station groups so identified were verified by use of discriminant analysis. Species groups were analyzed for constancy and fidelity to various station groups. Three major distribution patterns of benthic infaunal invertebrates were observed with nine distinct species groups composing the various patterns. The study area is divided into five distinctive regions by cluster analysis based on species distribution. Discriminant analysis showed three distinct regions utilizing species distributions and various environmental parameters. Many observations made in previous reports were corroborated.

Epifaunal data were analyzed for community structural parameters, for station and species groupings and for individual species distribution patterns by linear correlations and multivariate analyses. Epifaunal species groups were analyzed for constancy and fidelity to various station groups. Eight species groups were seen to be distributional through two major areas (shallow and deep) which were divided into six distinct regions. Single effect correlation coefficients of seven environmental parameters with the distribution of major species within each species group are presented as are linear additive models for distribution of species thought to be representative of various species groups.

INTRODUCTION

The benthic invertebrate epifauna and macroinfauna of the South Texas Outer Continental Shelf (STOCS) have been studied for three years (1975-1977). The third year of the study (1977) is reported here.

The primary goals of this study, were to: 1) identify and quantify the macroinfauna and epifauna inhabiting the STOCS region; 2) to delineate faunistically similar geographical regions within the study area and to identify faunal assemblages characteristic of these regions; and 3) to correlate observed distributions of invertebrate populations with biological, chemical and physical factors assayed in the study area.

Literature pertinent to invertebrate studies of the South Texas region has been reported in previous reports (Holland, *In* Parker, 1976). Although a number of benthic invertebrate studies have been undertaken in the same study area historically, none have attempted the scope of the study reported here. Epifaunal studies have been more prevalent than studies of macroinfauna. Estuarine and nearshore Gulf studies are more common than are outer continental shelf studies.

The report of the first year's work (Holland, *In* Parker, 1976) concentrated on spatial patterns of benthic invertebrate communities, community-structure parameters and taxonomic findings. Epifaunal abundance patterns were considered largely a function of depth or some combination of parameters associated with depth, whereas infaunal distribution was considered to be affected by sediment as well as depth or depth-related factors. The report of the second year of study (1976) continued the spatial distribution analysis and went into more detail on temporal analysis of benthic invertebrate population distributions. Included in the second year report (Holland, *In* Groover, 1977) were preliminary

results on small scale distribution of some infaunal species and an analysis of the effects of topographic highs on benthic infaunal (soft-bottom) communities surrounding these features. Epifaunal communities were characterized for various regions of the study area, primarily inner shelf and outer shelf communities. The inner-shelf communities were characterized by large numbers of individuals, low diversity and low equitability. Many typical inner-shelf species, such as *Trachypenaeus similis*, *Squilla empusa* and *Penaeus setiferus* generally have strong affinities for estuaries and showed seasonal variability in continental shelf distribution patterns. The outer-shelf assemblages were characterized by greater temporal stability, higher diversity, higher equitability and relatively small numbers of individuals.

Macroinfaunal communities were reported in 1976 (Holland, *In* Groover, 1977) as being distributed basically in the following three habitat-defined regions: 1) shallow-muddy-sand (10-27 m); 2) deep-silty-clay (65-134 m); and 3) deep-muddy-sand (65 and 91 m). Macroinfauna were most abundant along the inner shelf with decreasing numbers offshore and increasing equitability and diversity offshore. Populations comprising the macroinfaunal communities showed a greater tendency toward aggregation at the shallow muddy-sand stations than at deeper silty-clay stations.

The results reported here provide additional information on the variations in benthic macroinvertebrates both spatially and temporally on the STOCS. It is felt that these results when combined with the previous two study years should provide a good characterization of the STOCS benthos including both epifauna and infauna.

METHODS

Sampling and laboratory methods were essentially the same during 1977

as in previous years. The infaunal sampling intensity declined, however, in that monthly samples were not collected from Transect II.

Infaunal samples were collected seasonally from all stations and from two stations on both Southern Bank and Hospital Rock. Six replicate samples were taken from each station with a 0.1 m^3 Smith-McIntyre grab sampler.

Epifaunal samples were collected from all transect stations seasonally. One day and one night trawl was taken at each station on Transects I, II and IV, while one day and three night trawls were taken at each station on Transect II. Additionally, three night trawls were made at Stations 1-3, on Transect II, during the six monthly sampling periods. A 35-ft (10.7 m) Texas-box otter trawl was used for the epifauna collections.

After removal of a subsample core (5 cm diameter) for sediment analysis, infaunal samples were washed through a 0.5 mm mesh on board ship, narcotized and preserved in formalin with rose bengal added. Epifaunal samples were preserved in formalin aboard ship. In the laboratory, samples were re-preserved in 70% alcohol, sorted, identified to lowest possible taxon, counted and archived by taxon. The infaunal samples of the fall collection period were wet weighed before sorting to obtain a biomass estimate.

The measure of species diversity for the species' lists at each station during each sampling interval was calculated by a modified Shannon-Wiener diversity index (Pielou, 1966), while equitability (Lloyd and Ghelardi, 1964) and Hulbert's (1975) probability of interspecific encounter (P.I.E.) were also determined as in previous years. It was assumed that by combining a diversity index with a measure of evenness, showing species richness and total abundance, and providing the P.I.E. measure, a reasonable comparison of diversity between communities could be accomplished.

The tremendous quantity of data accrued in a large scale survey such as this and the fact that inclusion of many rare species into several of the numerical techniques (*e.g.*, cluster analysis) added nothing to the analysis and even caused misinterpretation in some cases, made it necessary to reduce data input into several analyses by eliminating rare species from consideration, as have others (*e.g.*, Thorson, 1957). In previous years work rare species were defined as those not collected at least three (3) times in the three seasonal collections. This cut-off point reduced the 1976 epifauna by 34% of the species but only omitted .04% of the individuals. Infauna was reduced more stringently due to the greater percentage of rare species. Therefore, cluster analysis was performed on approximately 40% of the species which comprised approximately 96% of the individuals. Cluster analysis for this year was limited to those species which were termed "Biologically Important Species" (BIS) according to the concept of Thorson (1957). These species were selected according to the following criteria. A species must have been collected at 20% of the stations, must have comprised 7% of the total number of individuals at any one station, or must have been one of the species comprising the top 50% of the individuals at any one station.

The cluster analysis technique utilized in 1976 was performed on an Amdahl 470V/6 at the Texas A&M University Data Processing Center. The program, Class, developed by Dr. R. W. Smith of the Department of Biology, USC, was modified by the STOCS data management group in close cooperation with personnel from the benthic ecology group. A new program which does the same analysis but is in Fortran was developed so that it could be utilized by the University of Texas Computation Center. The new program was checked by processing 1976 data and was found to produce equivalent results.

Analysis of species composition of the individual stations using principal components ordination (Orloci, 1966) was incorporated in this year's study to provide another means of numerical classification. This technique identified communities with similar species records by close position of ordination scores on an ordination plot. The similarity index used was that of Bray and Curtis (1957). Square root transformation was done on the raw species counts in order to decrease the effects of a few species with large abundances. Species utilized in this analysis were selected by a BIS technique similar to that utilized in the cluster analysis. The results of this method were compared with cluster analysis results and found to be almost identical in community classification.
To statistically define regions of the study area that differentiated from one another both biologically and environmentally, discriminant analyses (Morrison, 1969) was employed. A computerized program was selected from the Statistical Packages for Social Sciences (SPSS) and run on a CDC 6600 computer through the University of Texas, Austin. The discriminative variables chosen were the general community characteristics of the infauna, mean sediment parameters for each station of each cruise and the variables of bottom water temperature and salinity.

The discriminant analysis was undertaken to determine whether it might provide a more objective method of determining significant differences between station groupings than the more subjective techniques of cluster and ordination analysis. The analysis phase (contrasted to the classification phase) of this technique was subjected to the station groupings determined from both infaunal and sediment textural numerical evaluation (clustering and ordination). The results were evaluated for significance of the Mahalanobis D square distance between groups. The classification phase of this technique was employed to determine exactly

how many individual stations were misplaced in the final groups tested based on their discriminant scores.

Multivariate linear analyses utilizing species thought to be most representative of epifaunal groups delineated by cluster and ordination analyses were incorporated in this year's study. Key species of groups shown to be relatively consistent through time, were utilized as dependent variables with data from other elements within the STOCS project as independent variables.

RESULTS

A total of 59,220 individuals representing 667 species of infauna were collected in 75 Smith-McIntyre grab samples taken during 1977. Numerically dominant infaunal species included *Magelona phyllisae, Paraprionospio pinnata* and *Lumbrineris parvapedata*.

A total of 23,933 individuals representing 88 species of epifauna were collected in the 258 trawls taken during 1977. Three crustaceans (*Trachypenaeus similis, Penaeus aztecus* and *Sicyonia dorsalis*) comprised 60% of the total epifaunal catch by number. There were 24 species represented by only one individual.

Community structure parameters examined for the past three years included number of species, number of individuals, species diversity (H') and equitability (E). Infaunal community structure patterns for 1977 are presented in Figures 17.1 - 17.3.

In general, the number of infaunal species collected at various stations showed a basic spatial pattern with little temporal variability. Transects I and II were similar in spatial pattern of species abundance as were Transects III and IV but there was a decided difference between the two pairs of transects. Transects I and II showed little or no peak

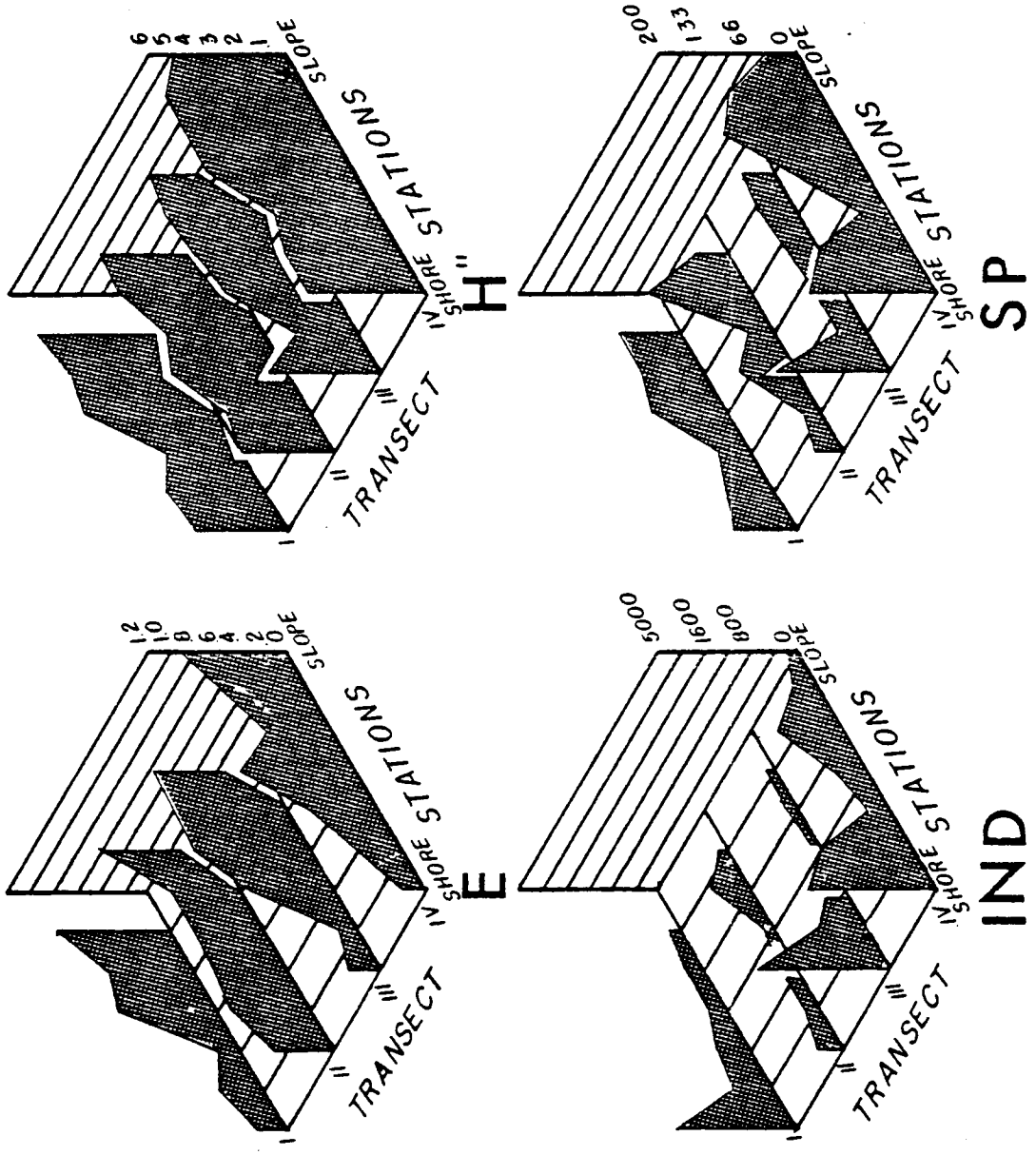

Figure 17.1 Shannon Diversity Values - H", Equitability- E, Number of Species and Number of Individiauls for Winter Infaunal Data.

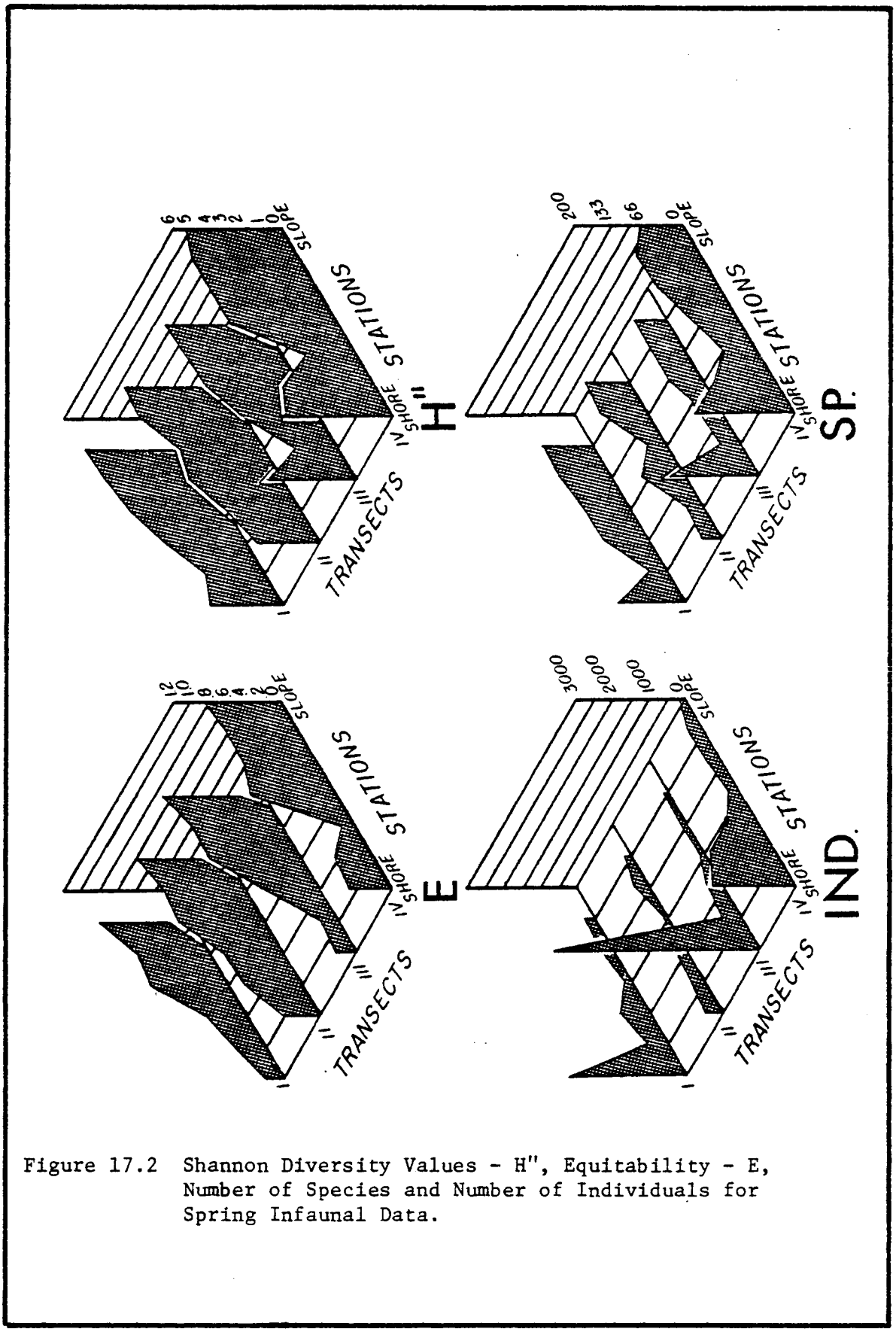

Figure 17.2 Shannon Diversity Values - H", Equitability - E, Number of Species and Number of Individuals for Spring Infaunal Data.

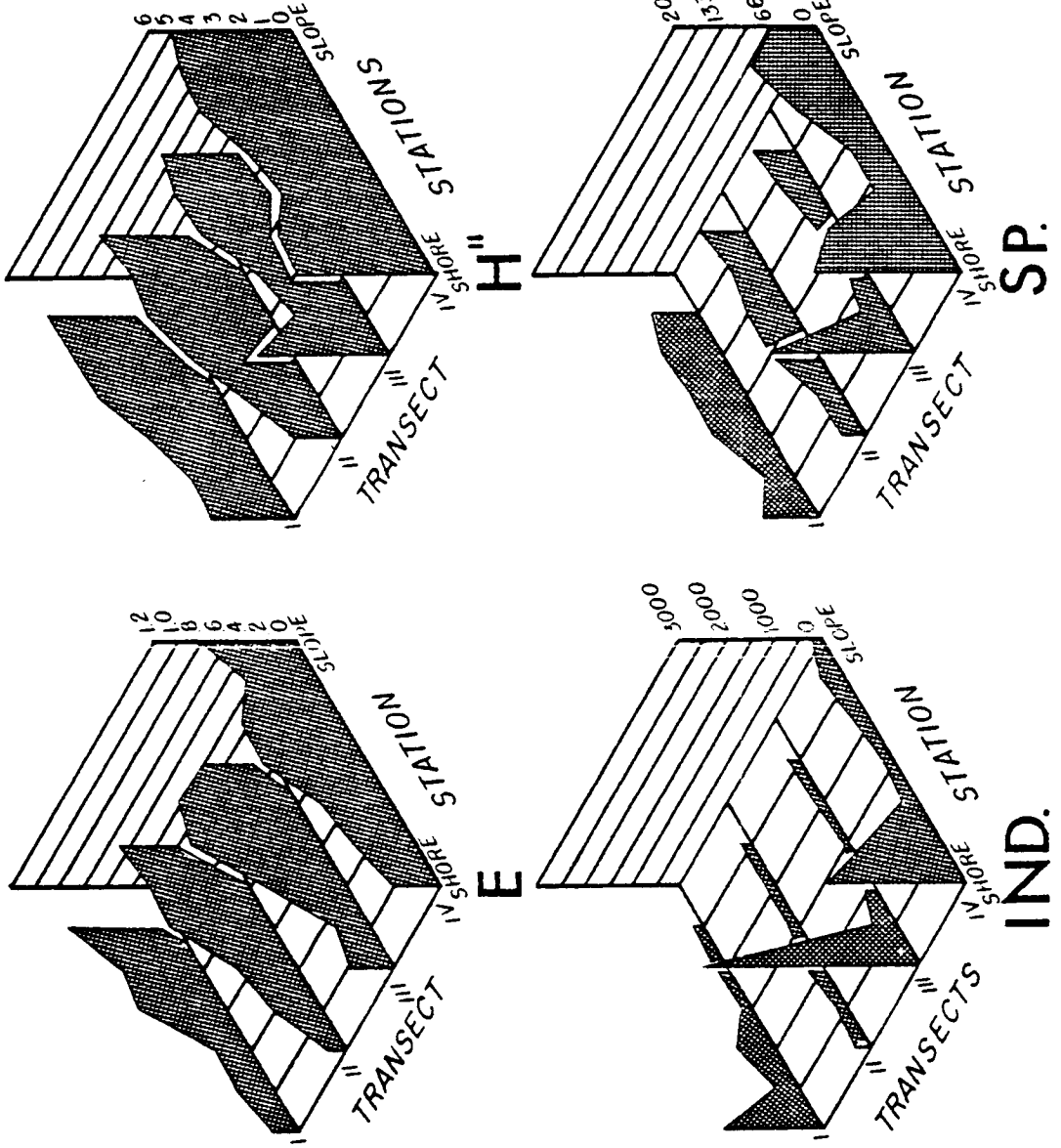

Figure 17.3 Shannon Diversity Values - H", Equitability - E, Number of Species and Number of Individuals for Fall Infaunal Data.

species abundance inshore. In fact, number of species on these two transects was often greatest at the offshore stations. Essentially the opposite case was true for Transects III and IV. Large peaks in number of species always occurred at the innermost sites on these transects. Transect III never showed high numbers of species offshore while Stations 3/IV and 6/IV had species numbers approaching those found at the innermost stations. Transect I had basically the same pattern in species richness over the three seasonal samples. It had a small inshore peak, a definite depression at the next shallowest station (Station 1) with the remainder of the stations displaying numbers of species approaching that of the innermost station. Basically little or no gradient in species richness with depth was observed but Station 1/I was consistently depauperate in species. Transect II had a slightly varying pattern of species richness. Winter and spring collections had no inshore peak with slight increases in species richness at Stations 2 and 6. These slight increases did not materialize in the fall samples. The pattern of species richness on Transect III remained very consistent through 1977. A definite inshore peak was seen in all three seasons with the remainder of the stations exhibiting poor species richness. Transect IV consistently had the greatest species richness overall with a fairly constant pattern of increased richness at the inner two stations (1 and 4), the next two stations (2 and 5) were always relatively depauperate while Stations 3 and 6 showed increasing species richness and a sharp decline in number of species was observed for collections at the deepest station (7/IV).

The number of individual infaunal organisms collected at each site over the three seasonal collections of 1977 showed extremely similar patterns through time on each transect. The general pattern was one of

decreasing density with depth. Transect II did not follow the general pattern in that there was never a decided peak in the innermost site on this transect and the numbers of individuals were consistently low, showing no relation to depth. A very slight increase in numbers of individuals was encountered at Station 6/II during the winter. Numbers of individuals always peaked inshore on Transect III. The greatest number of individuals collected per station was found at the spring collection of 4/III. All other stations along this transect exhibited very low numbers of individuals other than the innermost stations. This seemed to be the most uniformly depauperate transect of the study area. Transect IV generally followed the pattern of decreasing density with depth although a slight peak at the deeper stations (3 and 6) was observed in the winter collection. The inner two stations (1 and 4) always had large numbers of individuals.

Diversity (H') of infaunal communities in the STOCS region was relatively high compared to data from neighboring bay areas. There was a trend for diversity to increase with depth. Transect I had a slightly different pattern of diversity in the winter than in spring or fall. Station 1/I did not appear to have lowered diversity in the winter while 2/I did. The opposite was true in succeeding collections. The deepest sites (3, 5 and 6) always had the highest diversity on this transect. Transect II had a slight peak in diversity at Station 2 during the winter and spring but otherwise indicated a smooth increase in diversity with increasing water depth. Diversity values at the shallowest and deepest sites on Transect III were fairly similar. A decrease in diversity was always seen at Station 1/III and at Station 5/III in the fall. Transect IV had the highest diversity normally, with diversity being fairly uniform along the transect with decreases at Stations 2 and 5 common.

In general, equitability showed an increase with depth. Transect I had a consistent pattern of low equitability at the three shallowest sites and a greatly increased value at the deepest sites. Transect II showed the same basic pattern except that the winter collection on this transect showed a decreased equitability with little tendency to increase offshore. Transect III showed a slight variation on the general pattern in that only the inner two sites exhibited the decreased equitability common to the inner three sites of the other transects. The pattern of equitability was remarkably stable through time on Transect III. Transect IV had a more variable pattern of equitability. It exhibited the general pattern although the innermost three sites were more equitable than similar depths on other transects. Unusual depression in equitability were noted at Stations 3, 5 and 6 in winter, spring and fall, respectively.

Epifaunal community structure parameters are presented in Figures 17.4 - 17.6. Number of epifaunal species collected per station presented no consistent general pattern. The numbers collected were much smaller than in the infaunal collections. Along Transect I, epifaunal species numbers were fairly evenly distributed during each collection period. Differences between seasons were apparent. The winter sampling showed fewer species collected on this transect. The number of species collected at 5/I was somewhat depressed at all collection times. Transect II showed a varying pattern of species abundance spatially and temporally. The winter collection had a peak species abundance at 6/II which looked like an increase with depth. Both spring and fall collections had species abundance peaks at Station 2/II so that the abundance of species was greatest at mid-depth and decreased shoreward and offshore. On Transect III, there was a slight winter increase in species richness with depth. Spring collections at the deepest two stations (3 and 6) were extremely

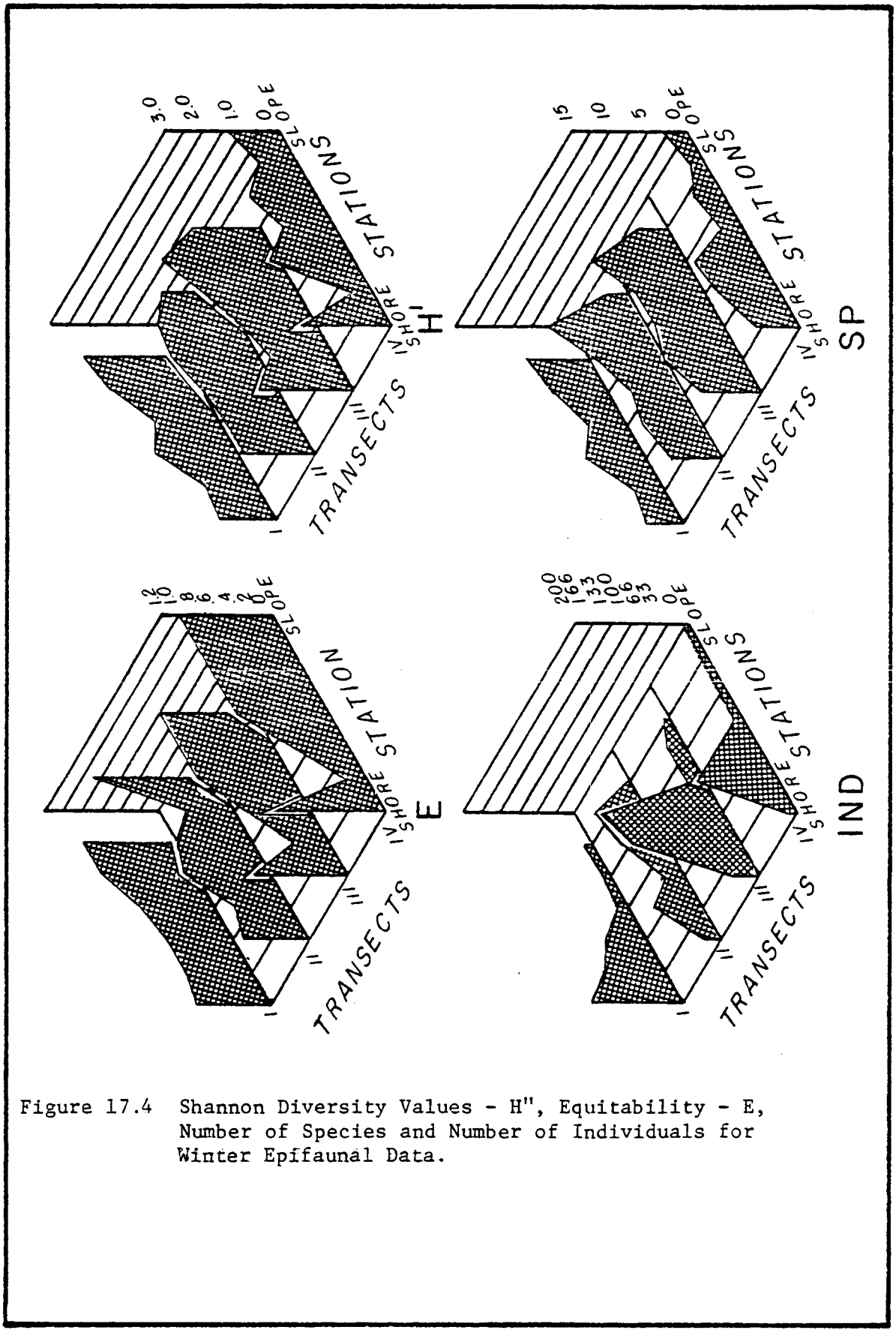

Figure 17.4 Shannon Diversity Values - H", Equitability - E, Number of Species and Number of Individuals for Winter Epifaunal Data.

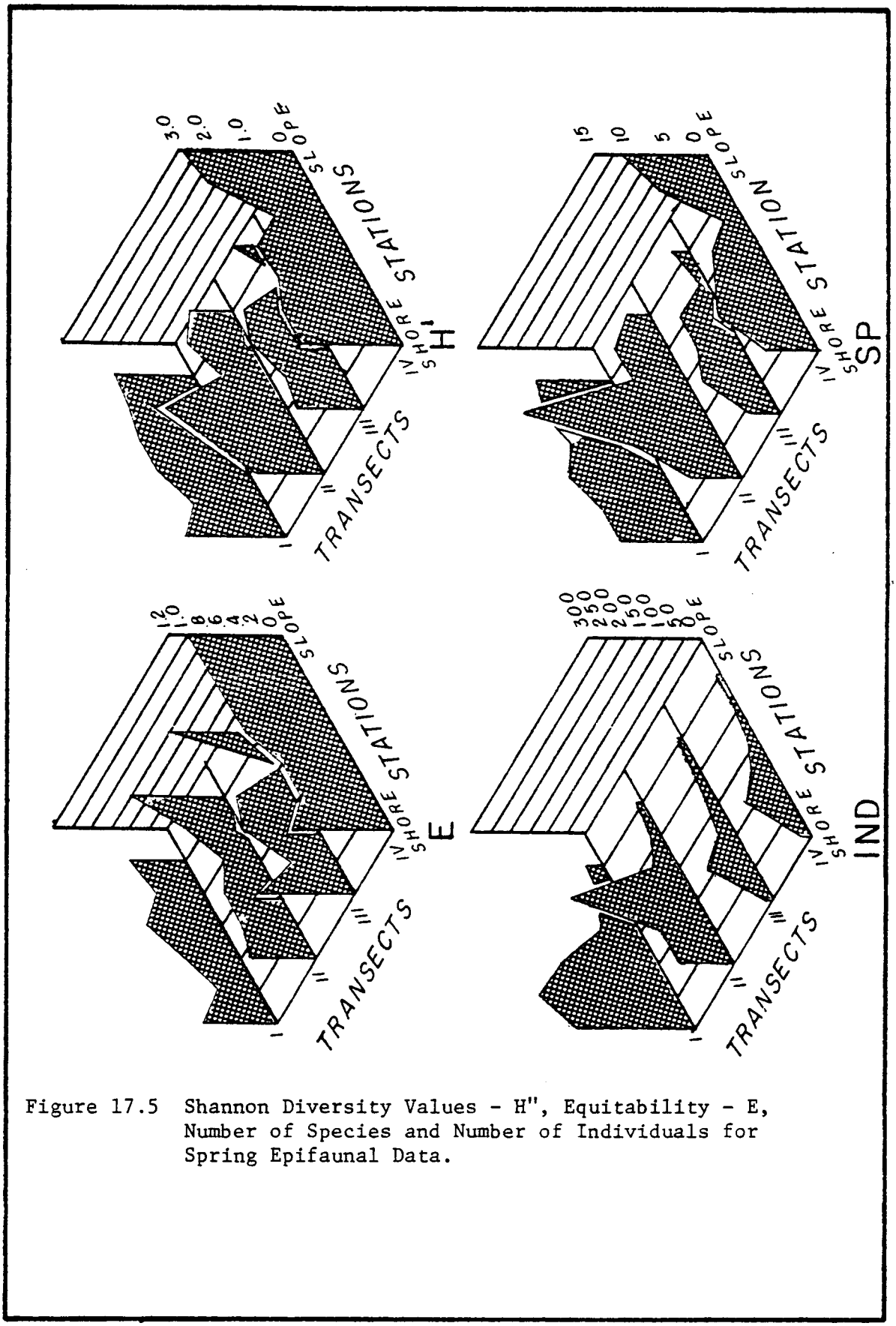

Figure 17.5 Shannon Diversity Values - H", Equitability - E, Number of Species and Number of Individuals for Spring Epifaunal Data.

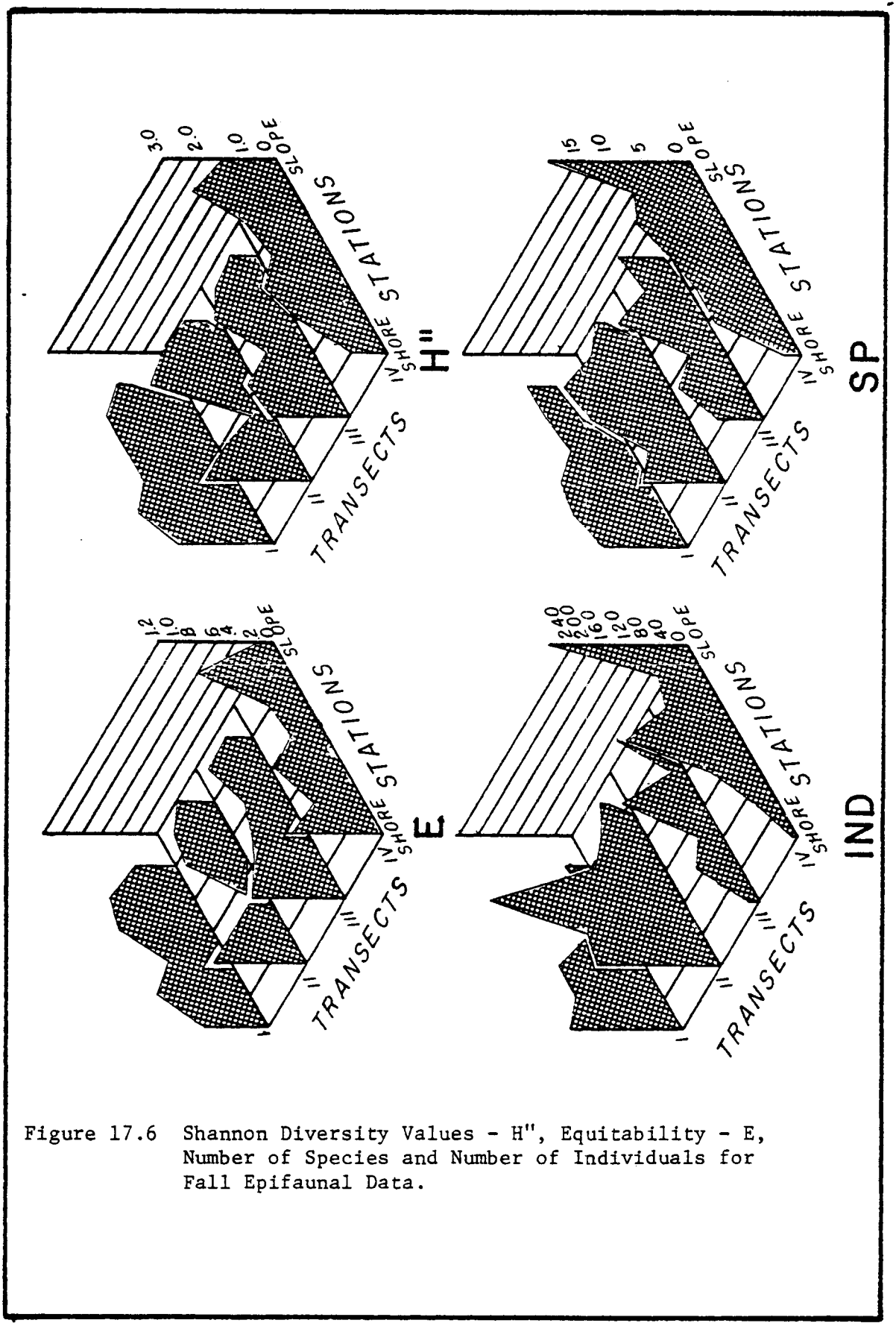

Figure 17.6 Shannon Diversity Values - H", Equitability - E, Number of Species and Number of Individuals for Fall Epifaunal Data.

depressed. Minor peaks in species abundance occurred at Stations 1/III and 2/III in the fall. Transect IV epifaunal species richness varied widely with season. The winter collection showed a strong decrease in species richness with depth. The spring had number of species more or less evenly distributed along the transect with Station 6/IV somewhat depressed. The fall collection exhibited a strong positive correlation of species richness and water depth.

The number of individual epifaunal organisms collected at each station had a general tendency to peak at mid-depth or shallow-intermediate depth and to decrease shoreward and offshore. Transect I epifaunal density distribution followed the general pattern but had maximal numbers of individuals at inshore sites, more so than other transects. A highly varied pattern of density was seen on Transect II. Winter collections were small and similar in numbers of individuals across the shelf. A major peak in density occurred in the spring collection at Station 2/II with numbers of individuals decreasing shoreward and offshore. The fall collection on this transect displayed the densest epifaunal communities observed for the entire year, particularly at the four shallowest stations. The number of epifaunal organisms collected on Transect III varied widely through the year. The winter collection had dense populations on the inner half of the study area. This transect was practically depauperate during the spring collections. Fall collections indicated peaks of abundances at Stations 1, 2 and 6. Transect IV had epifaunal density patterns similar to Transect III with the winter onshore collections slightly diminished and the fall collections generally increased.

Epifaunal diversity (H') was generally lower than that exhibited by infaunal collections. No trends were observed which were consistent across all transects so no general pattern of diversity could be proposed. Tran-

sect I generally had relatively high diversity consistent across the shelf with some tendency to increase with depth in the winter. Transect II epifaunal diversity was extremely consistent during the winter showing a major peak at Station 2/II in the spring and major decline at Station 3/II in the fall. Transect III exhibited a fairly high winter diversity with a minimum at Station 1/III. Increases in this variable with depth were observed, except at the deepest site where a decrease in diversity was seen. A major decrease in diversity was observed at 3/III in the spring collection. Spring diversity on Transect III was fairly uniform with decreases at Stations 5 and 6. Transect IV had relatively low diversities in the winter, uniformly high values in spring with the exception of Station 3/IV and a tendency for H' values to increase with depth in the fall.

Epifaunal equitability values showed no pattern consistent to all transects. There was a trend toward greater equitability inshore and offshore with mid-depth areas being depressed. Transect I showed a smooth pattern of increasing equitability with depth in the winter. Spring and fall values were more diverse with low equitability at Stations 1 and 6 in the spring and Stations 4, 2, and 3 in the fall. Transect II exhibited increased equitability at the deepest site (Station 3) in winter and spring which decreased sharply in fall concommitant with an increase in equitability at the nearshore stations. Transects III and IV were very similar in the winter with high equitability at all except the shallow mid-depth stations. Equitability on Transect III showed peaks shallow and deep with variable levels between in the spring while Transect IV values remained almost uniformly high. Fall collections on Transects III and IV indicated the trend toward greater equitability inshore and offshore with decreased values at mid-depths.

Infaunal data from all 25 stations for each of the three seasons was subjected to cluster analysis. One hundred and seventeen (117) infaunal species were selected for inclusion in this analysis by the BIS criteria. Thus an original data matrix of 75 site-times by 117 infaunal species was compiled and subjected to both normal and inverse cluster analysis.

The dendrogram resulting from normal analysis of infaunal data (Figure 17.7) indicated that our study area was divided into five distinct regions, each represented by a group of stations. These regions were most identifiable by depth, with the following designations: shallow (10-27 m); shallow-intermediate (18-24 m); intermediate (34-49 m); deep-intermediate (69-100 m); and deep (106-134 m). The apparent overlap of shallow and shallow-intermediate stations was due to one station (1/IV) with a depth of 27 m clustering with a group of three stations with depths of 15 m or less. Among all groups, only Station 1/IV (27 m) failed to comform to a clear cut depth differentiation. No station was clustered outside its respective group in any season (*i.e.* all stations showed 100% faithfulness to their station-groupings). Within each station-group, many individual stations showed close similarity through the three seasons. There was definitely no seasonal trend between station-groups nor was there any evidence to support seasonal groupings of stations within a station-group observed.

It was decided to statistically test the differences between station groupings that were derived from clustering and ordination techniques subjected to infauna and sediment characteristics separately. The multivariate procedure of discriminant analysis proved valuable in testing the hypothesis that there was significant difference between the station groupings of Figure 17.8 over the study interval. The analysis technique provided several tools for the interpretation of the infauna data. Among

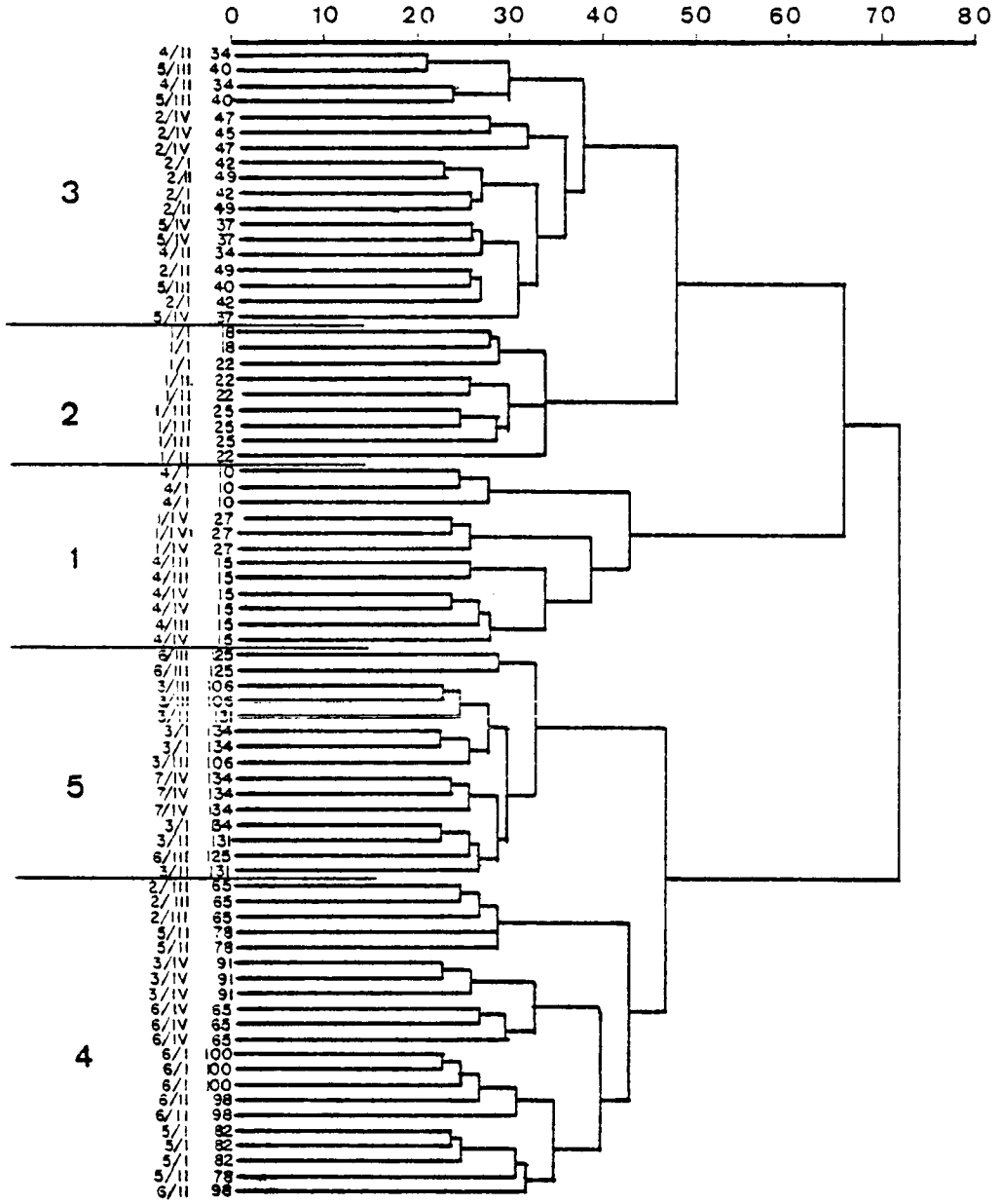

Figure 17.7 Normal Dendrogram from Cluster Analysis of Infaunal Data. Numbers Following the Station Designations Refer to Depth (in meters). Large Numbers to the Left Refer to Station Groups.

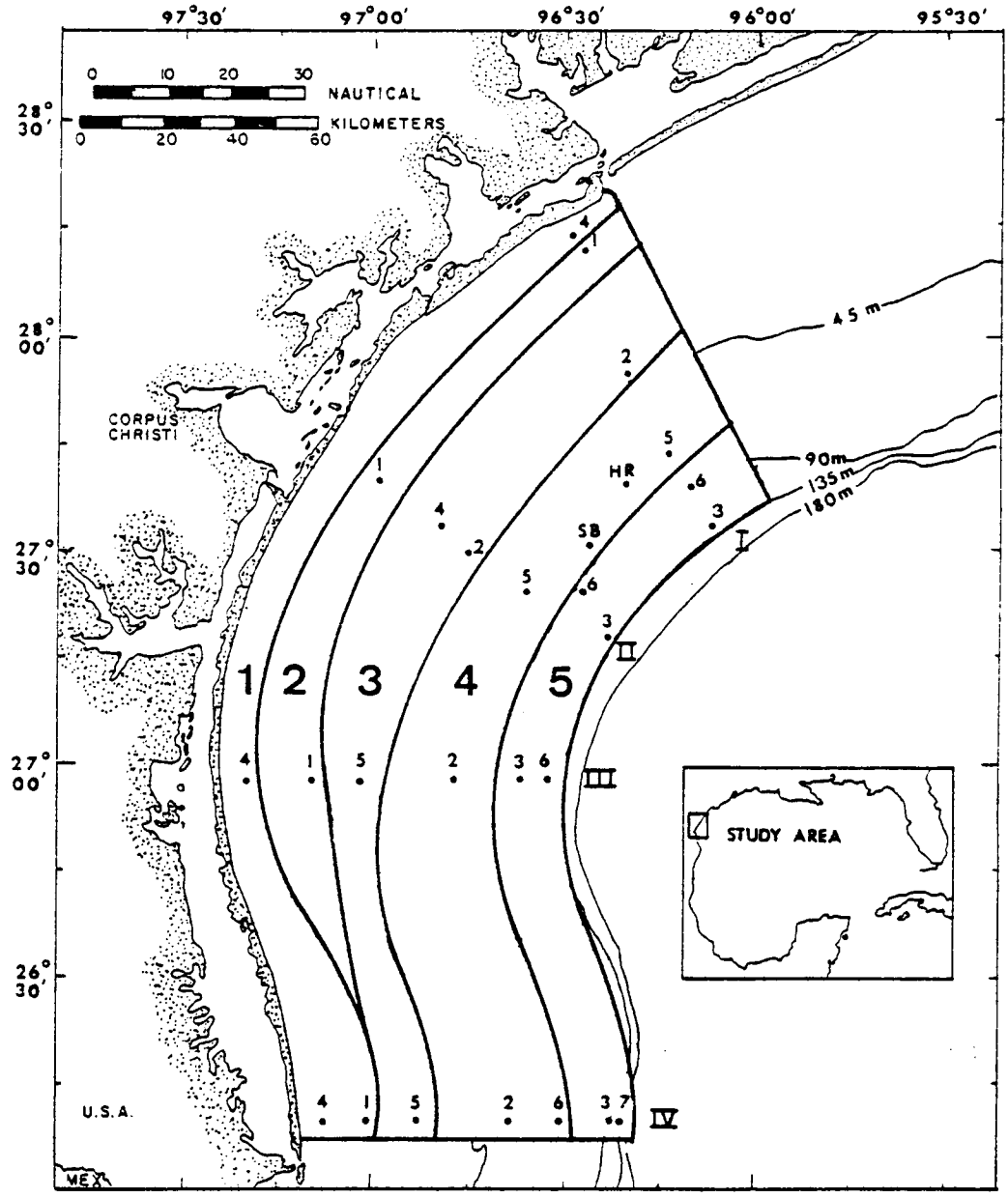

Figure 17.8 Location of Station-Groups (1-5) from Cluster Analysis of Infaunal Data.

these were the statistical tests for measuring the success with which the discriminating variables actually discriminated the station groupings when combined into discriminant functions and the spatial relationship that existed among these groups based on the final functions. The discriminating variables employed in this analysis were the general infaunal community characteristics as well as the environmental variables measured for each station during each sampling period. All the variables considered are listed in Table 17.1. The station groupings that were subjected to the analyses were modified from those defined by clustering techniques. Station Group 1 was the same in both instances. Station Group 2 defined for discriminant analyses however, contained both mid-depth station groups (II and III) from the clustering method. The discriminant Station Group 3 included clustering Groups 4 and 5 with the exception of Stations 3/IV and 6/III which comprised Station Group 4 for the discriminant analysis.

As illustrated by Figure 17.9, there was a spatial separation of station groups based on both infaunal and physical station characteristics. Group 1 (Group 1 from cluster also), the sandy stations, were well differentiated from the other groups by the discriminating variables. This was also the case for Group 4 (Stations 3/IV and 6/IV of Station Group 5 from cluster analysis) which further supported the difference in these stations from the other collection sites as strongly suggested by sediment characteristics and less by infaunal community structure parameters. Station Group 2 (cluster group 2 and 3) and 3 (cluster groups 4 and 5) although aligned more closely on the plot (Figure 17.9) did also differentiate from one another. The classification property of discriminant analysis indicated that 96% of the individual stations considered in this analysis for the entire study interval were correctly classified into a

TABLE 17.1

THE MEANS AND STANDARD DEVIATION FOR EACH STATION GROUPING OF THE DISCRIMINATING VARIABLE USED IN THE DISCRIMINANT ANALYSIS PROCEDURE TO TEST FOR DIFFERENCES BETWEEN THE GROUPS

MEANS

Abbreviation	Variable Description	Group 1	Group 2	Group 3	Group 4
SPC	Number of Species	150.58333	50.27083	59.43939	117.00000
ABUN	Total Number of Organisms	2971.79167	490.50000	195.36364	494.75000
DIV	Diversity	4.97910	3.90167	5.08160	5.83635
PIE	Probability of Interspecific Encounter	.91710	.83411	.95588	.96705
EQUI	Equitability	.35397	.53561	.93068	.77803
SAND	Percent Sand	72.33833	21.98083	7.19242	49.34667
SILT	Percent Silt	11.51333	35.60250	31.90773	16.09083
CLAY	Percent Clay	16.14708	42.41542	60.89909	34.56167
MGRSZ	Mean Grain Size	4.40958	7.47458	9.02212	6.03583
GRSTD	Grain Size Duration	2.85167	3.48771	3.11424	3.92833
GRSKEW	Grain Size Skewness	1.30333	.33542	-.08924	.54833
TEMP	Bottom Water Temperature	22.53708	22.01250	19.41030	20.40750
SAL	Bottom Salinity	34.32500	35.21021	36.23030	36.24000
ORD1	First Principal Ordinate from Infaunal Community Ordination	9.35379	3.62192	2.09545	3.38367
ORD2	Second Principal Ordinate from Infaunal Community Ordination	2.38942	2.24442	1.91242	4.89533

STANDARD DEVIATION

SPC	Number of Species	44.61421	13.94478	22.25041	32.11344
ABUN	Total Number of Organisms	1588.82489	305.65068	117.00791	268.90557
DIV	Diversity	.75013	.84490	.53528	.29014
PIE	Probability of Interspecific Encounter	.05673	.13603	.02900	.00986
EQUI	Equitability	.12678	.27183	.14870	.10682
SAND	Percent Sand	9.06434	14.47718	9.24675	14.93209
SILT	Percent Silt	3.48184	8.19747	5.23964	4.63925
CLAY	Percent Clay	6.80981	9.70989	9.34908	10.39945
MGRSZ	Mean Grain Size	.75382	.97101	.84588	1.17116
GRSTD	Grain Size Duration	.81570	.26616	.30285	.34443
GRSKEW	Grain Size Skewness	.80634	.27163	.21287	.30133
TEMP	Bottom Water Temperature	5.85683	4.84975	2.69727	1.54382
SAL	Bottom Salinity	1.84911	1.28661	.39938	.35152
ORD1	First Principal Ordinate from Infaunal Community Ordination	2.20737	.66997	.88032	.77451
ORD2	Second Principal Ordinate from Infaunal Community Ordination	1.04261	.46398	.84519	1.95702

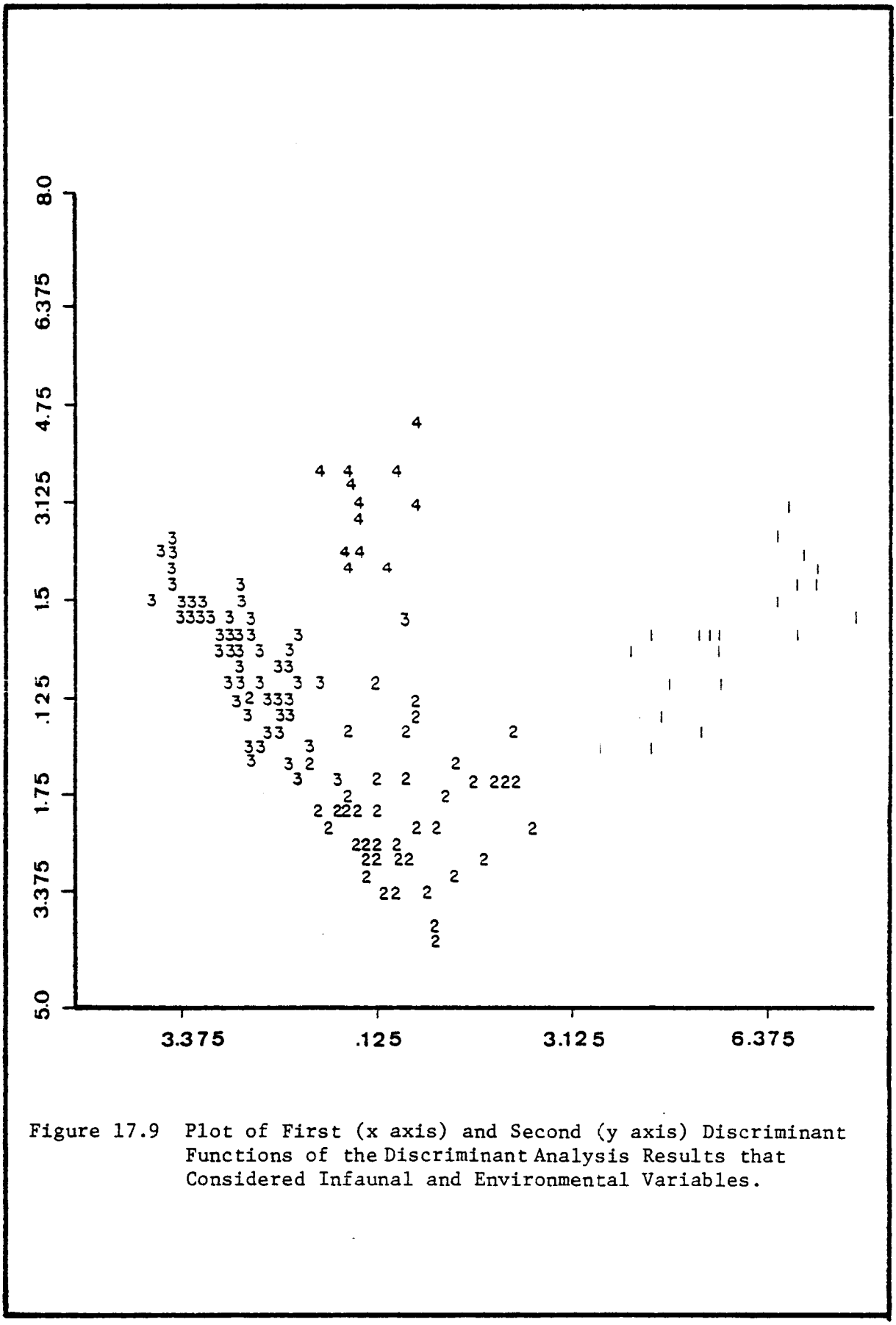

Figure 17.9 Plot of First (x axis) and Second (y axis) Discriminant Functions of the Discriminant Analysis Results that Considered Infaunal and Environmental Variables.

station grouping. The chi-square derived from the general Mahalanobis D square was 403.28 and was significant at $P < 0.0001$. Thus, there was very little probability that the groups could have been formed by chance. The separation between them was complete and very large.

Examination of the standardized discriminant function coefficients for the two functions that exhibited the group separation in Figure 17.9 showed that the first infaunal principal coordinate (from ordination), mean grain size, percent sand and clay and number of species were most important (highest coefficient values) in causing the discrimination observed (Figure 17.9). These variables helped to explain approximately 93% of the variation observed between stations over the study duration. Table 17.1 shows the means of all the variables used in the discriminant analysis for the four station groupings over the study period. Comparison of these means between station groups helped to illustrate why the most important variables listed above were so strong in differentiating between the groups. It should be noted that although the first principal coordinate from infaunal ordination was the strongest discriminating variable, there was not a great deal of difference between Station Groups 2 and 4 in respect to this variable. If the second principal coordinate was examined, however, it was evident that this variable provided additional separation between these two station groups. This distinction was secondary to that derived from the variables of mean grain size, percent sand and clay and species number, which the analysis deemed more powerful.

Inverse cluster analysis divided the 117 species utilized into nine groups which were characteristic of individual station groups or various combinations of station-groups. Two way coincidence tables (Tables 17.2 and 17.3) showing constancy (Table 17.2) and fidelity (Table 17.3) of

TABLE 17.2

CONDENSED TWO-WAY TABLE AS CONSTANCY OF A SPECIES IN A STATION GROUP

Species	Number of Occurrences	Station Group 1	2	3	4	5
Paraonis gracilis	74	MMMM	MMMM	MMMM	MMMM	MMMM
Cossura delta	74	MMMM	MMMM	MMMM	MMMM	MMMM
Sigambra tentaculata	71	MMMM	MMMM	MMMM	MMMM	MMMM
Armandia maculata	57	MMMM	XXXX	MMMM	MMMM	MMMM
Paraprionospio pinnata	73	MMMM	MMMM	MMMM	MMMM	MMMM
Nephtys incisa	63	IIII	MMMM	MMMM	MMMM	MMMM
Ninoe nigripes	56		MMMM	MMMM	XXXX	MMMM
Tharyx annulosus	50	MMMM	XXXX	IIII	MMMM	XXXX
Tharyx marioni	59	MMMM	MMMM	IIII	MMMM	MMMM
Lumbrineris parvapedata	68	MMMM	MMMM	MMMM	MMMM	MMMM
Mediomastus californiensis	63	MMMM	MMMM	MMMM	MMMM	IIII
Volvulella texasiana	43	IIII	MMMM	IIII	XXXX	XXXX
Spiophanes sp A	34	MMMM		IIII	XXXX	
Paraonis sp A	52	IIII	MMMM		MMMM	MMMM
Paraonides lyra	43	MMMM	XXXX		MMMM	IIII
Pilargis berkeleyae	14					
Corbula swiftiana	55	MMMM	MMMM	IIII	MMMM	
Polychaete sp. A	42	MMMM	IIII	IIII	XXXX	
Lumbrineris tenuis	39	MMMM	IIII	XXXX	IIII	
Notomastus cf. *latericeus*	47	MMMM	MMMM	MMMM	XXXX	
Drilonereis magna	34	MMMM	MMMM		IIII	
Magelona longicornis	49	XXXX	MMMM	MMMM	MMMM	
Ampelisca verrilli	42	MMMM	MMMM	IIII	IIII	
Nereid (Nicon) sp. A	43	MMMM	MMMM	MMMM	IIII	
Ampelisca agassizi	40	MMMM	MMMM	MMMM	IIII	
Ampelisca abdita	38	XXXX	MMMM	XXXX	IIII	
Asychis elongata	26	XXXX	IIII	IIII	IIII	
Nereid sp. B	23	IIII	IIII		XXXX	
Notomastus latericeus	21	XXXX			IIII	
Aedicira belgicae	31	MMMM	XXXX	IIII		
Mirauspio cirrifera	21	MMMM		XXXX		
Apseudes sp. A	21	IIII	MMMM			
Listriella barnardi	25	MMMM	IIII	XXXX		
Magelona rosea	36	MMMM	XXXX	XXXX		
Aricidea jeffreysii	36	MMMM	XXXX	XXXX		
Vitrinella floridana	19	XXXX		XXXX		
Mirauspio longibranchiata	21	IIII	XXXX	IIII		
Magelona phyllisae	32	MMMM		MMMM	IIII	
Sthenelais boa	29	MMMM		IIII	IIII	
Gyptis vittata	25	MMMM		IIII		
Natica canrena	18	MMMM		IIII		
Amphicte acutifrons	23	MMMM		IIII		
Paleanotus heteroseta	19	MMMM				
Aricidea cf. *fragilis*	19	MMMM				
Aricidea taylori	19	MMMM				
Owenia fusiformis	22	MMMM				
Anadara transversa	18	MMMM				
Pseudophilomedes sp. B	4					
Cascum pulchellum	3					
Abra aequalis	29	MMMM		IIII		
Notomastus americanus	18	XXXX				
Tellina versicolor	22	MMMM				
Spiophanes bombyx	9	MMMM				
Isolda pulchella	9	MMMM				
Ceratonereis irritabilis	7	IIII				
Clymenella torquata	15	MMMM				
Prionospio cristata	14	MMMM				
Ceratocephale oculata	21	MMMM				
Glottidia pyramidata	11	IIII				
Lumbrineris albidentata	20	XXXX				

TABLE 17.2 CONT.'D

Species	Number of Occurrences	Station Group 1	2	3	4	5
Kalliapseudes sp. A	14		XXXX			
Automate evermanni	28		XXXX		IIII	
Eudorella monodon	32		MMMM		XXXX	
Heterophoxus cf. *oculatus*	25				IIII	MMMM
Hippomedon cf. *serratus*	24		IIII		IIII	XXXX
Paramphinome pulchella	22				XXXX	
Amphareta parvidentata	17				XXXX	
Thyasira sp. A	22				XXXX	
Eyala sp. A	29		IIII		XXXX	IIII
Cyclocardia ventricosa	6					IIII
Ostracod sp. A	9					XXXX
Philomedes sp. A	14					MMMM
Syllis sp. C	16					MMMM
Eriopisa incisa	8					
Sanguinolaria sanguinolenta	10					IIII
Spiophanes longicirrus	31				MMMM	XXXX
Pitar cordatus	37				MMMM	MMMM
Scutopus sp. A	28				MMMM	XXXX
Stermaspis scutata	30				MMMM	MMMM
Sybilis cf. *affinis*	26				XXXX	MMMM
Paralacydonia paradoxa	29				XXXX	MMMM
Ampelisca sp. A	28				XXXX	MMMM
Alternochelata sp. A	22				IIII	MMMM
Dentalium sowerbyi	28				XXXX	MMMM
Thyasira pygmaea	22				IIII	MMMM
Onuphis sp. B	13				IIII	IIII
Ostracod sp. D	12					IIII
Goniada maculata	18				IIII	IIII
Spiophanes wigleyi	19				IIII	IIII
Xenanthura brevitelson	18					MMMM
Sarsiella cf. *zeei*	15					IIII
Apanthura magnifica	7					
Fabricia sp. A	5					
Sphaerosyllis cf. *sublaevis*	10				IIII	
Pseudophilomedes sp. A	6					
Rutiderma sp. A	3					
Rutiderma sp. B	9					
Onuphis sp. F	8	IIII				
Lumbrineris cf. *magalhaensi*	7					
Tanaid sp. B	4					
Terebellides stroemii	37	MMMM			XXXX	MMMM
Nuculana acuta	32	MMMM			IIII	MMMM
Aglaophamus circinata	31	MMMM			IIII	MMMM
Philine sagra	19	IIII			IIII	IIII
Glycera tesselata	30	IIII			XXXX	XXXX
Harbansus paucichelatus	25	XXXX			IIII	XXXX
Amphareta americana	17	XXXX			IIII	
Spiochaetopterus costarum	24	XXXX			IIII	
Prionospio steenstrupi	18	XXXX			IIII	
Sigambra bassi	22			MMMM	IIII	
Onuphis sp. A	30	XXXX	IIII		IIII	IIII
Laonice cirrata	22	XXXX	IIII			
Unciola serrata	20	XXXX			IIII	
Phyllodoce mucosa	27	XXXX			XXXX	
Cirrophorus lyriformis	27	IIII	MMMM			

MMMM = > .70
XXXX = .50 - .69
IIII = .30 - .49
Blank = < .30

TABLE 17.3

CONDENSED TWO-WAY TABLE OF FIDELITY OF A SPECIES IN A STATION GROUP

Species	Number of Occurrences	Station Group 1	2	3	4	5
Paraonis gracilis	74	IIII	IIII		IIII	IIII
Cossura delta	74		IIII	IIII	IIII	IIII
Sigambra tentaculata	71			IIII	IIII	IIII
Armandia maculata	57			IIII	IIII	IIII
Paraprionospio pinnata	73	IIII	IIII	IIII		
Nephtys incisa	63		IIII	IIII	IIII	IIII
Ninoe nigripes	56		IIII	IIII		IIII
Tharyx annulosus	50	IIII			IIII	IIII
Tharyx marioni	59	IIII			IIII	IIII
Lumbrineris parvapedata	68	IIII	IIII			
Mediomastus californiensis	63	IIII	IIII	IIII	IIII	
Volvulella texasiana	43		IIII			
Spiophanes sp A	34	IIII			IIII	
Paraonis sp A	52		IIII		IIII	IIII
Paraonides lyra	43	IIII			IIII	
Pilargis berkeleyae	14	IIII		IIII		IIII
Corbula swiftiana	55	IIII	IIII		IIII	
Polychaete sp. A	42	IIII			IIII	
Lumbrineris tenuis	39	IIII		IIII		
Notomastus cf. *latericeus*	47	IIII	IIII	IIII		
Drilonereis magna	34	IIII	IIII			
Magelona longicornis	49		IIII	IIII	IIII	
Ampelisca verrilli	42	IIII	IIII			
Nereid (Nicon) sp. A	43	IIII	IIII	IIII		
Ampelisca agassizi	40	IIII	IIII	IIII		
Ampelisca abdita	38	IIII	IIII	IIII		
Asychis elongata	26	IIII	IIII		IIII	
Nereid sp. B	23	IIII	IIII		IIII	
Notomastus latericeus	21	IIII			IIII	
Aedicira belgicae	31	XXXX	IIII			
Minuspio cirrifera	21	XXXX		IIII		
Apseudes sp. A	21	IIII	XXXX			
Listriella barnardi	25	XXXX	IIII	XXXX		
Magelona rosea	36	XXXX	IIII	IIII		
Aricidea jeffreysii	36	XXXX	IIII	IIII		
Vitrinella floridana	19	XXXX	IIII	XXXX		
Minuspio longibranchiata	21	IIII	IIII	IIII		
Magelona phyllisae	32	XXXX		XXXX		
Sthenelais boa	29	XXXX			IIII	
Gyptis vittata	25	MMMM		IIII		
Natica canrena	18	MMMM		IIII		
Amphicteis acutifrons	23	XXXX		IIII		
Paleanotus heteroseta	19	MMMM				
Aricidea cf. *fragilis*	19	XXXX	IIII			
Aricidea taylori	19	MMMM	IIII			
Owenia fusiformis	22	MMMM				
Anadara transversa	18	MMMM			IIII	
Pseudophilomedes sp. B	4	MMMM			IIII	
Caecum pulchellum	3	MMMM				
Abra aequalis	29	XXXX				
Notomastus americanus	18	XXXX				
Tellina versicolor	22	MMMM				
Spiophanes bombyx	9	MMMM				
Isolda pulchella	9	MMMM				
Ceratonereis irritabilis	7	MMMM				
Clymenella torquata	15	MMMM				
Prionospio cristata	14	MMMM		IIII		
Ceratocephale oculata	21	MMMM				
Glottidia pyramidata	11	XXXX	IIII			
Lumbrineris albidentata	20	XXXX			IIII	IIII

TABLE 17.3 CONT.'D

Species	Number of Occurrences	Station Group 1	2	3	4	5
Kalliapseudes sp. A	14		MMMM			
Automate evermanni	28		IIII		IIII	
Eudorella monodon	32		XXXX		IIII	
Heterophoxus cf. *oculatus*	25				IIII	XXXX
Hippomedon cf. *serratus*	24		IIII		IIII	IIII
Paramphinome pulchella	22				XXXX	
Amphicrete parvidentata	17				XXXX	
Thyasira sp. A	22				XXXX	
Eyala sp. A	29		IIII		IIII	IIII
Cyclocardia armilla	6					MMMM
Ostracod sp. A	9					MMMM
Philomedes sp. A	14					MMMM
Syllis sp. C	16					MMMM
Eriopisa incisa	8				IIII	XXXX
Sanguinolaria sanguinolent	10				IIII	MMMM
Spiophanes longicirrus	31				IIII	IIII
Pitar cordatus	37				IIII	IIII
Scutopus sp. A	28				XXXX	IIII
Sternaspis scutata	30				XXXX	XXXX
Byblis cf. *affinis*	26				IIII	XXXX
Paralacydonia paradoxa	29				IIII	XXXX
Ampelisca sp. A	28				IIII	XXXX
Alternochelata sp. A	22				IIII	MMMM
Dentalium sowerbyi	28				IIII	XXXX
Thyasira pygmaea	22				IIII	MMMM
Onuphis sp. B	13				IIII	XXXX
Ostracod sp. D	12				IIII	XXXX
Goniada maculata	18				IIII	IIII
Spiophanes wigleyi	19				IIII	IIII
Xenanthura brevitelson	18	IIII				MMMM
Sarsiella cf. *zeyi*	15				IIII	XXXX
Apanthura magnifica	7				MMMM	
Fabricia sp. A	5				XXXX	
Sphaerosyllis cf. *sublaevis*	10				MMMM	
Pseudophilomedes sp. A	6	IIII			XXXX	
Rutiderma sp. A	3				MMMM	
Rutiderma sp. B	9	XXXX			IIII	
Onuphis sp. F	8	MMMM			IIII	
Lumbrineris cf. *magalhaensi*	7	XXXX			IIII	
Tanaid sp. B	4		XXXX		IIII	
Terebellides stroemii	37	IIII			IIII	IIII
Nuculana acuta	32	XXXX				IIII
Aglaophamus circinata	31	XXXX				IIII
Philine sagra	19	IIII			IIII	IIII
Glycera tesselata	30				IIII	IIII
Bartansus paucichelatus	25	IIII			IIII	IIII
Amphicrete americana	17	XXXX			IIII	
Spiochaetopterus costarum	24	XXXX			IIII	
Prionospio steenstrupi	18	XXXX			IIII	
Sigambra bassi	22			MMMM	IIII	
Onuphis sp. A	30	IIII				IIII
Laonice cirrata	22	XXXX	IIII			
Unciola serrata	20	XXXX			IIII	
Phyllodoce mucosa	27	IIII			IIII	
Cirrophorus lyriformis	27	IIII	XXXX			

MMMM = > 3
XXXX = 2 - 2.99
IIII = 1 - 1.99
Blank = < 1

each species for each station-group enhance visualization of the association of species-groups with station groups.

Species Group I (SGI) contained species which were generally ubiquitous over the entire study area with relatively high constancy and low fidelity for all station groups. This group (SGI) contained many abundant species such as *Paraprionospio pinnata* and *Lumbrineris parvapedata* but also included some relatively uncommon but truly ubiquitous species such as *Pilargis berkelyae*. All but one species in this group were polychaetes.

Species Group II(SGII) also contained species which were nearly ubiquitous over the study area but were relatively rare or absent from the deepest stations. Constancy was relatively high at all but the deep and intermediate-deep station groups. This group of 13 species had nine polychaete, three amphipod and one pelecypod species.

Species Group III (SGIII) contained species with shallow to intermediate depth distribution. Most species within this group (SGIII) had higher constancy and fidelity in the shallow and shallow intermediate group than in the intermediate depth group. All had very low constancy for the deeper station groups. Of the eight species in this group; five were polychaetes, one was a tanaidacean, one an amphipod and one was a mollusc.

Species Group IV (SGIV) was a relatively large group (23 species) that were practically limited to the shallow station group. Several species (SGIV) were minimally represented in other station groups but this group showed high constancy and fidelity only at the shallow stations. This group contained 16 polychaete, five mollusc and two arthropod species.

Species Group V (SGV) was comprised of three crustacean species which were found primarily in the shallow-intermediate depth range. They were not found at the shallow or deep stations.

Species Group VI (SGVI) was comprised of six species, two polychaete and four crustacean, which appeared to be distributed in the intermediate-to-deep station groups, not being found in the shallow zones. Most species in this group showed higher constancy and fidelity for the deeper stations than for intermediate stations.

Species Group VI (SGVI) was comprised of 22 species; seven polychaetes, six molluscs, five ostracods, three amphipods and one isopod. This group was found primarily at the deeper stations with very low constancy or fidelity at intermediate or shallow sites.

Species Group VIII (SGVIII) was comprised of nine species; three polychaetes, two isopods, three ostracods and a tanaid. This group contained species found only on Transect IV. Most of these species were found both shallow and deep and showed low constancy with relatively high fidelity.

Species Group IV (SGIX) consisted of nine species; six polychaetes, two molluscs and an ostracod. This group of species exhibited a unique distribution pattern in that they had relatively high constancy at both the shallow and deep stations but were absent or rare at intermediate depths.

The station-groups delineated by cluster analysis were differentiated by species composition of the stations within the different groups. It was apparent that the biotic composition of the groups varied not only at the species but also at higher taxonomic levels. Table 17.4 shows the percent composition by phyla at each station group for the year. Generally, the percent contribution of polychaetes was highest at the shallow stations, tapering off slightly at deeper stations. It was observed that the percentage of polychaetes was lower than was to be expected at the shallow-intermediate group. This resulted from large numbers of Ampeliscid amphi-

TABLE 17.4

PERCENT MAJOR TAXA FOUND AT EACH STATION GROUP

Taxa	Station Group 1	2	3	4	5	6
Mollusc	9.78	3.67	8.18	20.50	16.18	12.30
Polychaete	72.95	46.22	68.02	58.56	52.4	56.90
Crustacea	6.45	24.87	15.28	10.34	18.16	14.90
Gastropod	1.28	3.07	5.78	3.62	2.38	1.10
Pelecypod	8.25	0.63	4.26	14.36	10.70	10.35
Ostracod	0.60	-	0.25	1.80	8.20	5.80
Malacostra	0.75	0.13	5.51	1.16	1.64	2.00
Isopoda	0.50	-	0.10	0.50	1.80	2.00
Amphipoda	3.6	24.0	7.20	4.66	4.98	3.40

pods being found at one station (1/III) within the shallow-intermediate group, thereby lowering the polychaete domination within this group. The percent contribution of molluscs and most arthropods was highest at the deeper stations. The above mentioned dominance of Ampeliscid amphipods at Station 1/III also interfered somewhat with this pattern.

Examination of taxa between species and phylum level showed that within the mollusca, pelecypods had the highest percent contribution in the deep and, secondarily, in the shallow station groups. Pelecypods were generally rare or absent from intermediate depth stations. Gastropods, however, showed their highest percent contribution (although it was low) at the intermediate depth stations. Within the arthropods, ostracods and isopods showed highest percentage contribution at the deeper stations while amphipods and malacostracans were more prevalent at intermediate depth stations.

Cluster analysis of epifauna data divided the study area into two major regions based on depth and/or distance from shore (Figure 17.10). All stations with 10 to 45 m depth (plus 2/II at 49 m) and located less than 30 miles offshore were grouped together (A). Stations with depths greater than 45 m and located at least 30 miles offshore formed the other major group (B). The two regions varied in other physical variables. Temperatures (10-29°C) and salinity (30-37 ppt) varied widely throughout the year in Group A. Group B stations were characterized by a more stable temperature (15-25°C) and salinity (35-37 ppt) regime. There was considerable overlap of sediment types between the two regions but the sandiest sediments were found at shallow, nearshore stations and the highest clay content was in sediments from the deep offshore stations.

Subdivisions of the dendrogram divided the study area into six groups of stations. These minor divisions generally corresponded to shallow

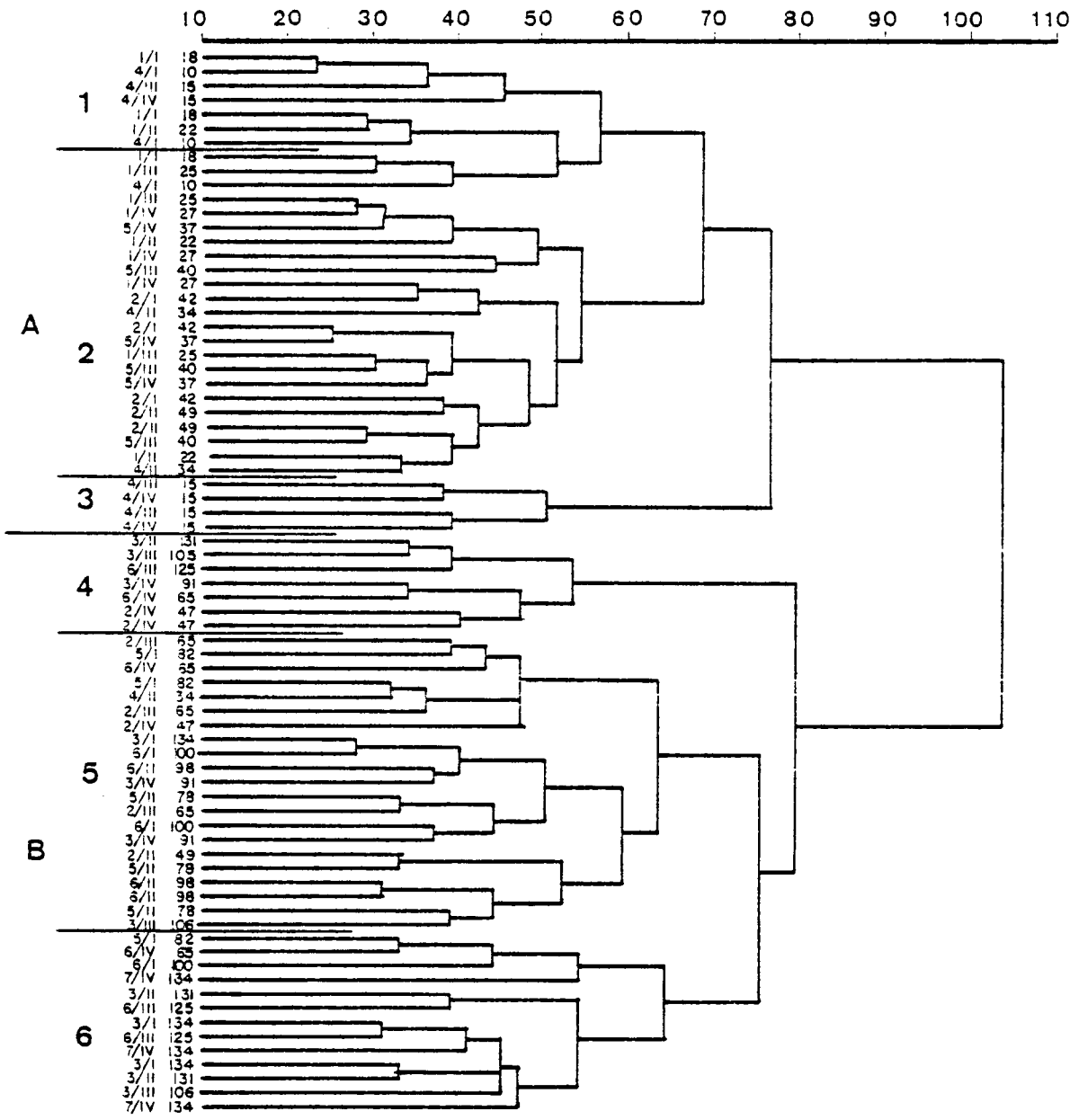

Figure 17.10 Normal Dendrogram From Cluster Analysis of Seasonal Epifaunal Data. Numbers to the Right of Station/Transect Designation Refer to Depth (in meters). Large Numbers and Letters on the Left Designate Station-Groups.

(10-15 m), shallow-intermediate (22-45 m), deep-intermediate (47-100 m), and deep (106-134 m) stations (Figure 17.11). Stations which clustered together two out of three seasons were considered to be a group. Seasonal changes in abundance and the mobility of epifaunal organisms precluded clean distinctions of station groups consistent through the year. Station Groups 3 and 4 contained Transect IV stations which had fewer individuals and species compared to the other groups. Station 3/III was not grouped because it was in a different station group each season.

Station groups were defined by the species found there. Clustering by species or inverse analysis resulted in eight species groups (Figure 17.12). The first three groups of species were collected only at stations with greater than 45 m depth; Species Group IV was taken most consistently at the same stations (Figure 17.13) Group V species were collected at intermediate depth stations but not at shallow or deep stations. Species in Groups VI and VII were most often collected at stations less than 45 m in depth. Group VIII species were collected at all but the deepest stations. Species representative of the station groups are listed in Table 17.5, along with correlation coefficients of the abundance of each species with physical variables. One method for interpreting data from STOCS study is to analyze distributions of species in response to the physical regime they encounter. Simple linear regression was used to test the hypothesis that there was a causal relationship between the abundance of a species and a physical parameter. Depth was the most consistently significant variable for all species except those collected at intermediate depths. Salinity appeared to be the least important variable.

Distribution of a species was probably influenced by several physical variables. Multivariate effects were analyzed by constructing linear additive models. The results were examined for reduction of the mean square

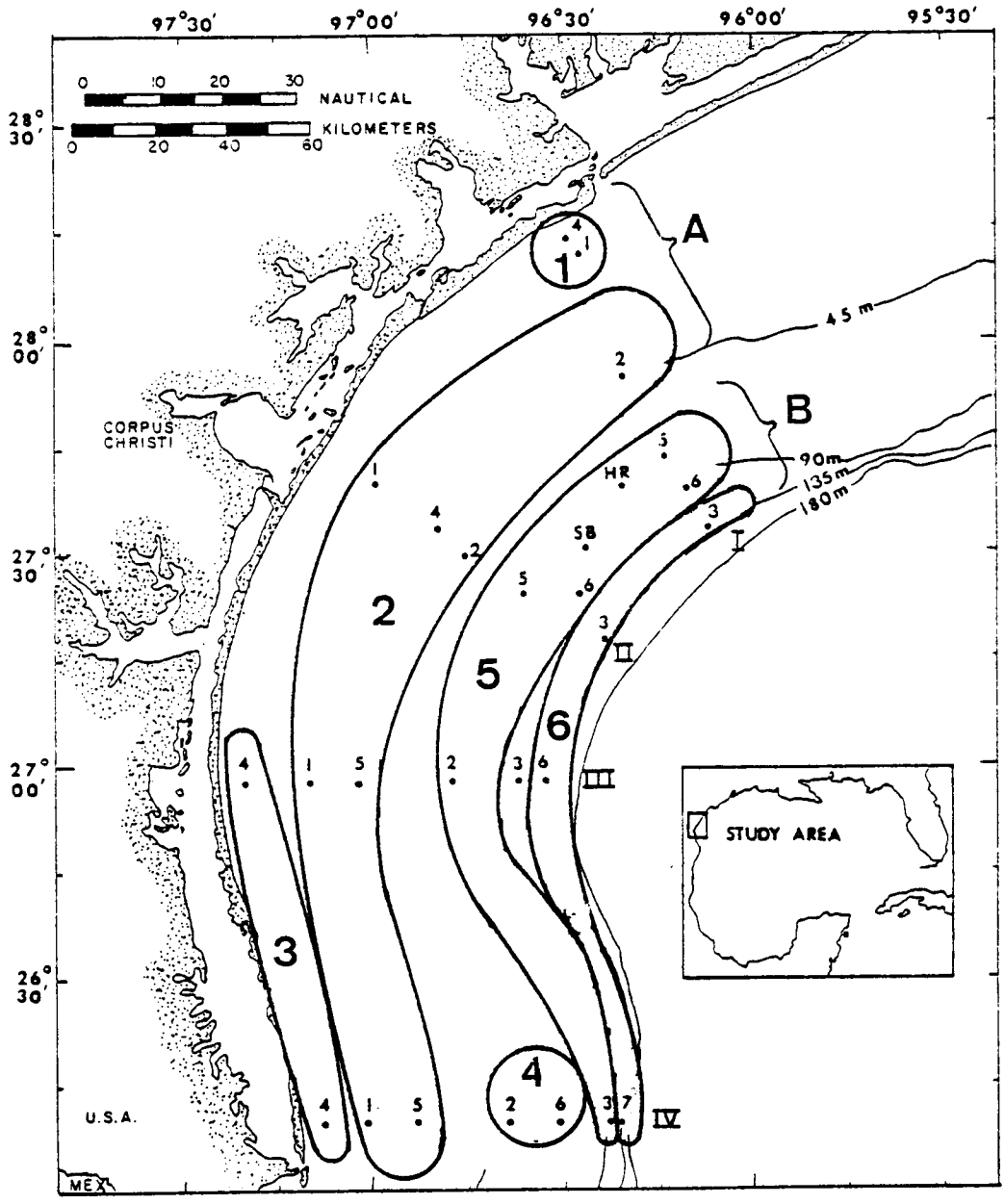

Figure 17.11 Location of Station Groups from Cluster Analysis of Seasonal Epifaunal Data.

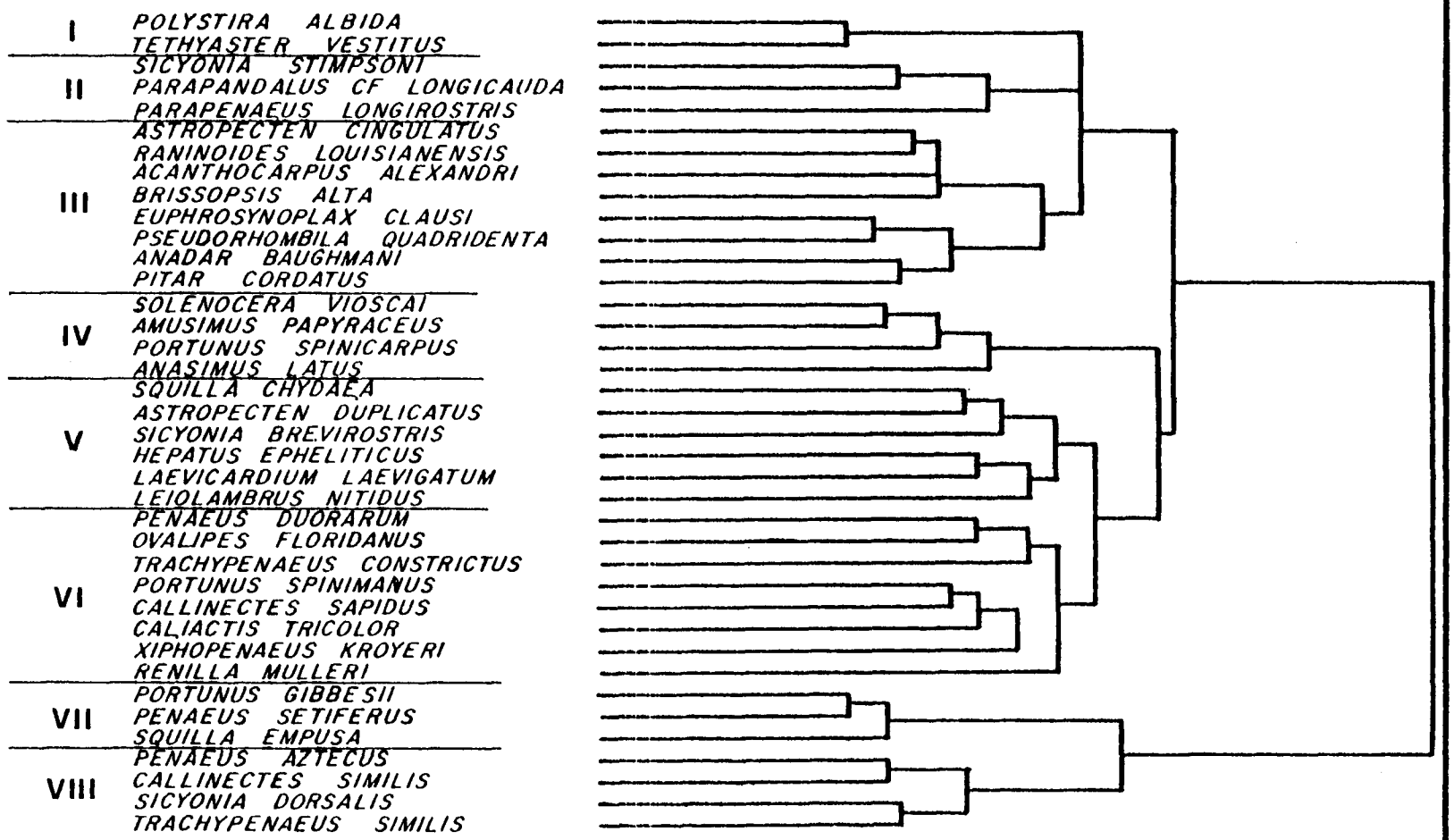

Figure 17.12. Species Dendrogram from Inverse Analysis of Seasonal Epifaunal Data. Roman Numerals Refer to Species-Groups.

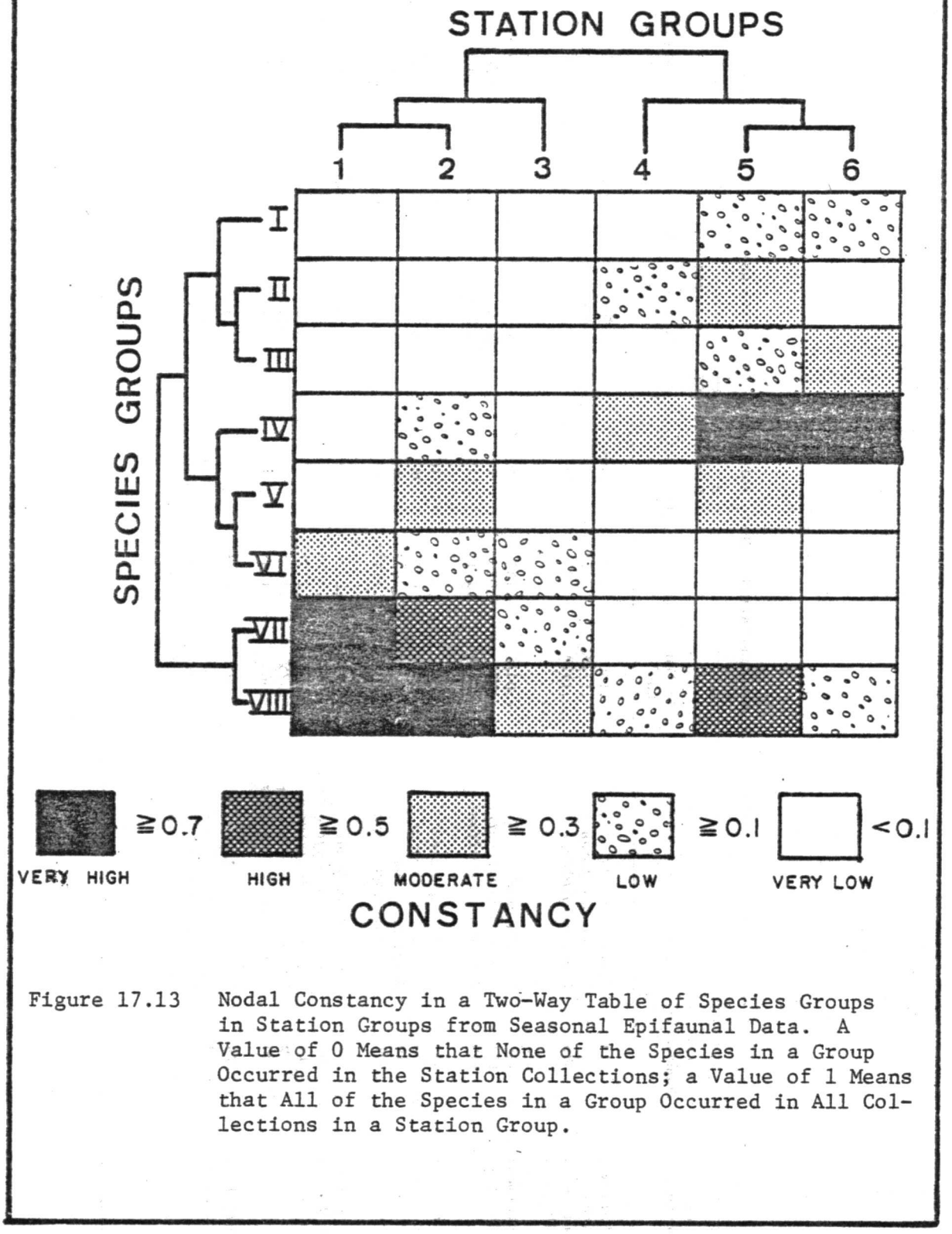

Figure 17.13 Nodal Constancy in a Two-Way Table of Species Groups in Station Groups from Seasonal Epifaunal Data. A Value of 0 Means that None of the Species in a Group Occurred in the Station Collections; a Value of 1 Means that All of the Species in a Group Occurred in All Collections in a Station Group.

TABLE 17.5

SPECIES CHARACTERISTIC OF VARIOUS DEPTH ZONES AND CORRELATION COEFFICIENTS OF THE SPECIES ABUNDANCE WITH BENTHIC PHYSICAL VARIABLES

Optimal Depth Zone	Total Abundance	Species	SINGLE EFFECT - CORRELATION COEFFICIENT						
			Julian Day	Depth	Temperature	Salinity	Mean Grain Size	Percent Silt	Transect
Shallow to Shallow-Intermediate (10-45 m)	513	*Squilla empusa*	.150	-.370*	.190*	-.250*	-.235*	-.105	-.204*
	230	*Penaeus setiferus*	.177*	-.327*	.212*	-.178*	-.219*	-.140	-.218*
	386	*Portunus gibbesii*	.192*	-.233*	.285*	-.015	-.138	-.062	-.125
Intermediate (29-91 m)	448	*Squilla chydaea*	-.037	-.133	.041	-.003	-.014	.215*	.001
	112	*Sicyonia brevirostris*	.113	.028	.111	.084	.031	-.046	-.052
	140	*Astropecten duplicatus*	.167*	-.151	.219*	-.090	-.072	.183*	-.041
Intermediate to Deep (40-134 m)	583	*Amusium papyraceus*	.076	.156	-.010	.096	.139	.085	-.130
	1160	*Solenocera vioscai*	.111	.087	.062	-.048	.093	.199*	-.124
	119	*Anasimus latus*	.175*	.262*	-.087	.091	.078*	-.004	.067
	1101	*Portunus spinicarpus*	.184*	.214*	-.066	-.007	.111	.009	.059
Deep-Intermediate to Deep (65-134 m)	37	*Anadara baughmani*	.092	.272*	-.066	.103	.244*	.003	.020
	84	*Parapenaeus longirostris*	.002	.288*	-.069	.054	.167*	-.015	-.052
	14	*Raninoides louisianensis*	.058	.274*	-.094	.122	.242*	-.027	.063
	19	*Brissopsis alta*	-.025	.183*	-.054	.059	.128	-.029	.128
	30	*Astropecten cingulatus*	-.005	.178*	-.096	.084	.141	.047	-.003
Ubiquitous Except Deep (10-106 m)	1775	*Penaeus aztecus*	.084	-.182*	.147	.049	-.024	.108	-.061
	3319	*Sicyonia dorsalis*	.146	-.075	.159	.045	-.034	.129	-.037
	2443	*Trachypenaeus similis*	.102	-.352*	.036	-.341*	-.024	.207*	-.113
	1265	*Callinectes similis*	.222*	-.292*	.407*	.112	-.110	.212*	-.163*

*Level of significance $\alpha = 0.01$

(a measure of the reduction of the variance) at several levels of significance for rejecting the null hypothesis (Table 17.6). The independent variables were depth, temperature, salinity, mean grain size, percent silt, Julian day and transect. An important point to note was that the mean square reduction for all species models was generally low and never exceeded 27% implying that a great deal of the variance remained. Species (Group VII) representing shallow and shallow-intermediate depth stations shared a common response of decreased abundance with increased depth toward the southern transects. Intermediate depth stations were represented by species (Groups IV and V) which were each responding to different environmental conditions. Depth was the only significant variable for explaining the distribution of species collected at deep-intermediate to deep stations (Group III). The ubiquitous species (Group VII) were collected at most stations and as was expected, the multivariate models of these species had little in common. Although there were species groups characteristic of station groups, these results indicated that few species showed a common response to the physical environment found at those stations. The species that comprised a species cluster generally exhibited a wide variety of responses to a variety of physical variables.

DISCUSSION

Infauna

Infaunal communities of the STOCS have historically been little studied. The present three year study remains the most extensive research program known to have investigated the macroinfaunal communities of this portion of the Gulf of Mexico. Previous reports by the author have reported basic similarities between these studies and those of investigators on other continental shelf areas. For example: zonation of infaunal assemblages

TABLE 17.6

LINEAR ADDITIVE MODELS FOR SPECIES REPRESENTATIVE OF THE SPECIES GROUPS FROM CLUSTER ANALYSIS

Species Group	Species	Multiple Effects Linear-Additive Model	Significance Level (α)	Percent Mean Square Reduction
VI	*Penaeus duorarum*	A = .23 (mean grain size) + 1.98	.01	10
VII	*Squilla empusa*	A = -.17 (% silt) - .08 (depth) - 2.9 (Transect) + 20.3	.01	22
		A = -.17 (% silt) - .08 (depth) + .01 (Julian Day) - 2.8 (Transect) + 18.0	.02	24
VII	*Penaeus setiferus*	A = -.08 (% silt) - .03 (depth) + .01 (Julian Day) - 1.35 (Transect) + 7.9	.01	22
VII	*Portunus gibbesii*	A = .42 (temperature) - .03 (depth) - 4.85	.01	10
		A = .42 (temperature) - .03 (depth) - 1.2 (transect) - 2.0	.02	12
V	*Squilla chydaea*	A = .13 (% silt) - 1.8	.01	4
		A = .63 (mean grain size) + .19 (% silt) + 1.2	.04	6
V	*Sicyonia brevirostris*	A = .003 (Julian Day) + .04	.08	1
V	*Astropecten duplicatus*	A = .15 (temperature) - .34 (salinity) + .05 (% silt) + 8.2	.01	10
IV	*Amusium papyraceus*	A = .80 (mean grain size) - 3.31	.01	3
IV	*Solenocera vioscai*	A = .30 (% silt) - 2.89	.01	3
IV	*Anasimus latus*	A = -.45 (temperature) + .02 (Julian Day) + 6.39	.01	12
		A = -.35 (temperature) + .02 (depth) + .02 (Julian Day) + 3.76	.02	14
IV	*Portunus spinicarpus*	A = -2.9 (temperature) + .15 (depth) + 40.76	.01	11
III	*Anadara baughmani*	A = .01 (depth) - 0.16	.01	7
III	*Parapenaeus longirostris*	A = .01 (depth) - 0.35	.01	8
III	*Raninoides louisianensis*	A = .002 (depth) - 0.07	.01	7
III	*Brissopsis alta*	A = .003 (depth) - 0.13	.01	3
		A = .003 (depth) + 0.11 (transect) - 0.40	.04	5
III	*Astropecten cingulatus*	A = .003 (depth) - 0.07	.01	3
VIII	*Penaeus aztecus*	A = 10.8 (mean grain size) - 0.64 (depth) - 24.2	.01	6
VIII	*Sicyonia dorsalis*	A = 4.36 (temperature) - 0.70	.02	3
VIII	*Trachypenaeus similis*	A = -2.24 (temperature) - 9.13 (salinity) + 1.0 (% silt) - 0.31 (depth) + 0.14 (Julian Day) + 355.0	.01	27
VIII	*Callinectes similis*	A = 0.97 (temperature) + 2.45 (salinity) - 0.11 (depth) - 3.17 (transect) - 86.5	.01	26

* A = predicted abundance

with depth; increase in species richness in sandy-shelly sediment; decreased diversity and increased dominance in physically-controlled communities; increased diversity and increased equitability in biologically accomodated communities, etc. The 1977 data was analyzed in order to corroborate our initial findings.

Basic parameters, descriptive of various communities, generally include species richness, density of individuals, species diversity and equitability These four were closely analyzed to attempt to describe general patterns of communities within the study area and to make comparisons between transects and between stations within a transect.

Several patterns of interest were apparent from the species richness data. First, the general spatial pattern of species richness on each transect remained very stable temporally. This implied that either benthic macroinfaunal communities in our area displayed little seasonal fluctuation in major component species or that a highly defined seasonal succession was occurring in which one species replaced another. Thus, the number of species varied little through time. There was no evidence to support the latter hypothesis from our 1977 data or from preceding years. Data from each station for each collection (Appendix P) tended to support the former hypothesis. Consequently, with few exceptions, there was little temporal variability in the various infaunal populations comprising the communities of the shelf. This was particularly true of the more numerically dominant species. The lack of seasonality of dominant infaunal species was also observed in a study of the wet weight biomass of fourteen infaunal species selected for relative "importance" to the infaunal community. Importance was defined as density, size or uniqueness (Holland and Holt, 1977). The relatively small biomass and the constancy with which various infaunal species were collected indicated that most of the infaunal species exhibited

a very short life span and consequently a relatively high turn-over rate in the warm waters of the South western Gulf. In an earlier report (Holland, *In* Groover, 1977), the use of a technique (Gaufin *et al.*, 1956) was proposed by which efficiency of collection of species at a given site could be estimated. In that report, it was shown that on Transect II between 65 and 72% of the total number of species originally collected in 12 replicate samples could be collected in six samples and that between 87 and 93% of the non-rare species (defined as having been collected in more than one of the original 12 samples) could be collected in six replicate samples. Applying this information to the above hypothesis of relative temporal stability of component species, it was readily seen that observed variation in a species at a station through time may well be more a facet of collecting efficiency than of actual temporal variation. This was especially true for the less common species.

The second pattern observed in the species richness data was that Transects I and II were similar in having little or no peak in species richness at the innermost sites and often having more species at deeper stations than at shallow ones. Transects III and IV were more nearly similar in that large peaks of species richness always occurred at the shallow station although Transect IV always had high species richness at Stations 3/IV and 6/IV also. This pattern (possibly due to latitudinal differences) was of interest because we had earlier postulated (Holland, *In* Parker, 1976) a possible Caribbean influence on the southernmost transects. There was a group of infaunal species observed (SGVIII) which were limited to Transect IV. So there continued to be evidence for some latitudinal variation within the study area. It was felt, however, that the major differences between transects observed in the species richness data were

also influenced by sediment type. Recent information from Dr. Behrens concerning the percentage composition of sediment particles greater than 1 mm (0 phi) correlated nicely with the observed species richness data. There may have been several mechanisms influencing species richness. These included some depth related parameters influencing the northern two transects; sediment particle size which may have been more important on the southern transects due to larger particle size at the inshore station on Transect III and at several stations on Transect IV; and the latitudinal influence because of increased species richness on the southernmost transect.

Any discussion of species richness as a community structure parameter should note that it is a quantitative parameter not a qualitative one in terms of the biotic community. That is, communities with the same species richness are not necessarily the same in component species. A major misuse of species richness information comes from the fact that these data are invariably presented as species collected from a certain sample size and comparisons between areas are made on samples of equal sizes. It was shown (Holland, *In* Groover,, 1977) that sampling efficiency varies such that six replicate samples in one area may well sample that area more efficiently (*i.e.*, catch more of the species in that area) than six samples from another area. It is true that the fewer the samples taken, the greater the disparity may be. There is probably a 5 to 6% efficiency difference between the inshore samples and offshore samples when considering only the non-rare species collected in six replicates. There is probably 7-8% difference in the efficiency of catch of the total species. In both cases, sampling is less efficient in the deeper sites. This is due to the scale of distribution relative to the sample size. The species inshore are distributed or tend to be distributed on a smaller scale and therefore are

sampled more efficiently with a given (small) sample size. If a correction for this disparity is built into our data, the offshore data would be slightly enhanced relative to the onshore data. With as many as six replicates, this disparity is relatively small and thus was not corrected for. A real problem occurs when data from only one or two grabs is reported which may involve a disparity of 15-20% efficiency between areas.

A definite pattern of decreasing density (number of individuals per unit area) with increasing water depth was observed on all transect although minor peaks in density occurred on some transects at deeper sites. We felt that there was a multiplicity of reasons explaining this fact. The inshore waters had richer supplies of nutrients in the form of detritus, phytoplankton and dissolved materials. This afforded a greater carrying capacity in the ecosystem which may have directly affected the benthos. The nature of the inshore sediments (sandy-shelly), provided greater niche availability. The physically dominated nature of the inshore community may have selected for species with higher reproductive capacity while the biologically accomodated offshore community possible could not tolerate high densities of individual populations.

Speculatively, the trophic level of various members of each community may limit individual densities, *i.e.*, inshore communities with organisms of all trophic levels may allow for crowding whereas a community comprised of predominantly one major trophic level (non-selective deposit feeding) may require more space per individual thereby limiting density. This line of reasoning suffers from lack of information on the feeding habits of many, if not most, marine benthic macroinvertebrates.

The number of individuals per station remained very stable through all seasonal collections adding credence to our hypothesis that many infaunal

species in our study area were short-lived species and the populations were essentially reproducing year-round, maintaining on the average very stable population numbers. There were, of course, some populations that showed periodic increases presumably due to reproduction and recruitment but the variability inherent in many of these "blooms" suggested the capability to reproduce practically year round. Again, the biomass study previously mentioned (Holland and Holt, 1977) showed a high degree of constancy in individual population numbers throughout the year.

Transect II was generally the most depauperate transect in that it lacked the inshore peak abundance common to the other three transects. The innermost station on Transect II (1/II) was about seven meters deeper than the innermost station on the other three transects. It lacked the sandy-shelly stations that apparently so influenced the number of individuals on the other three transects. While it was true that sandy-shelly substrate apparently is highly correlated with large numbers of individuals at the innermost stations on Transects I, III and IV, there must have been other factors involved in the increased densities at these stations. Although Stations 3/IV and 6/IV had sandy-shelly sediment, they did not produce the numbers of individuals observed in the inshore sandy-shelly stations. Again, we believed other factors including food availability, nature of the community, trophic levels, etc. were interacting to allow the increase in density at the inshore stations. It was true that sharply increased infaunal densities were observed at Station 6/IV in the winter collection of 1977. This collection had two-to-three fold the number of individuals of other collections at this station. Of the 984 individuals collected, 42% were accounted for by the dominant 10 species (of 171 total species). Apparently there was a minor bloom in some of the dominant species accompanied by a large number of relatively rare species collected.

Transect IV exhibited the overall highest densities of organisms. This probably occurred due to the sandy-shelly substrate which was much more prevalent on this transect.

Diversity and equitability are community structure parameters that are closely interrelated. Species diversities at various stations in our study area generally ranged between 3 and 6, which was considerably higher than those observed (Holland *et al.*, 1974; 1975) in estuaries adjacent to the present study area. Fewer species and individuals per station also characterized the estuarine studies which utilized a much smaller sample size. Diversity of infaunal communities of the STOCS had a decided tendency to increase offshore. The increase in equitability with depth was generally much more pronounced. Equitability is a measure of how evenly the number of individuals is spread between the number of species present and as such is actually a part of the diversity measure. It is felt that the increase in diversity offshore in the infauna communities was simply a reflection of the lack of numerical dominance by a few species which did occur at the nearshore stations. Several stations had chronically low diversities and low equitability (*i.e.* Station 1/III and 5/IV) at which one or two species were found to generally dominate the samples. Ampeliscid amphipods (most often *Ampelisca agassizi*) dominated Station 1/III year round and *Paraprionospio pinnata* and nemerteans were most dominant at 5/IV. This tendency for dominance by a few species was characteristic of physically controlled communities and added further credence to our population of inshore physically controlled communities and offshore biologically accommodating communities.

Cluster analysis of the infaunal data essentially corroborated with the data of previous years in that a number of station groups primarily related to water depth, somewhat modified by sediment types, were delineated. As

previously reported (Holland *et al.*, *In* Groover, 1977), zonation of infaunal assemblages with depth on continental shelves is a commonly reported pattern (Day *et al.*, 1971; Field, 1971). Five station clusters were delineated by normal cluster analysis of 1977 infauna data. These five station groups were arranged on a perfect depth gradient with the exception of one station (1/IV), which at 27 m was clustered with three stations of 15 m or less. This apparent anomaly was closely checked and we agreed that the program had properly classified 1/IV with the shallower stations. It had excellent representation by the ubiquitous (SGI) group, the nearly ubiquitous group (SGII) and the shallow-intermediate group (SGIII). Of the group of 16 species (SGIV) specifically characterizing the shallow stations, 12 were found at 1/IV in the winter, 15 in the spring and 15 in the fall. Although most of the species from SGIV were common to 1/IV. There was a definite tendency for them to be found in reduced numbers, especially dominant forms. It was significant that the three collections from 1/IV clustered together first and then were added to the remaining six station-time collections from Stations 4/I and 4/III which had agglomerated without pattern. These nine station-time collections were then joined by the three station 4/IV collections to make up the shallow group. This same pattern was true for sediment composition of these four stations, *i.e.* Stations 4/I and 4/III had sandy-shelly sediments which clustered indiscriminantly. Station 1/IV had significantly greater sand-shell in its sediments and thus would join the former two stations after their collections had been added by the agglomerative process. Finally Station 4/I, with the highest percentage of sand and shell, combined with the rest to complete the group. Thus it seemed that although Station 1/IV was 12 m deeper than the three sites with which it clustered it was central to them in sediment type and was correctly clustered with them.

Each of the station clusters was characterized by one or more species groups. Station Group I, the shallowest stations on Transects I, III and IV plus the slightly deeper 1/IV showed relatively large numbers of species including most species of SGI, SGII, SGIII, SGIV, SGV, and SGIX. All these species showed relatively high constancy at the group 1 stations indicating that they were found often at these inshore stations. Only species groups III, IV, and IX indicated high levels of fidelity to Station Group 1 indicating that these species, especially SGIV are found primarily at the very shallow stations. Most of the species showing high fidelity to the very shallow stations were polychaetes although a few molluscs (*e.g. Natica canrena, Anadara transversa, Abra aequalis* and *Tellina versicolor*) showed both high constancy and high fidelity to stations in Group 1. *Caecum pulchellum* showed high fidelity but low constancy indicating low frequency of collection usually limited to Station Group 1, the shallow water stations.

Station Group 2, comprised of three shallow-intermediate stations, was well represented by the first three species groups as far as constancy of collection. Little fidelity to Station Group 2 was shown by any of the first three species groups with the exception of the tanidacena, *Apseudes* sp. A. A small group, SGV, showed both high constancy and high fidelity to the shallow-intermediate stations. All of the species represented by SGV were crustaceans.

Station Group 3 was comprised of six stations at intermediate depths of 34-49 m. This station group again was well represented by the first three species groups in constancy but was generally lacking species which showed high fidelity. Two polychaetes, *Magelona phyllisae* and *Sigambra bassi*, from SGIV and SGVI, respectively showed high constancy and fidelity to this station group. An amphipod and mollusc from SGIII each showed relatively high fidelity to Station Group 3.

Station Group 4 had good representation from SGI and SGII but again little fidelity from species within these groups SGV, SGVI, and SGVII each showed fair to high constancy at Station Group 4 with moderate levels of fidelity. SGVIII showed little constancy but high levels of fidelity to Station Group 4 indicating that species in this group were relatively rare but when collected usually were found at Station Group 4. Species Group IX with its unusual distribution pattern showed moderate constancy and fidelity to Station Group 4.

Station Group 5, the deepest stations, was represented by SGI with moderate to high constancy and with low fidelity. Species Group VII seemed truly representative of the deep stations by showing both high levels of constancy and fidelity. Again, SGIX was well represented at the deepest sites but showed low levels of fidelity.

From the foregoing discussion, it became readily apparent that most of the station groups were represented by species groups either ubiquitous or site specific. A pattern was discernible indicating that the very shallow and very deep stations were represented by large distinct groups of species other than the ubiquitous groups. The shallow-intermediate and intermediate deep-stations each showed small groups of species with high fidelity. At the intermediate stations, no distinct groups of species showed fidelity although several individual species from the various groups did. Apparently, there were gradients of two distinct groups of benthic infauna. The first, a shallow group gradually diminished offshore and a deep group, declined in constancy and fidelity inshore. Across these two major divisions were the ubiquitous to semi-ubiquitous groups which showed high constancy across the shelf with little fidelity to any group of stations. The unusual group of species in SGIX showed moderate to high constancy at the shallow and deep stations but were absent or rare

from the intermediate depths. They showed moderate fidelity to the shallow stations but low fidelity to the deep stations. This distribution pattern was not explainable.

Along with having species representative of various portions of the continental shelf, it was apparent from 1977 data that various shelf regions were dominated by different higher order of taxa. Polychaetes, although found everywhere, were also most abundant in those groups specifically characteristic of the nearshore stations. The deeper station species groups were characterized more by molluscs and crustaceans. It appeared that if the ubiquitous species were not included, polychaete species would diminish offshore to be gradually replaced by molluscs and crustaceans as dominants in the infaunal community.

Analysis of station groups by discriminant analysis verified the basic results from cluster analysis. Three major station clusters occurred which encompassed the five clusters delineated by cluster analysis. The sandy inshore-stations were grouped identically by both analysis techniques. Discriminant analysis resulted in non-separation of cluster groups II and III, and IV and V, essentially lumping the shallow-intermediate and intermediate stations as well as the intermediate-deep and deep stations. This same result could have been arrived at from the cluster program by reading the dendrogram at a higher level of similarity. Discriminant analysis did separate out Stations 3/IV and 6/IV, making them a separate group. This separation was made more on abiotic factors, primarily sediment mean grain size than on invertebrate community information which was the only factor considered by the cluster analysis. Cluster analysis did cluster these two stations first, then joined them with other stations to make cluster Station Group IV. If the cluster dendrogram had been read at a lower level of similarity, a single cluster containing

these two stations would have been present. The discriminant analysis allowed for statistical testing for the validity of the observed groups and as a very low level of statistical probability existed that these groups could have occurred by chance, our confidence in these groups was fortified.. The discriminant analysis did re-enforce our feeling that a number of factors including but not limited to depth and sediment were acting on benthic infaunal distribution patterns in the STOCS region during the study period.

Epifauna

Epifaunal community structure parameters (diversity, number of individuals, etc.) showed no general trends on spatial patterns. Variation in temporal and spatial abundances of dominant species in 1976 was found to be due to recruitment of young age classes (Holt and Holland, 1977). Generally the variation in abundance was due to large numbers of young at shallow to shallow-intermediate stations and migration of the adult population, accompanied by reduction in abundance, to the deeper stations. The same pattern was found in 1977 data except there was a stronger tendency for the large abundances to be concentrated at stations along Transects I and II.

The division of the 1977 STOCS study area into station groups based on depth and factors associated with depth was consistent with the results from 1976 data analyses. Species groups characteristic of the various depth zones were also consistent for the two years. Although a species group was highly constant to a station group, most individual species that comprised a group, responded in a unique way to the physical environment common to the stations.

Since epifaunal species have different physical and biological needs,

and move considerable distances, analysis of individual species distributions may be the best method for interpreting the STOCS data. An important aspect of this initial study is the evaluation of STOCS in terms of numbers and kinds of species. Further information that can be derived from the data include an understanding of the distribution of species important to man (directly or indirectly) and the identification of species with narrow or critical tolerances to change.

Linear additive models presented here indicated that epifaunal species distributions were significantly correlated with abiotic variables but only a small amount of the variation was explained. Relationships of species abundance to physical variables were often non-linear, better characterized by gaussian and exponential sine curves. Preliminary non-linear, multiplicative models, using the same physical variables, reduced the mean square by as much as 80% and were therefore superior models for predicting species distribution. With a thorough analysis of species distribution over the three years of study, important species and areas critical to the needs of a species can be determined.

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CHAPTER EIGHTEEN

DEMERSAL FISHES

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ABSTRACT

The collection and analysis of samples of benthic fishes on the South Texas Outer Continental Shelf (STOCS) was continued for the third consecutive year. The sampling regime consisted of three seasonal surveys (winter, spring and fall) on all four transects used in previous years and six monthly surveys on Transect II. Data on relative abundances, gross distribution patterns and average catches for selected species are summarized.

A brief comparison of the data contained in this report with data from the previous year (1976) was made. Differences between 1976 and 1977 were observed in patterns of the numbers of species, numbers of individuals and total biomasses caught and in various diversity indices. These differences have been attributed to shortcomings in the design of the sampling program. Specifically, low replication, differences between years in the timing of seasonal cruises and the distribution of sampling effort over the study area were considered to have contributed to confounding attempts to resolve whatever patterns of distribution and abundance were shown by the demersal fishes on the STOCS.

Correlative patterns between selected environmental parameters and several species were examined. The use of such patterns serves to identify the environmental variables of importance to demersal fishes and also represents a starting point for the development of a predictive capability for abundances of benthic fishes based on knowledge of environmental conditions.

Statements about the functional relationships between the demersal fishes of the STOCS could not be made from the information generated by this study. A more detailed examination of the data on fishes and of information generated by other work elements of the STOCS program may, however, facilitate a better understanding of the benthic ichthyofauna of the STOCS.

INTRODUCTION

The study presented herein represents the third continuous year of regular sampling of selected stations on the South Texas Outer Continental Shelf (STOCS). As in past years, the primary mission of the study was a characterization of the ichthyofauna of the region against which future studies may be compared.

This report is confined to the presentation of descriptive information on the relative distributions and abundances of the major components of the ichthyofauna under study. Our work during 1976 (Wohlschlag, *In* Groover, 1977) demonstrated the existence of significant differences in faunal composition between depth zones on the STOCS. These differences continued to be recognized by treating data from day and night samples separately and by retaining the classification of sampling stations into station groups based on depth as described in our report for 1976 and in Table 18.1 of this report.

MATERIALS AND METHODS

Sampling was conducted on both a seasonal (all transects) and monthly (Transect II only) basis. Sampling dates are given in Table 18.2. Sampling dates for the corresponding seasons and months for the 1975 and 1976 sampling programs are also given for comparison. The distribution of sampling effort over stations for 1977 is summarized in Table 18.3.

Samples consisted of 15-minute trawls for epibenthic macroinvertebrates and demersal fishes, as in previous years. The trawl was a conventional Gulf coast 10.7 m "flat trawl" with a 12.2 m lead line and a 9.1 m head line, each made of 12.7 mm steel impregnated rope. There was a 0.9 m separation between the net wings and the 0.76 by 1.52 m doors (otter boards) which were fitted with steel runners. Net materials were

TABLE 18.1

DIVISION OF COLLECTING STATIONS INTO STATION GROUPS BASED ON DEPTH
(ROMAN NUMERALS INDICATE TRANSECTS)

	Stations			
Station Group 1	4/I	1/II	4/III	4/IV
(≤ 30 meters)	1/I		1/III	1/IV
Station Group 2	2/I	4/II	5/III	5/IV
(31-90 meters)	5/I	2/II	2/III	2/IV
		5/II		6/IV
Station Group 3	3/I	3/II	3/III	3/IV
(≥ 91 meters)	6/I	6/II	6/III	7/IV

TABLE 18.2

DATES OF SAMPLING CRUISES*

	1975	1976	1977
Seasonal Cruises			
Winter	December 3, 1974- January 25, 1975	February 8-9, 14-16 & 26-28 March 9-11	January 28-30; February 1-2, 9-10 & 13-14
Spring	April 8 - May 16	June 10-14, 19-20 & 25-28	May 24-27; May 31 - June 4
Fall	August 27 - September 12	September 19-23; October 6-11	September 26-28; October 4-7
Monthly Cruises			
March		March 26-28	March 10 & 15
April		April 8-10	April 17 & 20
July		July 17-19	July 8 & 11
August		August 5-7, 27-28	August 5-7
November		November 15-17	November 20 & 30
December		December 8-9	December 18 & 19

*Dates given for 1975 bracket the actual cruise dates.

TABLE 18.3

NUMBER OF TRAWLS MADE AT EACH STATION DURING 1977
(D = Day; N = Night)

	Transect I		Transect II		Transect III		Transect IV	
	D	N	D	N	D	N	D	N
Station 1	3	3	6	27	3	3	3	3
Station 2	3	3	6	27	3	3	3	3
Station 3	3	3	6	27	3	3	3	3
Station 4	3	3	6	9	3	3	3	3
Station 5	3	3	6	9	3	3	3	3
Station 6	3	3	6	9	3	3	3	3
Station 7	-	-	-	-	-	-	3	3
	18	18	36	108	18	18	21	21

Day = 93

Night = 165

Total = 258

of white, untreated nylon twine. The wings and the main body of the net had 44.5 mm stretched mesh of No. 18 nylon twine. The 3.0 m bag was made of 44.5 mm No. 36 stretched mesh. As in most of 1976, a bag liner (which was employed during 1975 and the first part of 1976) was not used for the 1977 sampling. Conventional chafing gear surrounded the bag. All trawls were taken from the twin-screwed R/V LONGHORN at 900 rpm which, with net drag, was equivalent to a dragging speed of approximately two knots.

The statistics of diversity (H_n"), Probability of Interspecific Encounter (P.I.E.), and equitability were calculated according to the procedures described for the 1976 collection year (Wohlschlag, *In* Groover, 1977).

RESULTS AND DISCUSSION

All stations were classified into station groups based on depth, as defined by Table 18.1 and illustrated in Figure 18.1. This was the same classification employed for the 1976 data analysis.

The numbers of trawls made for day and night periods are shown in Tables 18.4 and 18.5. A total of 258 samples were taken in 1977, compared to 240 in 1976. As in 1976, the bulk of the 1977 sampling effort focused on the seasonal sampling periods. The number of samples taken for the 1977 seasonals was roughly similar to the number taken during 1976, so some comparisons of the resultant data could be made between the two years. There were 132 species captured during the 1977 sampling effort, compared to 128 caught during 1976 (this latter figure supercedes the inaccurate count of 131 reported by Wohlschlag *In* Groover, 1977). The following discussion will focus only on seasonal samples, since the data for monthly samples were based on a small number of collections.

A greater number of species were caught in night trawls than in day trawls during the seasonal sampling cruises (see Table 18.6). Part of this difference was attributed to the greater sampling effort expended during

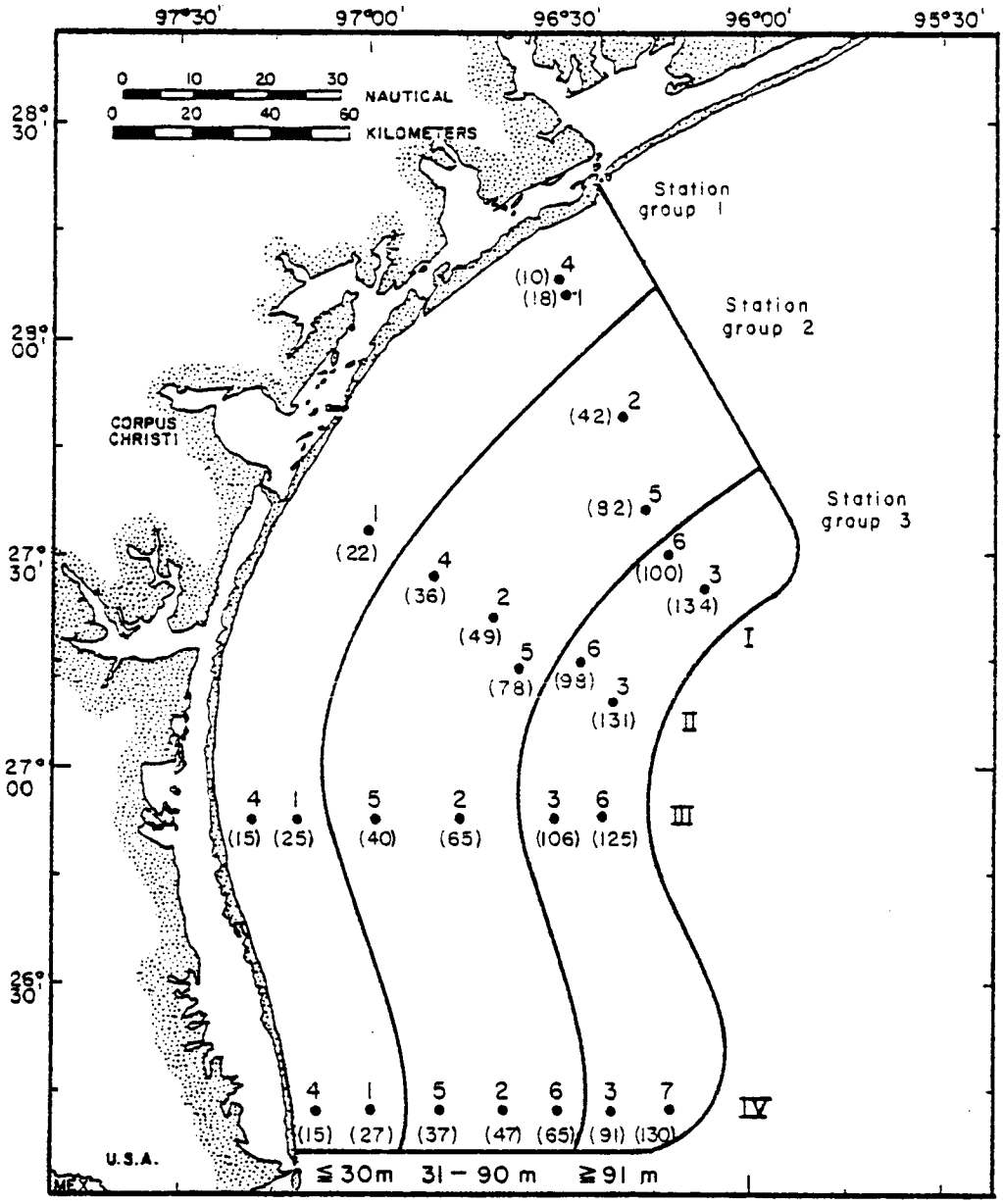

Figure 18.1 Station Groups by Depth. Numbers in Parenthesis are Depths in Meters.

TABLE 18.4

NUMBER OF TRAWLS PER STATION GROUP IN 1977

	Winter	Spring	Fall	March	April	July	August	November	December	
Day										
Station Group 1	8	8	8	-	-	-	-	-	-	24
Station Group 2	13	13	13	-	-	-	-	-	-	39
Station Group 3	8	10	10	2	-	-	-	-	-	30
	29	31	31	2	-	-	-	-	-	93
Night										
Station Group 1	9	9	9	3	3	3	3	3	3	45
Station Group 2	16	16	16	3	3	3	3	3	3	66
Station Group 3	10	12	12	5	3	3	3	3	3	54
	35	37	37	11	9	9	9	9	9	165
									Grand Total =	258

TABLE 18.5

NUMBER OF TRAWLS PER TRANSECT IN 1977

	Winter	Spring	Fall	March	April	July	August	November	December	
Day										
Transect I	6	6	6	-	-	-	-	-	-	18
Transect II	12	12	12	-	-	-	-	-	-	36
Transect III	4	6	6	2	-	-	-	-	-	18
Transect IV	7	7	7	-	-	-	-	-	-	21
	29	31	31	2	-	-	-	-	-	93
Night										
Transect I	6	6	6	-	-	-	-	-	-	18
Transect II	18	18	18	9	9	9	9	9	9	108
Transect III	4	6	6	2	-	-	-	-	-	18
Transect IV	7	7	7	-	-	-	-	-	-	21
	35	37	37	11	9	9	9	9	9	165
								Grand Total =		258

TABLE 18.6

TOTAL NUMBER OF SPECIES CAUGHT IN EACH STATION GROUP DURING 1977

	Winter	Spring	Fall	March	April	July	August	November	December
Day									
Station Group 1	19	28	45	-	-	-	-	-	-
Station Group 2	28	28	48	-	-	-	-	-	-
Station Group 3	20	27	32	13	-	-	-	-	-
Night									
Station Group 1	27	37	47	13	18	21	20	20	21
Station Group 2	44	51	52	23	23	23	20	26	25
Station Group 3	36	39	45	24	18	28	24	16	27

night cruises. However, the difference between the numbers of night and day trawls taken during the seasonal cruises was rather small, and it appears reasonable to conclude that some biological reason existed for the observation that night trawls yielded greater numbers of species than did day trawls during 1977. Night trawling also yielded greater numbers of species than did day trawling during the 1976 seasonal cruises, even though the sampling efforts expended on day and night trawls were roughly the same.

Other consistent trends observed for the 1977 data were: (1) Station Group 2 generally yielded the greatest numbers of species during both day and night sampling, probably due to the higher sampling effort expended on Station Group 2; and (2) fall samples yielded the greatest numbers of species.

Total catches (number of individuals per trawl) for each station group during each sampling period are given in Table 18.7. This table illustrates that the greatest catches occurred during the spring for day trawls and during the fall for night trawls. The lowest catches occurred in winter for both day and night trawls.

Table 18.8 presents values for the average biomass caught per trawl for day and night collection periods. The lowest biomasses were taken during the winter for both day and night trawls. The fall night trawls yielded the highest seasonal biomasses. Spring and fall day trawls yielded much higher biomasses than did winter day trawls.

Values for various diversity indices for the three station groups are presented in Tables 18.9 (day) and 18.10 (night). Station Group 2 appeared to show a trend of higher diversity values (H_n") than the other two station groups. It also had the highest probability of interspecific encounter (P.I.E.) in all cases except for spring day trawls. No other

TABLE 18.7

TOTAL NUMBER OF INDIVIDUALS (OF ALL SPECIES) CAUGHT (PER TRAWL) IN EACH STATION GROUP DURING 1977

	Winter	Spring	Fall	March	April	July	August	November	December
Day									
Station Group 1	12	1051	208	-	-	-	-	-	-
Station Group 2	28	188	125	-	-	-	-	-	-
Station Group 3	27	110	95	74	-	-	-	-	-
Night									
Station Group 1	20	85	178	37	75	95	103	58	109
Station Group 2	22	79	123	38	45	94	65	117	111
Station Group 3	48	80	156	42	82	135	199	119	148

TABLE 18.8

TOTAL BIOMASS (IN GRAMS) OF ALL SPECIES CAUGHT (PER TRAWL) IN EACH STATION GROUP DURING 1977

	Winter	Spring	Fall	March	April	July	August	November	December
Day									
Station Group 1	288.0	12726.6	4245.5	-	-	-	-	-	-
Station Group 2	670.9	2800.8	4257.9	-	-	-	-	-	-
Station Group 3	1709.5	3837.5	3843.6	3414.1	-	-	-	-	-
Night									
Station Group 1	662.3	1274.0	6047.5	478.5	1000.4	982.3	1733.6	1009.4	1256.2
Station Group 2	650.3	1696.4	2816.1	2517.4	1446.6	1443.6	845.0	2468.5	2182.0
Station Group 3	2040.5	3732.0	5562.7	1660.2	4083.4	5328.0	7822.0	4073.9	4989.1

TABLE 18.9

VALUES FOR THE SHANNON-WEAVER DIVERSITY INDEX (H_n"), PROBABILITY OF INTERSPECIFIC ENCOUNTER (P.I.E.) AND EQUITABILITY (E) FOR EACH STATION GROUP (BASED ON NUMERICAL ABUNDANCE OF SPECIES IN DAY TRAWLS)

		Winter	Spring	Fall
Station Group 1	H_n"	2.482	1.566	1.988
	P.I.E.	0.898	0.680	0.685
	E	0.421	0.143	0.133
Station Group 2	H_n"	2.641	1.407	3.000
	P.I.E.	0.909	0.633	0.926
	E	0.286	0.107	0.250
Station Group 3	H_n"	2.053	1.339	2.363
	P.I.E.	0.793	0.547	0.873
	E	0.300	0.148	0.188

TABLE 18.10

VALUES FOR THE SHANNON-WEAVER DIVERSITY INDEX (H_n"), PROBABILITY OF INTERSPECIFIC ENCOUNTER (P.I.E.) AND EQUITABILITY (E) FOR EACH STATION GROUP (BASED ON NUMERICAL ABUNDANCES OF SPECIES IN NIGHT TRAWLS)

		Winter	Spring	Fall
Station Group 1				
	H_n"	2.651	2.497	2.278
	P.I.E.	0.908	0.864	0.773
	E	0.321	0.210	0.156
Station Group 2				
	H_n"	3.000	2.971	2.271
	P.I.E.	0.993	0.924	0.994
	E	0.286	0.216	0.135
Station Group 3				
	H_n"	2.400	2.360	2.232
	P.I.E.	0.863	0.846	0.817
	E	0.194	0.179	0.156

clear patterns were evident.

A listing of all species of fishes caught during 1977, arranged in systematic order, with total number of individuals and total biomass of each species caught is given in Table 1, Appendix Q. The most commonly encountered species and the most abundant species captured during 1977 are listed in Tables 18.11 and 18.12, respectively. If a species was included in one list, it usually occurred in the other. Some frequently encountered species (*e.g. Synodus foetens* and *Upeneus parvus*), however, were not caught in relatively high abundance and, conversely, some of the most abundant species (*e.g. Cynoscion nothus* and *Chloroscombrus chrysurus*) were not frequently caught.

The ten most abundant species (with abundance ≥ 10 individuals) caught in each station group during each season are listed in Tables 18.13 (day) and 18.14 (night). Most of these species also occurred in the top ten listing for the corresponding station groups and time periods in 1976.

Occurrences of each of the major species in the top ten listings were tabulated and are presented in Table 2, Appendix Q. These tables gave an indication of how predominant certain species were among the ichthyofauna of the three station groups during each of the seasons.

Many of the species which occurred in the top ten listings for a particular station group were not found during 1977 in one or two of the other station groups. This was consistent with the premise that faunal composition changed with depth. These species are presented in Table 18.15. Several of the species showed the same patterns as in 1976, however, the majority of the species did not occur in the absence list for 1976.

Values of the average catch per trawl are given for each of the common species in Appendix Q. Values were computed for station groups

TABLE 18.11

THE FIFTEEN MOST COMMONLY ENCOUNTERED SPECIES FOR 1977

	Species	Number of Occurrences
✓	*Serranus atrobranchus*	101
✓	*Pristipomoides aquilonaris*	96
✓	*Synodus foetens*	87
✓	*Trachurus lathami*	83
✓	*Stenotomus caprinus*	83
✓	*Centropristis philadelphica*	80
✓	*Syacium gunteri*	77
✓	*Prionotus paralatus*	70
	Micropogon undulatus	67
	Peprilus burti	64
✓	*Upeneus parvus*	61
✓	*Porichthys porosissimus*	56
✓	*Prionotus stearnsi*	53
✓	*Prionotus rubio*	51
	Lutjanus campechanus	50

✓ indicates species which were also among the 15 most commonly encountered species in 1976

TABLE 18.12

THE FIFTEEN MOST ABUNDANT SPECIES FOR 1977

	Species	Number of Individuals
✓	*Peprilus burti*	5574
✓	*Trachurus lathami*	4380
✓	*Serranus atrobranchus*	2878
✓	*Micropogon undulatus*	2856
✓	*Stenotomus caprinus*	1648
	Prionotus paralatus	1615
✓	*Pristipomoides aquilonaris*	1446
✓	*Cynoscion nothus*	1248
✓	*Syacium gunteri*	1099
✓	*Chloroscombrus chrysurus*	642
✓	*Polydactylus octonemus*	636
	Diplectrum bivittatum	524
	Centropristis philadelphica	456
	Trichopsetta ventralis	449
	Prionotus stearnsi	401

✓ indicates species which were also among the 15 most abundant species caught in 1976

TABLE 13.13

TEN MOST ABUNDANT SPECIES CAPTURED IN DAY TRAWLS IN EACH STATION GROUP DURING EACH SEASON.
SPECIES LISTED ALSO HAVE ABUNDANCE ≥ 10 INDIVIDUALS.
NUMBERS OF INDIVIDUALS CAPTURED ARE GIVEN FOR EACH SPECIES, 1977 DATA

Station Group 1

WINTER		SPRING		Fall	
Species	No.	Species	No.	Species	No.
Syacium gunteri	20	√*Peprilus burti*	4289	√*Micropogon undulatus*	906
√*Cynoscion arenarius*	15	√*Trachurus lathami*	1727	*Cynoscion nothus*	139
√*Peprilus burti*	14	√*Micropogon undulatus*	750	√*Syacium gunteri*	91
√*Micropogon undulatus*	10	√*Chloroscombrus chrysurus*	602	*Polydactylus octonemus*	85
		√*Cynoscion nothus*	462	√*Lutjanus campechanus*	77
		Brevoortia patronus	181	*Trachurus lathami*	67
		√*Anchoa hepsetus*	91	*Peprilus burti*	46
		Harengula pensacolae	88	√*Diplectrum bivittatum*	28
		Etrumeus teres	53	*Anchoa hepsetus*	28
		√*Polydactylus octonemus*	46	*Citharichthys spilopterus*	21

√ - Denotes species which also occurred in the top ten list for the corresponding time period and station group in 1976.

TABLE 18.13 CONT.'D

Station Group 2

WINTER		SPRING		FALL	
Species	No.	Species	No.	Species	No.
√*Pristipomoides aquilonaris*	55	√*Trachurus lathami*	1207	*Harengula pensacolae*	269
√*Serranus atrobranchus*	48	√*Peprilus burti*	846	√*Trachurus lathami*	201
√*Prionotus stearnsi*	45	*Etrumeus teres*	83	√*Serranus atrobranchus*	155
Sphoeroides parvus	44	√*Serranus atrobranchus*	50	√*Peprilus burti*	120
√*Saurida brasiliensis*	30	√*Pristipomoides aquilonaris*	47	*Cynoscion arenarius*	101
√*Stenotomus caprinus*	24	√*Synodus foetens*	47	*Synodus foetens*	78
Selar crumenophthalmus	17	*Scomber japonicus*	31	*Micropogon undulatus*	78
Trachurus lathami	16	√*Saurida brasiliensis*	25	√*Polydactylus octonemus*	57
Centropristis philedelphica	15	√*Stenotomus caprinus*	24	*Diplectrum bivittatum*	56
√*Synodus foetens*	14	√*Upeneus parvus*	15	√*Stenotomus caprinus*	56
		Diplectrum bivittatum	15		

TABLE 18.13 CONT.'D

Station Group 3

WINTER		SPRING		FALL	
Species	No.	Species	No.	Species	No.
√*Pristipomoides aquilonaris*	82	*Trachurus lathami*	708	√*Trachurus lathami*	183
√*Serranus atrobranchus*	37	√*Pristipomoides aquilonaris*	167	√*Serranus atrobranchus*	180
√*Stenotomus caprinus*	31	*Stenotomus caprinus*	71	√*Pristipomoides aquilonaris*	145
√*Upeneus parvus*	10	√*Serranus atrobranchus*	61	√*Prionotus paralatus*	110
√*Prionotus paralatus*	10	*Synodus foetens*	16	*Stenotomus caprinus*	99
		√*Prionotus paralatus*	15	√*Upeneus parvus*	55
		Upeneus parvus	11	√*Pontinus longispinis*	36
				Caulolatilus intermedius	33
				√*Trichopsetta ventralis*	26
				√*Prionotus stearnsi*	16

TABLE 18,14

TEN MOST ABUNDANT SPECIES CAPTURED IN NIGHT TRAWLS IN EACH STATION GROUP DURING EACH SEASON.
SPECIES LISTED ALSO HAVE ABUNDANCE ≥ 10 INDIVIDUALS.
NUMBERS OF INDIVIDUALS CAPTURED ARE GIVEN FOR EACH SPECIES, 1977 DATA

Station Group 1

WINTER		SPRING		FALL	
Species	No.	Species	No.	Species	No.
Trichiurus lepturus	28	√*Polydactylus octonemus*	212	√*Micropogon undulatus*	724
√*Syacium gunteri*	25	*Cynoscion nothus*	115	√*Lutjanus campechanus*	138
√*Cynoscion arenarius*	23	√*Micropogon undulatus*	106	√*Syacium gunteri*	114
√*Cynoscion nothus*	18	√*Cynoscion arenarius*	64	√*Polydactylus octonemus*	96
Anchoa mitchilli	12	*Peprilus burti*	50	*Cynoscion nothus*	71
Peprilus burti	10	*Syacium gunteri*	35	*Orthopristis chrysoptera*	67
		Upeneus parvus	24	√*Sphoeroides parvus*	57
		Trachurus lathami	21	√*Diplectrum bivittatum*	51
		√*Sphoeroides parvus*	17	*Chaetodipterus faber*	26
		Chloroscombrus chrysurus	13	√*Prionotus rubio*	23

√- Denotes species which also occurred in the top ten list for the corresponding time period and station group in 1976.

TABLE 18.14 CONT.'D

Station Group 2

WINTER		SPRING		FALL	
Species	No.	Species	No.	Species	No.
√*Stenotomus caprinus*	55	√*Stenotomus caprinus*	196	√*Serranus atrobranchus*	315
√*Serranus atrobranchus*	46	√*Serranus atrobranchus*	153	*Prionotus paralatus*	181
Sphoeroides parvus	31	*Prionotus paralatus*	133	*Diplectrum bivittatum*	173
√*Syacium gunteri*	29	√*Syacium gunteri*	96	√*Stenotomus caprinus*	161
√*Porichthys porosissimus*	20	√*Prionotus stearnsi*	88	√*Syacium gunteri*	146
Diplectrum bivittatum	18	*Upeneus parvus*	84	√*Centropristis philadelphica*	124
√*Centropristis philadelphica*	14	√*Synodus poeyi*	60	*Micropogon undulatus*	121
√*Trichopsetta ventralis*	14	√*Centropristis philadelphica*	54	√*Prionotus stearnsi*	99
Kathetostoma albigutta	13	*Pristipomoides aquilonaris*	45	*Cynoscion nothus*	90
Synodus poeyi	12	√*Bollmannia communis*	27	√*Pristipomoides aquilonaris*	72

TABLE 18.14 CONT.'D

Station Group 3

WINTER		SPRING		FALL	
Species	No.	Species	No.	Species	No.
✓*Serranus atrobranchus*	123	✓*Serranus atrobranchus*	251	✓*Serranus atrobranchus*	564
✓*Stenotomus caprinus*	85	✓*Pristipomoides aquilonaris*	205	✓*Prionotus paralatus*	492
✓*Pristipomoides aquilonaris*	74	✓*Stenotomus caprinus*	162	✓*Stenotomus caprinus*	208
✓*Trichopsetta ventralis*	43	✓*Pontinus longispinis*	49	✓*Pristipomoides aquilonaris*	114
✓*Prionotus paralatus*	31	*Trachurus lathami*	42	*Trachurus lathami*	95
Syacium gunteri	17	✓*Trichopsetta ventralis*	41	✓*Trichopsetta ventralis*	71
Pontinus longispinis	16	✓*Prionotus paralatus*	40	*Upeneus parvus*	52
✓*Prionotus rubio*	13	*Urophycis cirratus*	30	✓*Pontinus longispinis*	41
Upeneus parvus	14	*Hoplunnis tenuis*	15	✓*Halieutichthys aculeatus*	38
		Upeneus parvus	15	*Urophycis cirratus*	24

TABLE 18.15

ABSENCE OF MAJOR SPECIES IN THE STATION GROUPS DURING 1977

	Species	Never Found in Station Group I	II	III
o	*Anchoa hepsetus*			X
✓	*Anchoa mitchilli*		X	X
o	*Bollmannia communis*			X
o	*Brevoortia patronus*			X
o	*Caulolatilus intermedius*	X		
o	*Chaetodipterus faber*			X
✓	*Chloroscombrus chrysurus*			X
o	*Citharichthys spilopterus*			X
o	*Cynoscion nothus*			X
✓	*Etropus crossotus*			X
o	*Etrumeus teres*			X
o	*Harengula pensacolae*			X
o	*Hoplunnis tenuis*	X		
o	*Kathetostoma albigutta*	X		
o	*Orthopristis chrysoptera*			X
✓	*Polydactylus octonemus*			X
✓	*Pontinus longispinis*	X		
o	*Selar crumenophthalmus*	X		X
✓	*Sphoeroides parvus*			X

✓ corresponds to observations for 1976
o did not occur in the absence list for 1976

(Appendix Q, Table 3) and for transects (Appendix Q, Table 4).

The information in Appendix Q, Table 3 could be used to classify species according to where on the STOCS they were predominantly found. Viewing the data without regard to the seasons, most of the species could be described as either shallow-water, shallow to mid-depth, mid-depth to deep, or deep-water. This categorization is presented in Table 18.16. Several species in Table 3, Appendix Q either showed ambiguous abundance patterns over depth zones or were not abundant enough to allow such categorization, and were therefore omitted from Table 18.16.

There appeared to be relatively little segregation of the major species into particular transects or groups of transects, (Table 4, Appendix Q), although a few species were absent from some transects (Table 18.17). Most species were found on all four transects, and several species were particularly well represented over the four transects. These species were *Serranus atrobranchus*, *Trachurus lathami*, *Stenotomus caprinus*, *Pristipomoides aquilonaris* and *Peprilus burti*.

Data on relative abundances of species and species composition of individual trawls are presented in Table 4, Appendix Q.

It is highly desirable to make comparisons between the data of different years in an attempt to identify those patterns of abundance and distribution shown by demersal fishes which are constant from year to year and those patterns which are variable between years. Caution must be exercised, however, in attempting to make year-to-year comparisons and in interpreting these comparisons because of two important sources of confusion that were inherent in the sampling program.

The first of these was nonuniformity in both time and space of the sampling regimes for the three years. Even though sampling was attempted

TABLE 18.16

CHARACTERISTIC DEMERSAL FISHES OF THE DIFFERENT DEPTH ZONES

Shallow (Station Group I)

Anchoa hepsetus
Brevoortia patronus
Chloroscombrus chrysurus
Citharichthys spilopterus
Cynoscion nothus
Chaetodipterus faber
Lutjanus campechanus
Micropogon undulatus
Orthopristis chrysoptera
Polydactylus octonemus

Mid-Depth (Station Group II)

Centropristis philadelphica
Prionotus stearnsi
Saurida brasiliensis
Synodus foetens
Synodus poeyi

Deep (Station Group III)

Caulolatilus intermedius
Pontinus longispinis
Trichopsetta ventralis

Shallow-to-Mid-Depth

Cynoscion arenarius
Diplectrum bivittatum
Harengula pensacolae
Peprilus burti
Sphoeroides parvus
Syacium gunteri
Trichiurus lepturus

Mid-Depth-to-Deep

Prionotus paralatus
Pristipomoides aquilonaris
Serranus atrobranchus
Stenotomus caprinus

TABLE 18.17

RESTRICTION OF MAJOR SPECIES TO PARTICULAR TRANSECTS.
SPECIES LISTED UNDER EACH GROUP OF TRANSECTS WERE CAPTURED ONLY ON THOSE TRANSECTS DURING 1977.
(THIS TABULATION IS BASED ON ALL MONTHLY AND SEASONAL DATA.)

Transects	Species
I, II	*Chaetodipterus faber* *Citharichthys spilopterus* *Hoplunnis tenuis*
II, IV	*Selar crumenophthalmus*
I, II, III	*Anchoa mitchilli*
I, II, IV	*Brevoortia patronus*
I, III, IV	*Etrumeus terres* *Orthopristis chrysoptera*

on a seasonal basis for the three years, the exact dates of these seasonal sampling periods varied widely, as shown in Table 18.2. Monthly sampling dates also differed between years (Table 18.2) but, of course, to a lesser extent than did the seasonal samples. Nonuniformity of sampling over space was due to the variance from year to year in the sampling effort expended in different parts of the STOCS study area.

It should be noted, however, that although the detailed distribution of sampling effort over the sampling stations differed between years, there was reasonable correspondence between years in the relative expenditure of sampling effort over the three station groups seasonally. Evidence that the sampling schemes for 1976 and 1977 were broadly comparable is provided by Tables 18.11 and 18.12. Of the 15 most commonly encountered species during 1977 (Table 18.11), 12 were also among the 15 most commonly encountered species during 1976. Of the 15 most abundant species caught during 1977 (Table 18.12), 10 were among the 15 most abundant species caught during 1976.

The second source of confusion to consider was the modest amount of replication employed in the sampling program. There is a limit to the amount of interpretation which one can safely indulge in on the basis of only one, two, or even three trawls taken at a single station during a given season. An attempt was made to circumvent this constraint to some degree by lumping stations into station groups, thereby increasing the sample sizes on which conclusions have been based.

The following discussion is restricted to seasonal samples since monthly data are too few to base a credible discussion on. Also, for this discussion, attention is focused on the 1976 and 1977 data; the 1975 data were not thought comparable to 1976 and 1977 data.

Comparison of the 1977 data with 1976 data showed a number of dis-

crepancies. In 1977, unlike 1976, fall samples yielded the greatest numbers of species. In 1976, Station Group 3 consistently had the lowest numbers of species, which was not apparent in 1977. The highest total catches, in terms of numbers of individuals, occurred during spring for day trawls and during fall for night trawls in 1977; this was not evident in 1976. The lowest total catches in 1976 generally occurred in Station Group 3, which was not true in 1977. In 1977, the lowest total biomasses were taken during winter for both day and night trawls, which was not true for 1976, and higher total biomasses were taken in fall than in other seasons for night trawls. The 1976 data generally showed no trends in total biomasses taken. In addition, no trends in the diversity indices, which were consistent between 1976 and 1977, were evident.

The patterns of occurrences of major species among the top ten species drawn from the 1977 data (Table 2, Appendix Q), demonstrated general agreement with the patterns shown by the same species in 1976. Numerous minor discrepancies did, however, exist. Values for the average number of fishes caught per trawl, for the station group data (Table 3, Appendix Q), differed between the 1976 and 1977 data to varying degrees for different species. Some species, such as *Synodus foetens*, showed reasonable correspondence between the 1976 and 1977 values, while others, such as *Anchoa hepsetus*, showed wide differences.

In spite of the differences in the sampling regime between 1976 and 1977, some types of observations were fairly consistent. One such observation was the tendency of certain species to be caught in either day or night trawls. Examination of Table 3, Appendix Q, which gives average numbers of individuals caught for each of the major species, revealed the propensities of certain species to be caught during night or day. For

instance, *Anchoa hepsetus* showed an average catch rate of 16.1 individuals per trawl during the day, but only .5 individuals per trawl during the night. Species which showed such obvious differences are presented in Table 18.18.

Twenty-two (22) species showed correspondence between the two years in their tendencies to be caught during either day or night from the 30 major species for which information on the average number of individuals caught per trawl was available for both 1976 and 1977. The remaining eight species had higher total yields during the day in one year and during the night in the other year. For a more definitive and comprehensive statement on day-night differences in captures of these species based on a statistical analysis (of data from 1976 only), see Wohlschlag (*In* Groover, 1977) and Vetter (1977).

Seasonal changes in abundances of the fishes were quite evident. Although most of the major species showed seasonal trends in abundance to at least some degree (Table 3, Appendix Q), a few of them had especially prominent peaks during spring and two species peaked during fall. In particular, *Chloroscombrus chrysurus*, *Cynoscion nothus*, *Peprilus burti*, and *Trachurus lathami* showed substantially elevated abundances during spring, while *Serranus atrobranchus* peaked in the fall and *Micropogon undulatus* showed elevated abundances during spring and fall. These peaks were probably related to the influx into the system of young-of-the-year, but an analysis of lengths would be required to corroborate this.

Seasonal changes were also observed in the constellation of predominant species in each of the three station groups, as documented by Tables 18.13 and 18.14. For example, for day trawls in Station Group 1, eight new species entered the top ten list between winter and spring, and there was a change of four species between spring and fall. In Station Group 2

TABLE 18.18

SPECIES OF DEMERSAL FISHES WHICH SHOWED OBVIOUS DIFFERENCES IN AVERAGE RATES OF CAPTURE BETWEEN DAY AND NIGHT TRAWLS. 1977

Species Caught at Higher Abundance During Day Trawls	Species Caught at Higher Abundances During Night Trawls
Anchoa hepsetus	*Prionotus paralatus*
Brevoortia patronus	*Serranus atrobranchus*
Chloroscombrus chrysurus	*Stenotomus caprinus*
Cynoscion nothus	*Syacium gunteri*
Etrumeus teres	*Synodus poeyi*
Harengula pensacolae	*Urophycis cirratus*
Micropogon undulatus	
Synodus foetens	
Trachurus lathami	

(for day trawls), five species on the top ten list changed between winter and spring and four species changed between spring and fall. It was not possible to determine from the data to what extent these changes in the predominant species were due to migratory activities of the fishes or to the recruitment of young. References in the literature, however, cite the large-scale migratory activities for some of these species (*e.g.* Gunter, 1945) and this aspect of the ecology of the local fishes presents a highly interesting topic for further study.

Drawing from the data of Tables 18.13 and 18.14, we categorized the species according to the season(s) in which they predominated. This scheme is presented in Table 18.19. It was observed that while a large number of species predominated in a faunal assemblage only during a single season (*e.g. Anchoa mitchilli* only during winter and *Caulolatilus intermedius* only during fall), an equally large number of species were abundant all year round. Twelve species were particularly prominent constitutents of the STOCS ichthyofauna, and are marked with asterisks in Table 18.19.

The results of this study on the distribution patterns of particular species generally appeared to conform with those presented by Chittenden and McEachran (1976) as well as with the data of earlier workers discussed by these authors. There were some points of difference, however, between other results and those of Chittenden and McEachran. Specifically, these authors reported a richer species composition in winter than in summer, whereas trawls in this study yielded the lowest numbers of species (for all station groups) during winter. They also reported a higher biomass on brown shrimp grounds (corresponding to Station Groups 2 and 3) than on white shrimp grounds (corresponding to Station Group 1). No strong statement on trends in biomasses caught with change in depth could be made from the data collected in this study. On the other hand, Chittenden and

TABLE 18.19

THE MAJOR SPECIES CAUGHT DURING 1977 CLASSIFIED ACCORDING TO THE SEASON(S) IN WHICH THEY PREDOMINATED THE SPECIES ASSEMBLAGE IN WHICH THEY OCCURRED

Winter

Anchoa mitchilli
Kathetostoma albigutta
Porichthys porosissimus
Selar crumenophthalmus
Trichiurus lepturus

Spring

Bollmannia communis
Brevoortia patronus
Chloroscombrus chrysurus
Etrumeus teres
Hoplunnis tenuis
Scomber japonicus

Fall

Caulolatilus intermedius
Chaetodipterus faber
Citharichthys spilopterus
Halieutichthys aculeatus
Lutjanus campechanus
Orthopristis chrysoptera

Winter-Spring

Saurida brasiliensis
Synodus poeyi

Spring-Fall

Anchoa hepsetus
Harengula pensacolae
Polydactylus octonemus
Urophycis cirratus

Winter-Fall

Prionotus rubio

All Year

Centropristis philadelphica
Cynoscion arenarius
* *Cynoscion nothus*
* *Diplectrum bivittatum*
* *Micropogon undulatus*
* *Peprilus burti*
Pontinus longispinis
* *Prionotus paralatus*
Prionotus stearnsi
* *Pristipomoides aquilonaris*
* *Serranus atrobranchus*
Sphoeroides parvus
* *Stenotomus caprinus*
* *Syacium gunteri*
Synodus foetens
* *Trachurus lathami*
* *Trichopsetta ventralis*
* *Upeneus parvus*

McEachran reported that biomasses caught were lower in winter than in summer which was consistent with the observation that for the 1977 BLM-STOCS program, lowest catches (in terms of biomass) occurred in the winter.

The published information on species composition of the demersal ichthyofauna of the Gulf of Mexico was reviewed in depth by Chittenden and McEachran (1976). These authors discussed the correspondence of characteristic faunas with depth and sediment type and also touched briefly upon the possible roles of temperature and salinity in affecting community composition. For the BLM-STOCS program efforts in identifying and quantifying the effects of environmental variables on the distribution and abundance of species has thus far been limited. These initial results, however, are instructive and have therefore been included in this report. (Also see Wohlschlag, *In* Groover, 1977).

The relationships between abundances of selected species and some physical variables were examined by plotting abundance of these species against values of a particular variable. Representative plots for four major species, *Trachurus lathami*, *Syacium gunteri*, *Chloroscombrus chrysurus*, and *Peprilus burti* are presented in Figures 18.2 to 18.34.

It can be seen that *Trachurus lathami* (Figures 18.2 - 18.10) was ubiquitous with respect to depth. The greatest frequencies of capture and highest abundances occurred in trawls taken in the 17-26°C temperature range and the 31.5 - 36.5 ppt salinity range. Higher frequencies of captures occurred at stations with relatively low levels of sand (< 16% sand). Highest frequencies of capture and abundances also occurred at stations with sediment composition of 28-41% silt and 40-70% clay. High abundances occurred in trawls taken between 0600 and 1600 hours, with a peak between 0800 and 1500 hours. The species was taken at highest

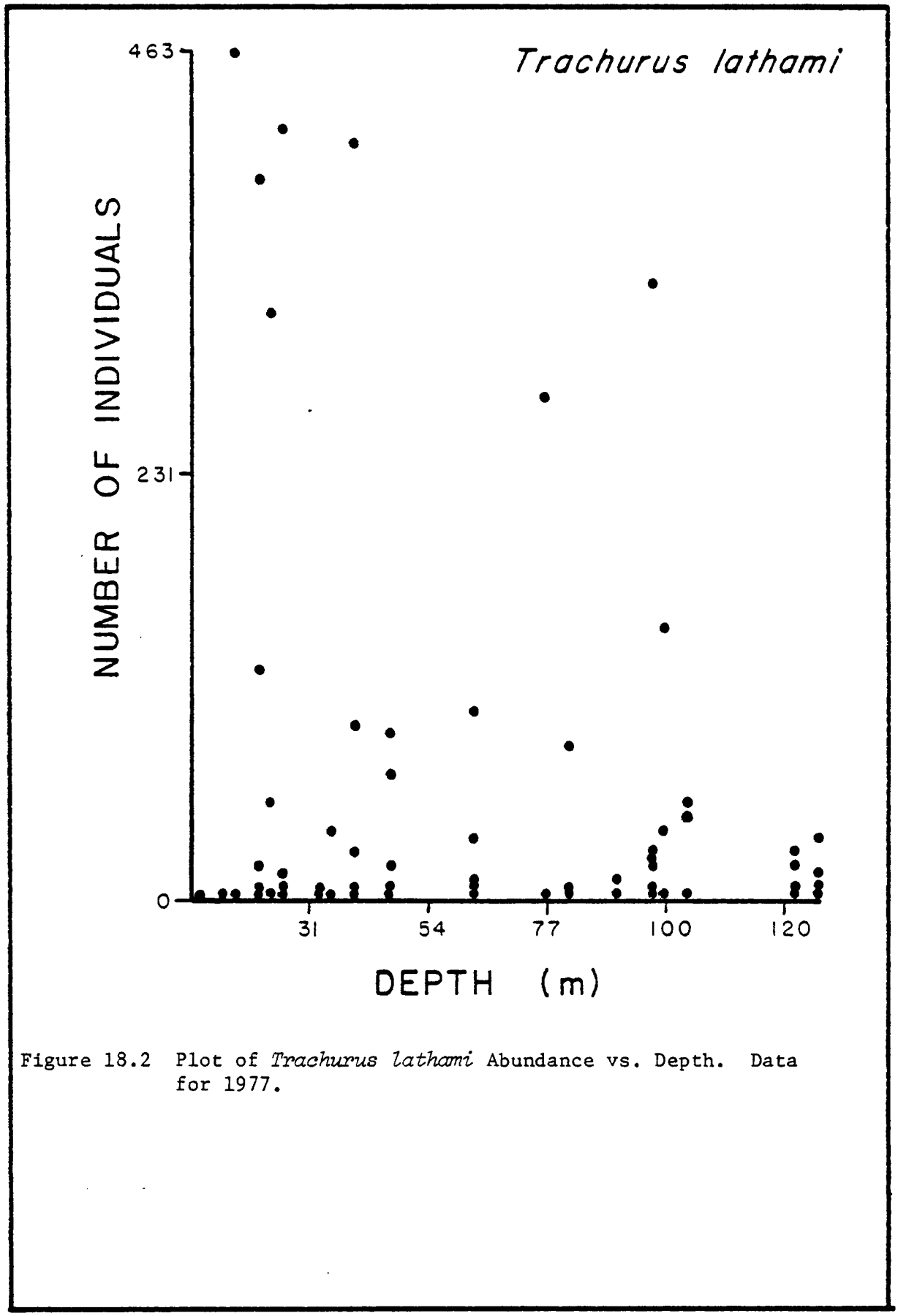

Figure 18.2 Plot of *Trachurus lathami* Abundance vs. Depth. Data for 1977.

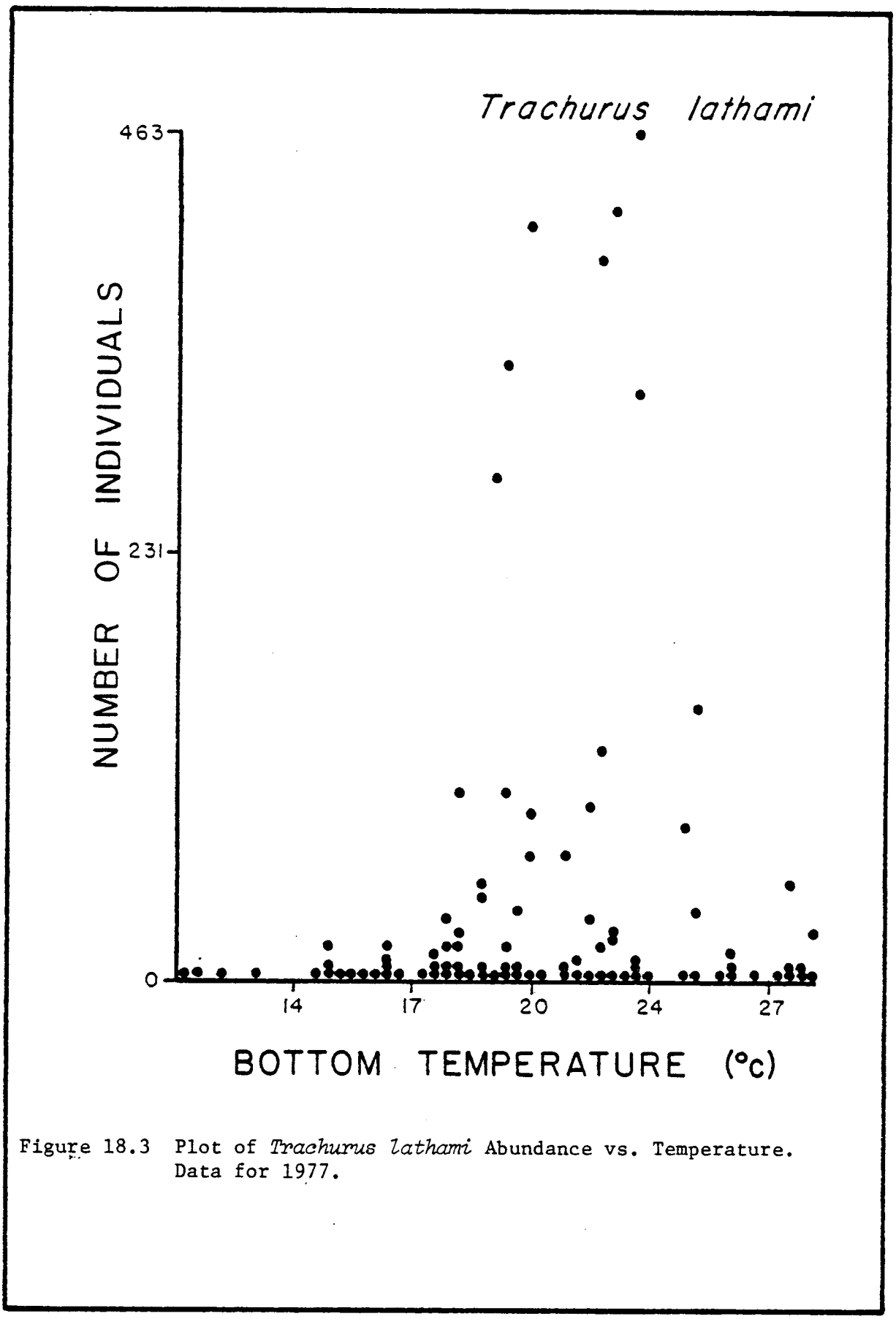

Figure 18.3 Plot of *Trachurus lathami* Abundance vs. Temperature. Data for 1977.

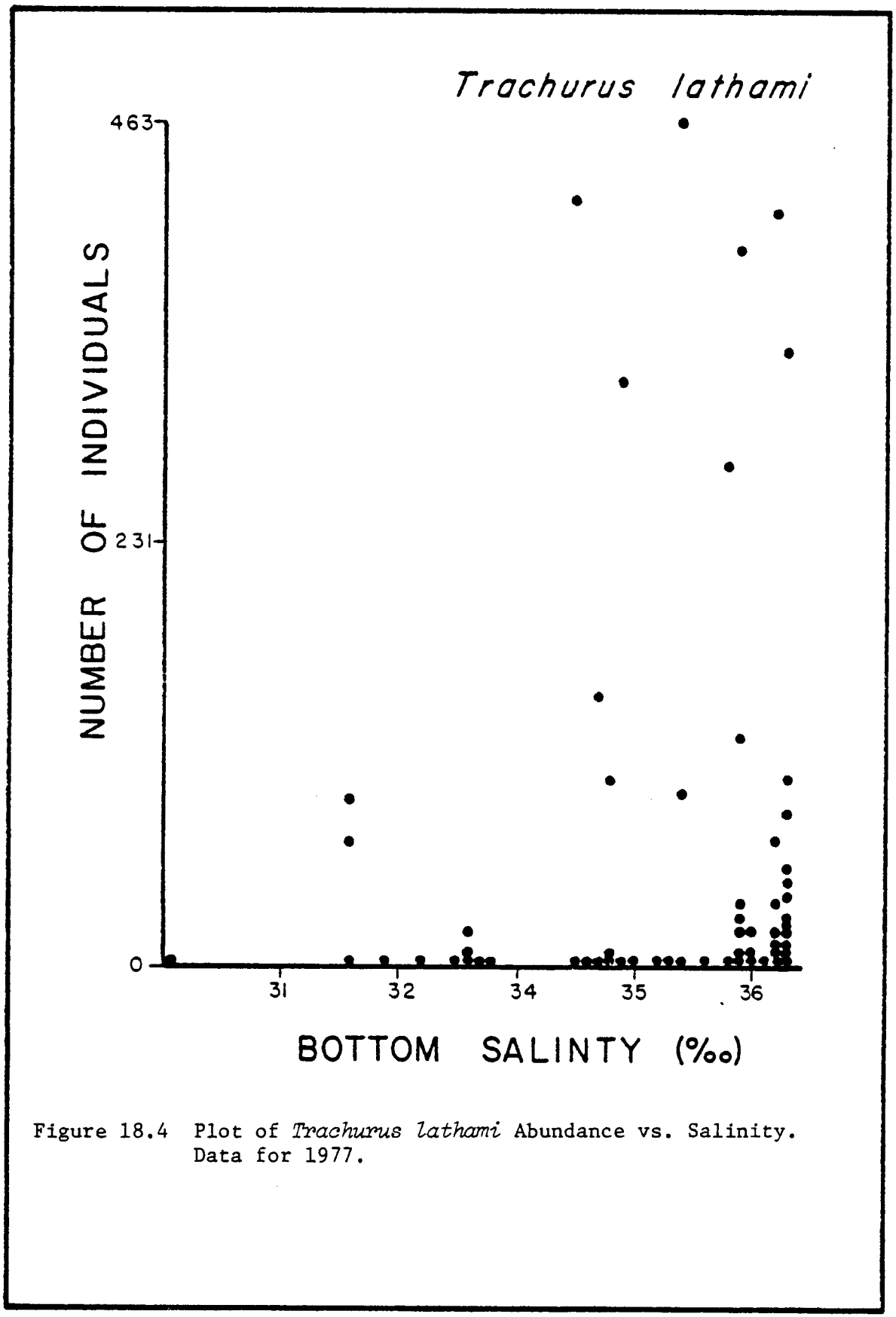

Figure 18.4 Plot of *Trachurus lathami* Abundance vs. Salinity. Data for 1977.

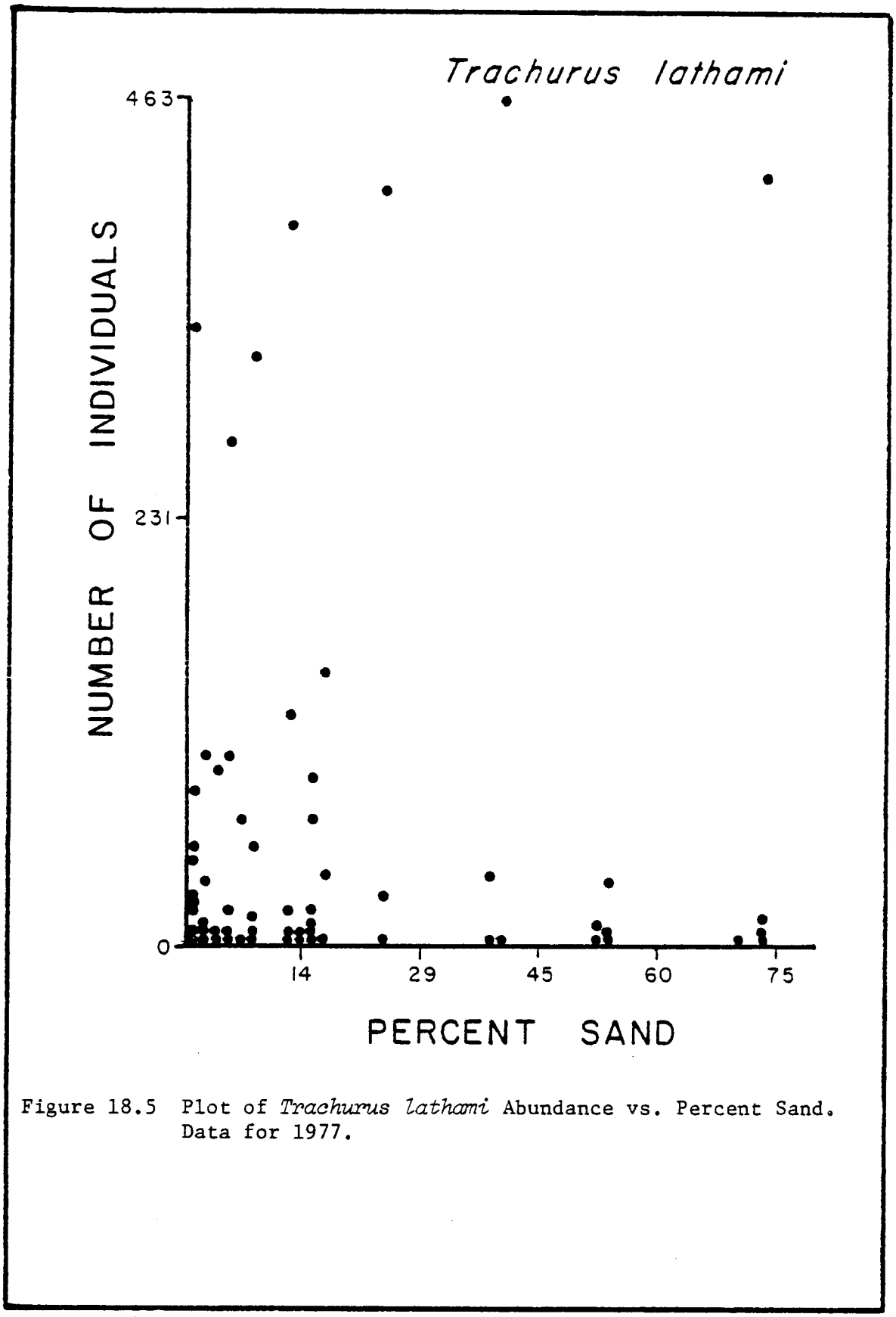

Figure 18.5 Plot of *Trachurus lathami* Abundance vs. Percent Sand. Data for 1977.

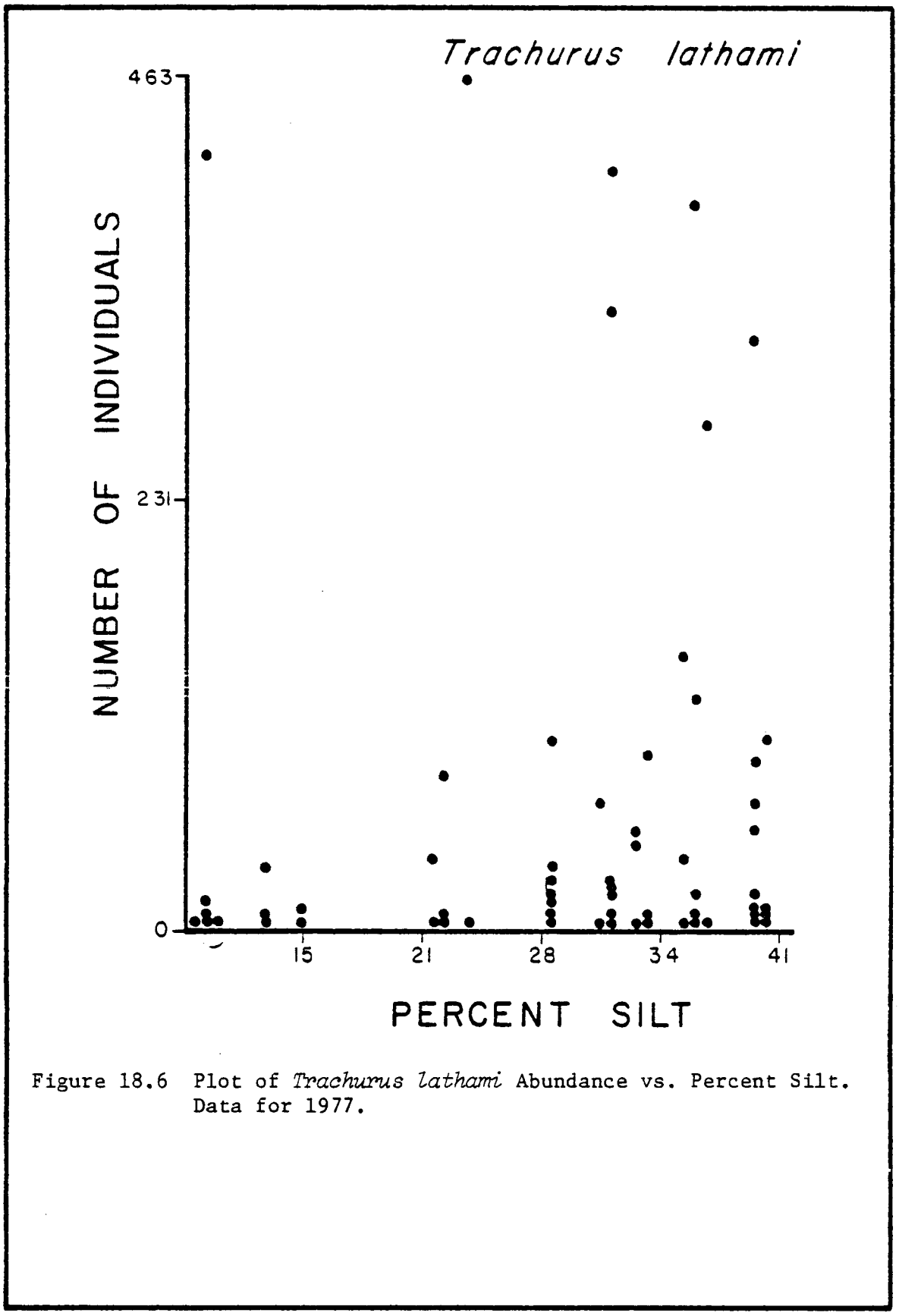

Figure 18.6 Plot of *Trachurus lathami* Abundance vs. Percent Silt. Data for 1977.

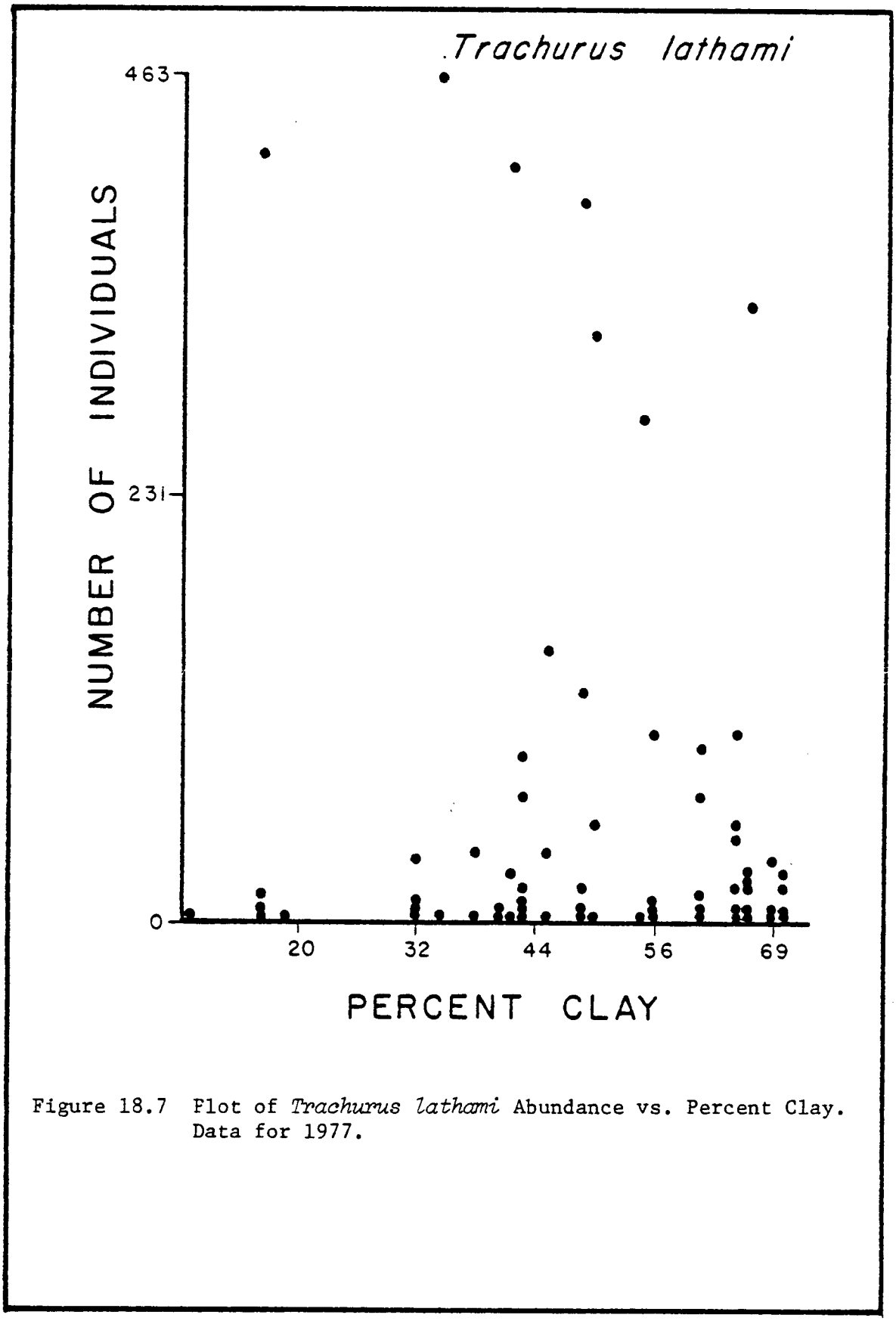

Figure 18.7 Plot of *Trachurus lathami* Abundance vs. Percent Clay. Data for 1977.

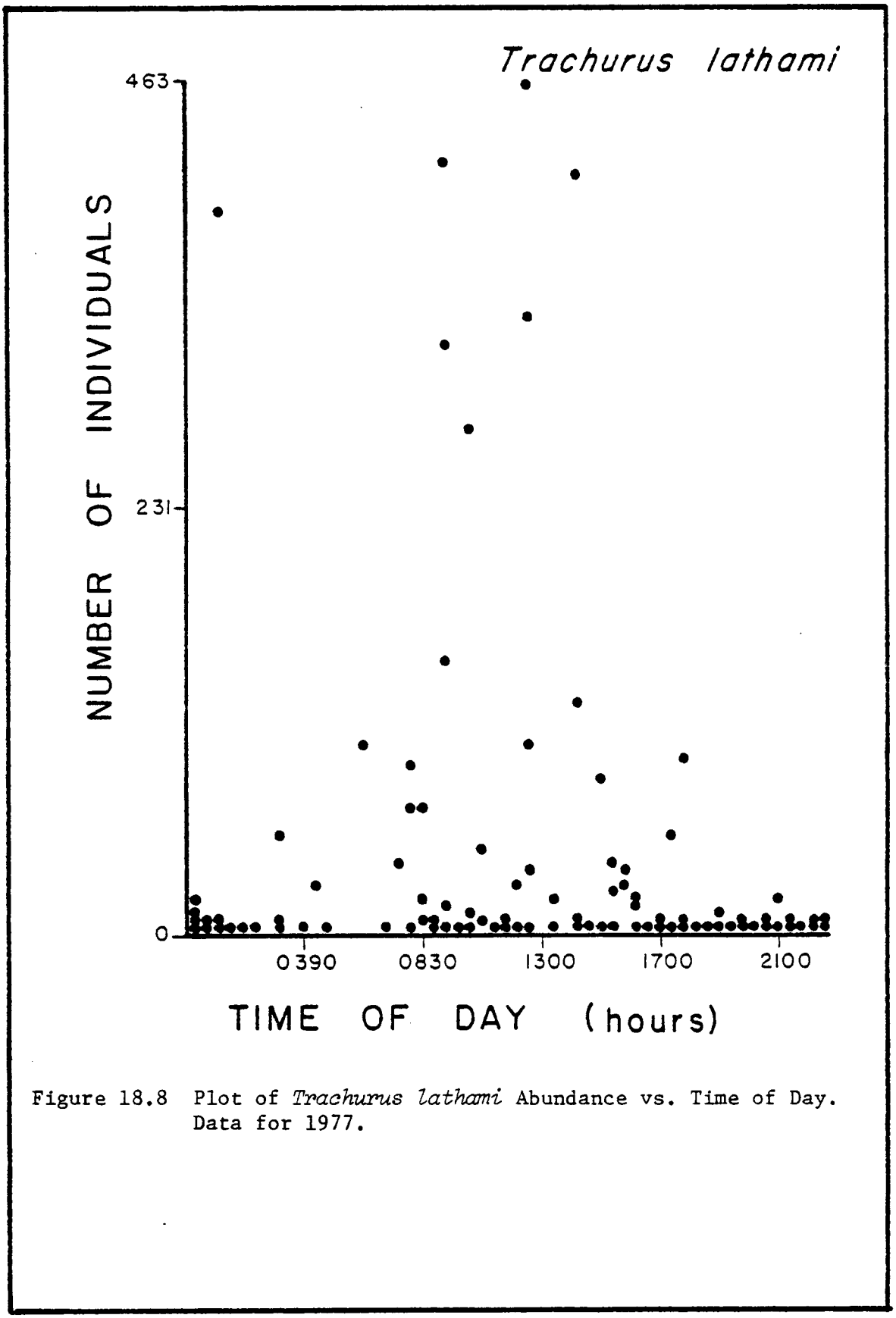

Figure 18.8 Plot of *Trachurus lathami* Abundance vs. Time of Day. Data for 1977.

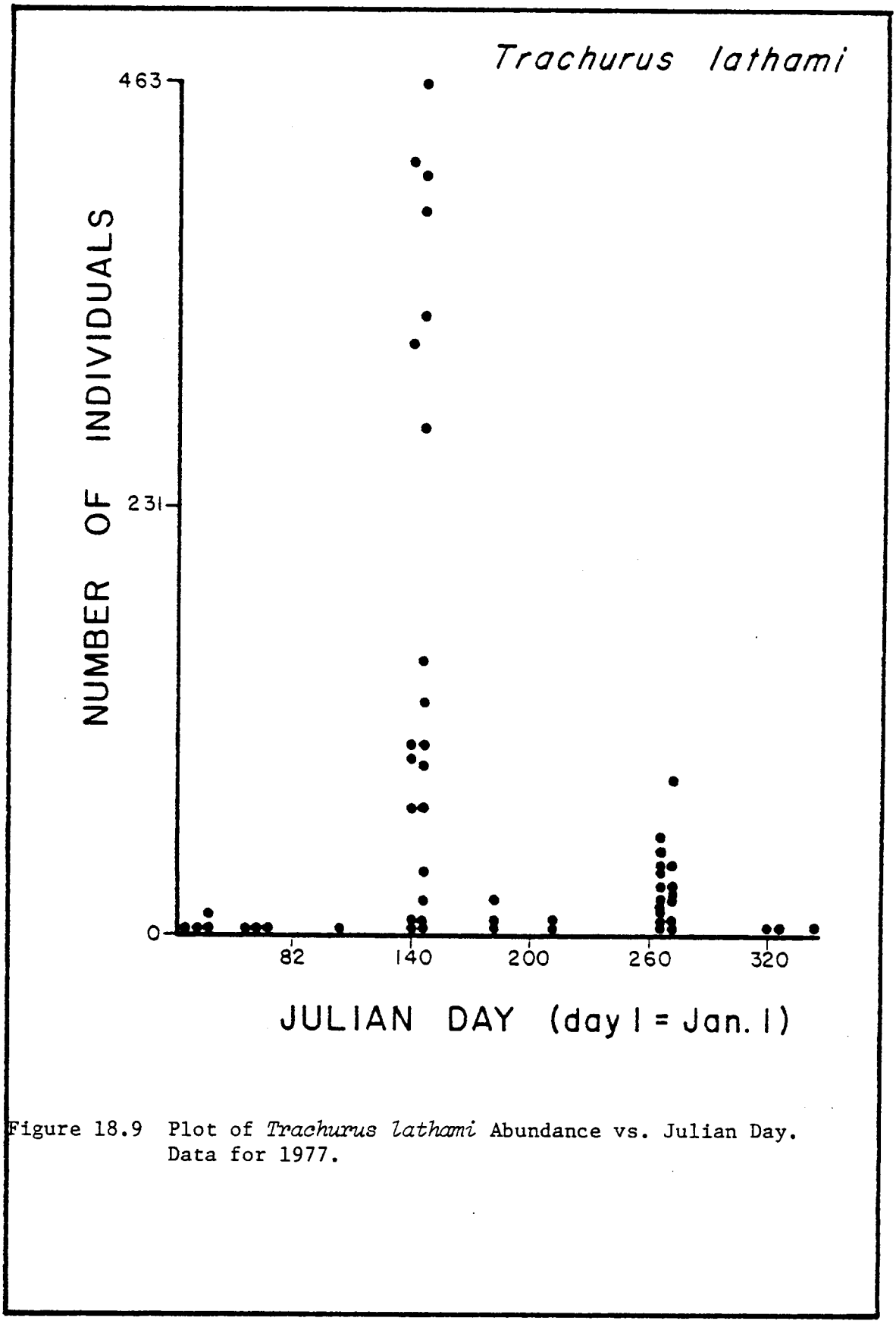

Figure 18.9 Plot of *Trachurus lathami* Abundance vs. Julian Day. Data for 1977.

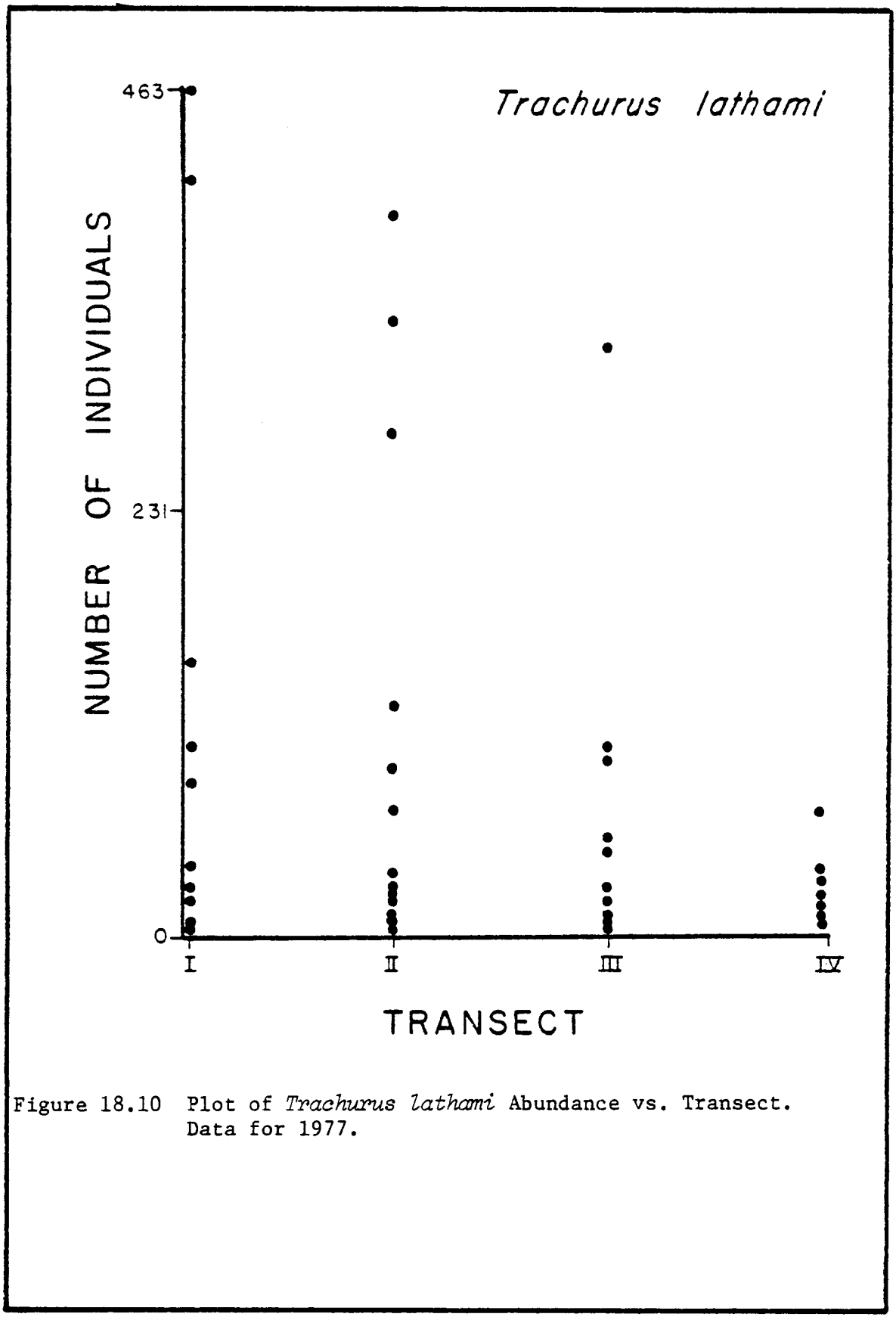

Figure 18.10 Plot of *Trachurus lathami* Abundance vs. Transect. Data for 1977.

abundances on Transects I, II and III.

Peprilus burti (Figures 18.11 and 18.18) was caught mainly at depths less than 50 m. Highest abundances were encountered in the 20-24°C temperature range and salinities greater than 34.5 ppt. This species was caught in abundance over a wide range of sediment composition (~ 10-75% sand; < 41% silt; ~ 15-50% clay). Highest abundances also occurred during the spring, when it was caught in abundance exclusively during daylight periods (at approximately 1400 hrs).

Chloroscombrus chrysurus (Figures 18.19 through 18.26) was taken mainly at depths less than 50 m with temperatures greater than 24°C. No preference for particular salinities was evident. This species occurred over a wide range of sediment composition (< 82% sand; < 44% silt; < 61% clay). *C. chrysurus* showed no discernible pattern in the time of day at which it was captured.

Syacium gunteri (Figures 18.27 to 18.34) was caught mainly at shallow stations (< 47 m). It showed a high frequency of occurrence in the 14-30°C temperature range with greatest abundances at the higher temperatures. It also showed a high frequency of occurrence in the 31.5 - 36.5 ppt salinity range with greatest abundances at the higher salinities. Most captures occurred at stations with a sediment composition of < 45% sand (with a peak at ~ 14%), 23-44% silt (with a peak at ~ 37%) and < 69% clay (with a peak at ~ 50%). This species was frequently encountered and abundant at all times of the (24-hr) day.

It is important to bear in mind differences which may arise between plots based on data collected on different years, for a single species. For example, plots of the abundance of *Lutjanus campechanus* against temperature, salinity and sediment composition are given for each of the

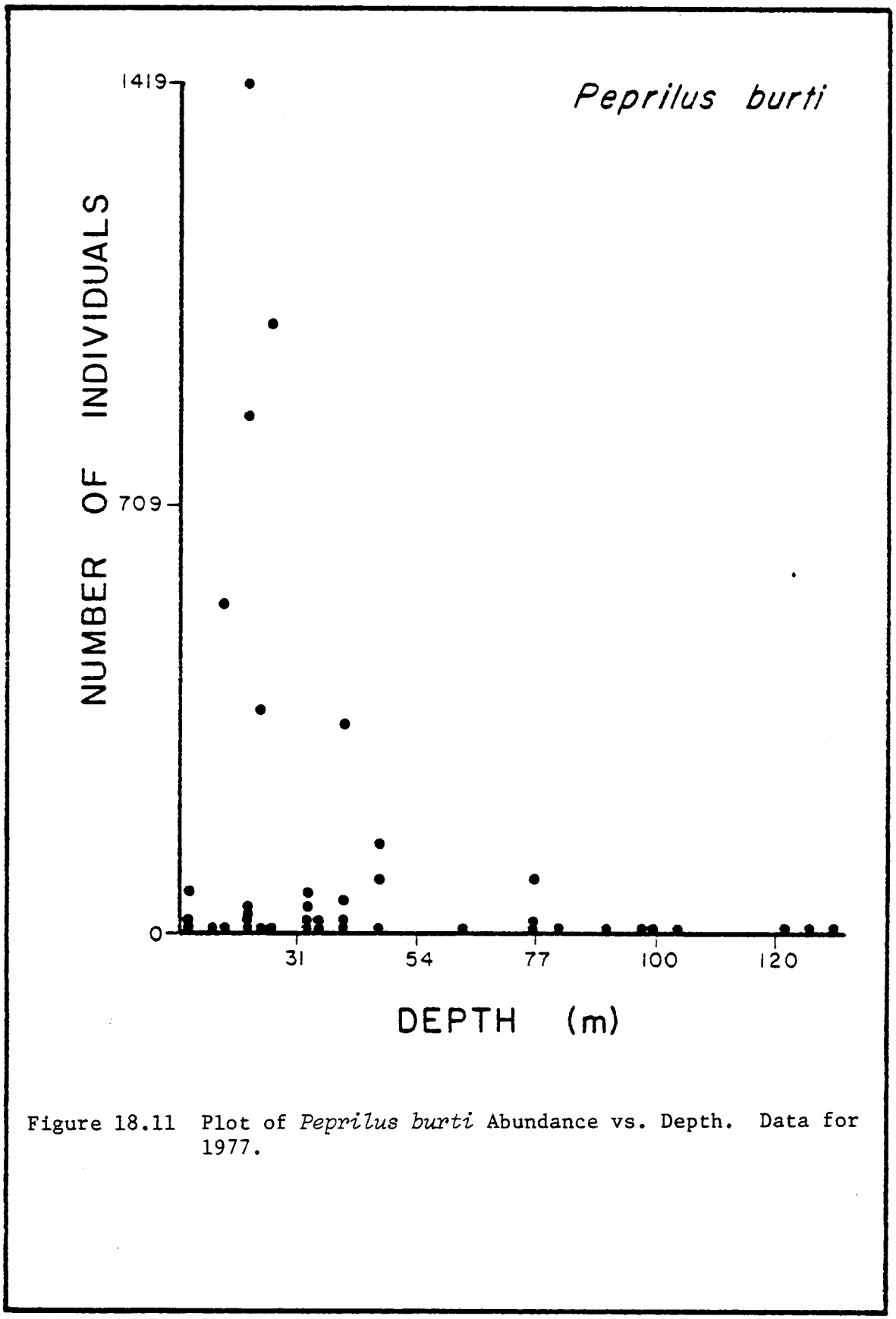

Figure 18.11 Plot of *Peprilus burti* Abundance vs. Depth. Data for 1977.

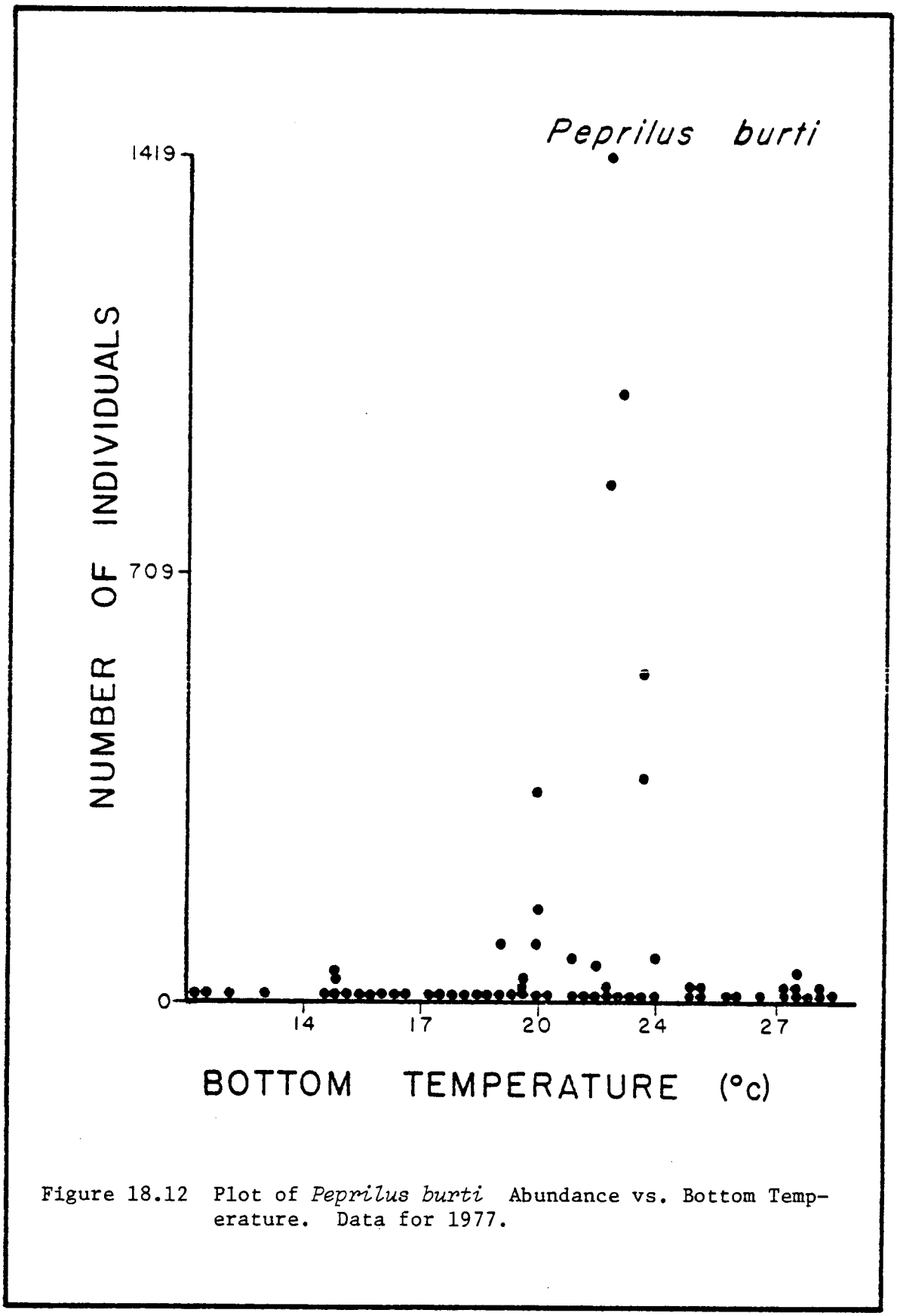

Figure 18.12 Plot of *Peprilus burti* Abundance vs. Bottom Temperature. Data for 1977.

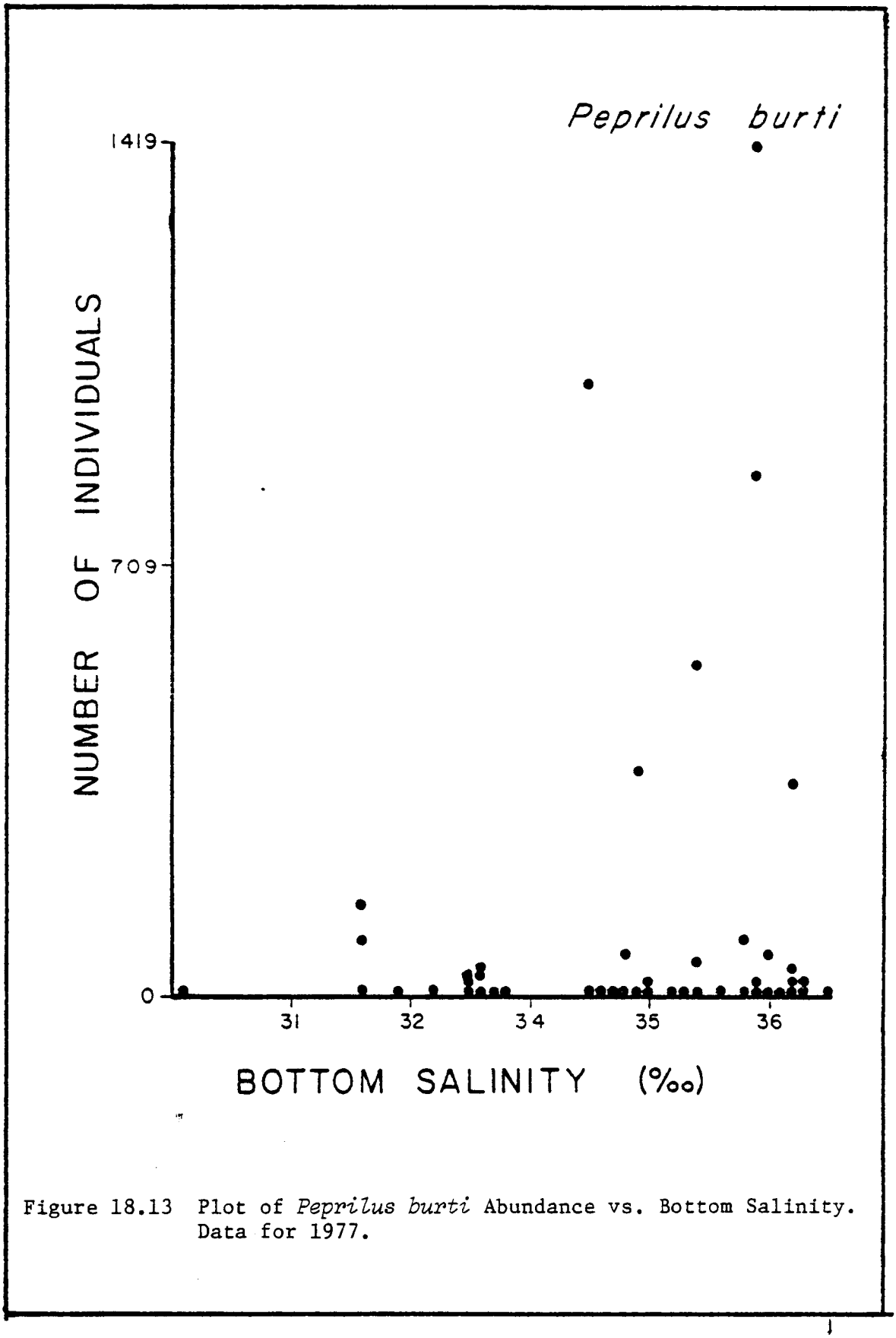

Figure 18.13 Plot of *Peprilus burti* Abundance vs. Bottom Salinity. Data for 1977.

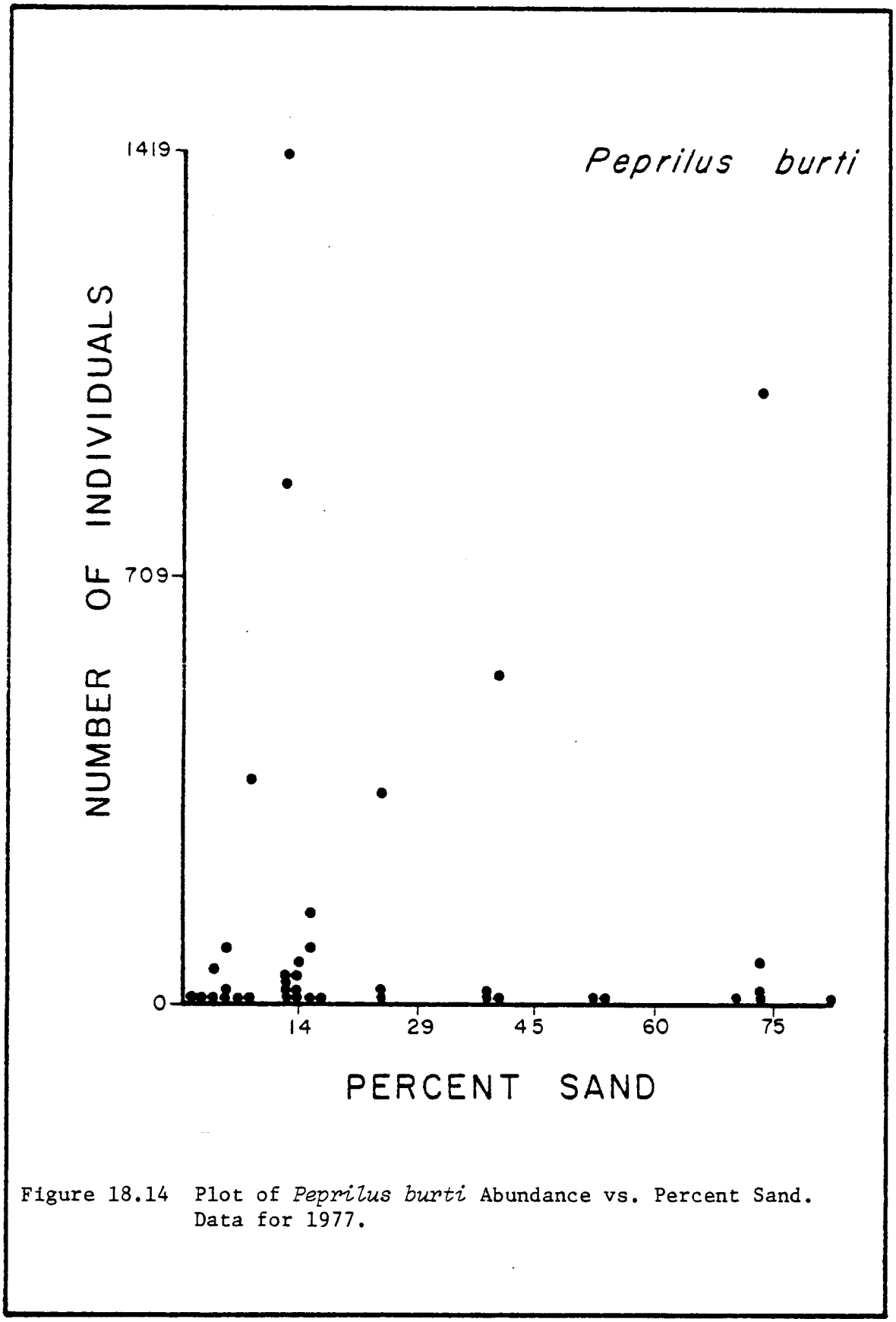

Figure 18.14 Plot of *Peprilus burti* Abundance vs. Percent Sand. Data for 1977.

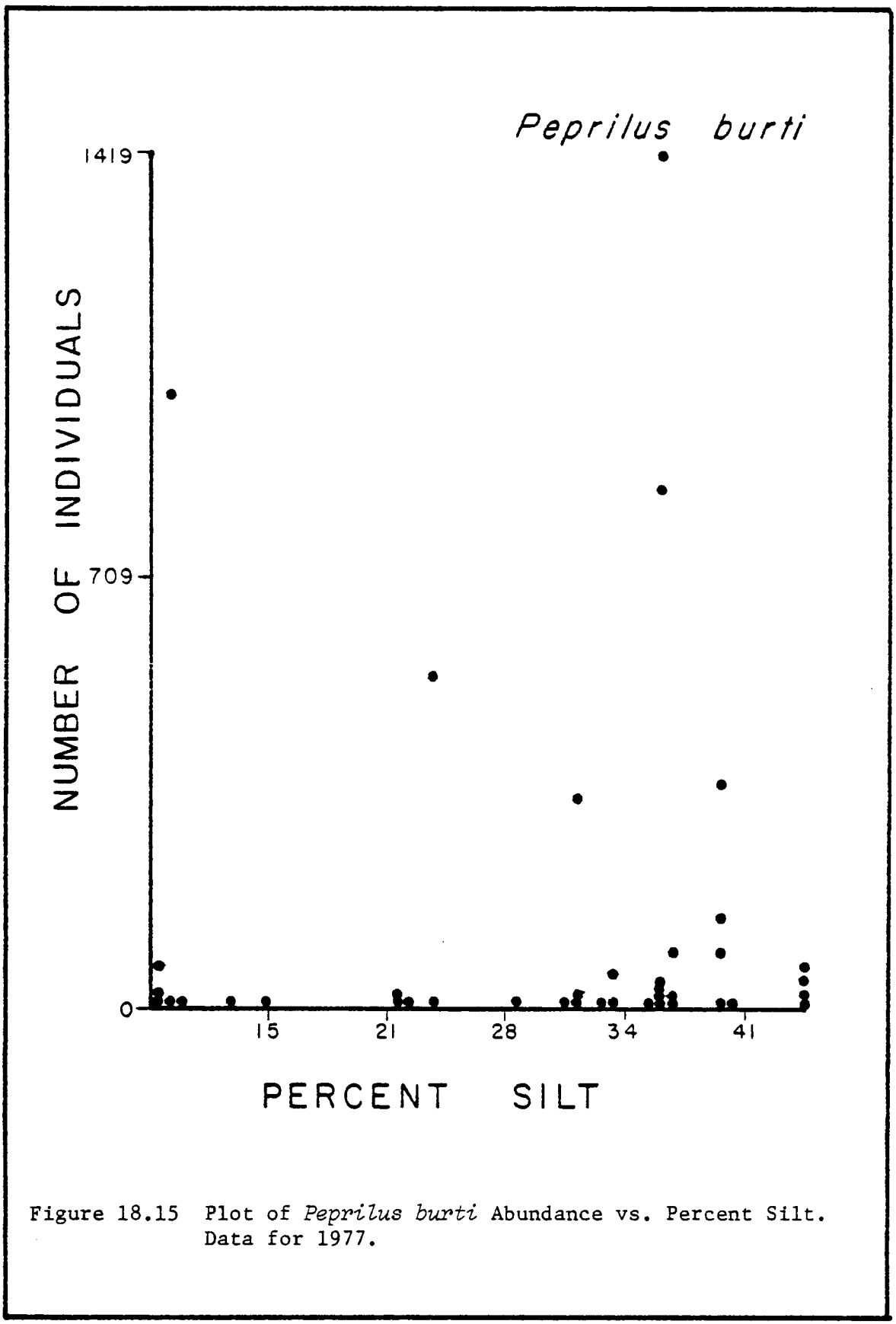

Figure 18.15 Plot of *Peprilus burti* Abundance vs. Percent Silt. Data for 1977.

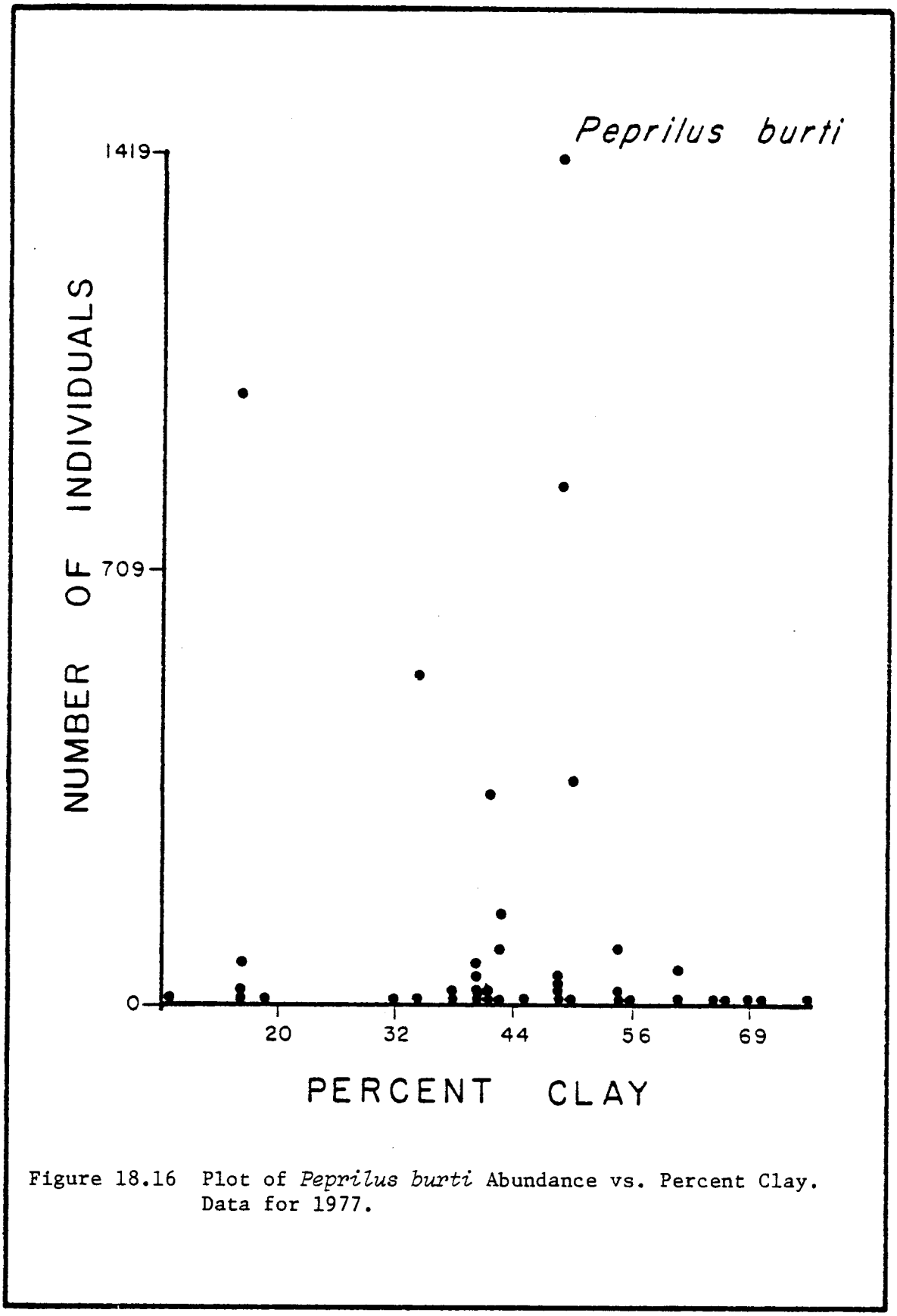

Figure 18.16 Plot of *Peprilus burti* Abundance vs. Percent Clay. Data for 1977.

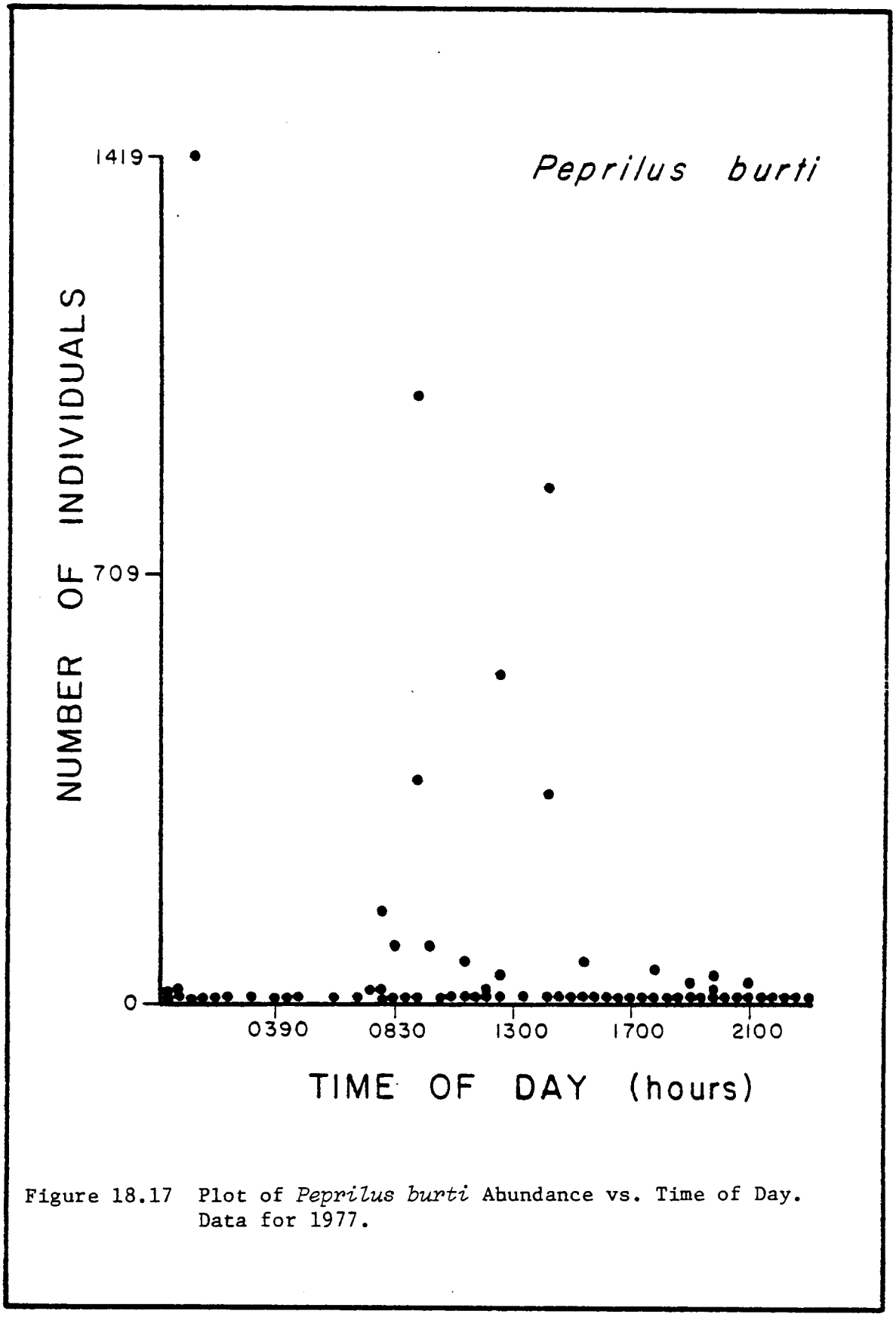

Figure 18.17 Plot of *Peprilus burti* Abundance vs. Time of Day. Data for 1977.

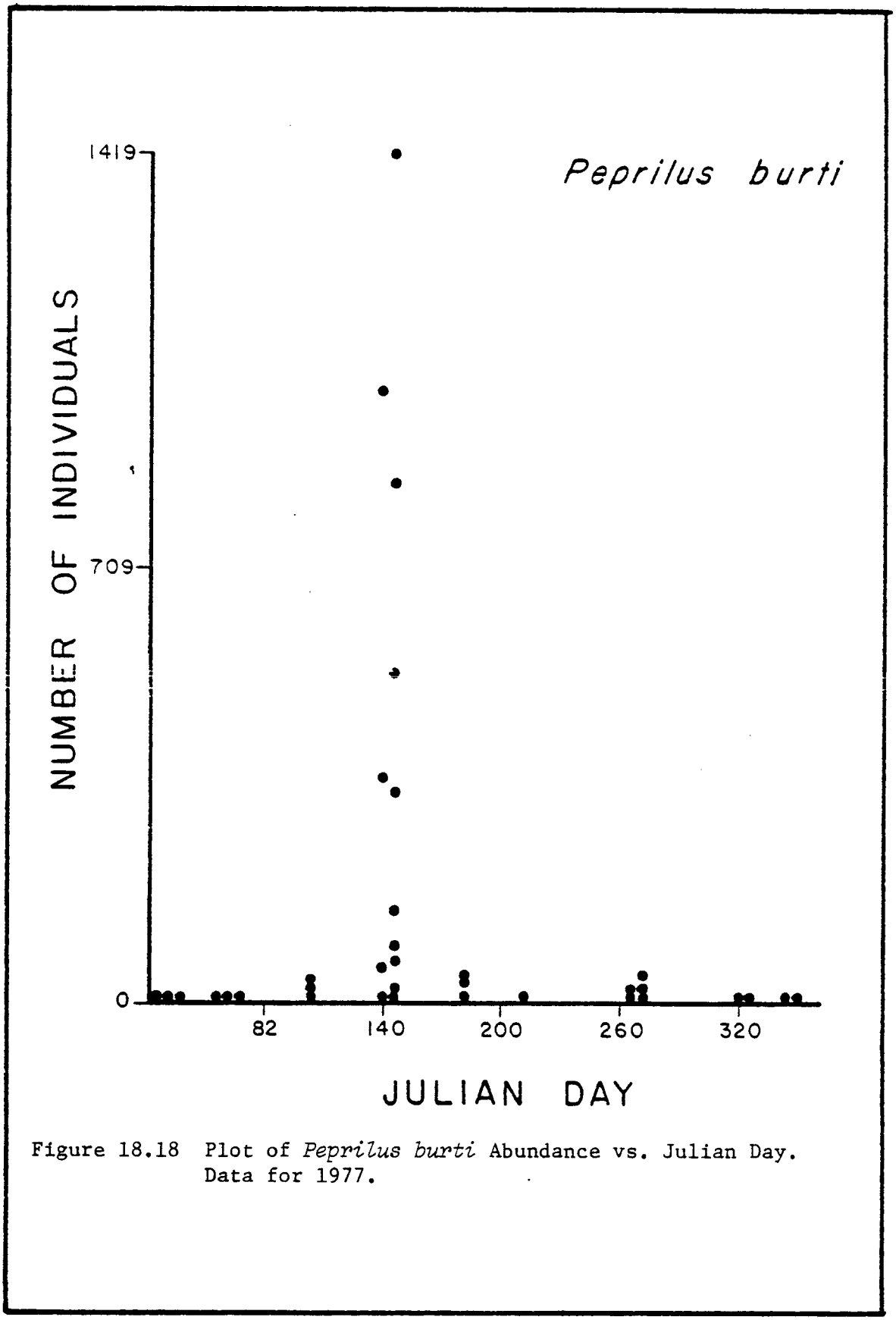

Figure 18.18 Plot of *Peprilus burti* Abundance vs. Julian Day. Data for 1977.

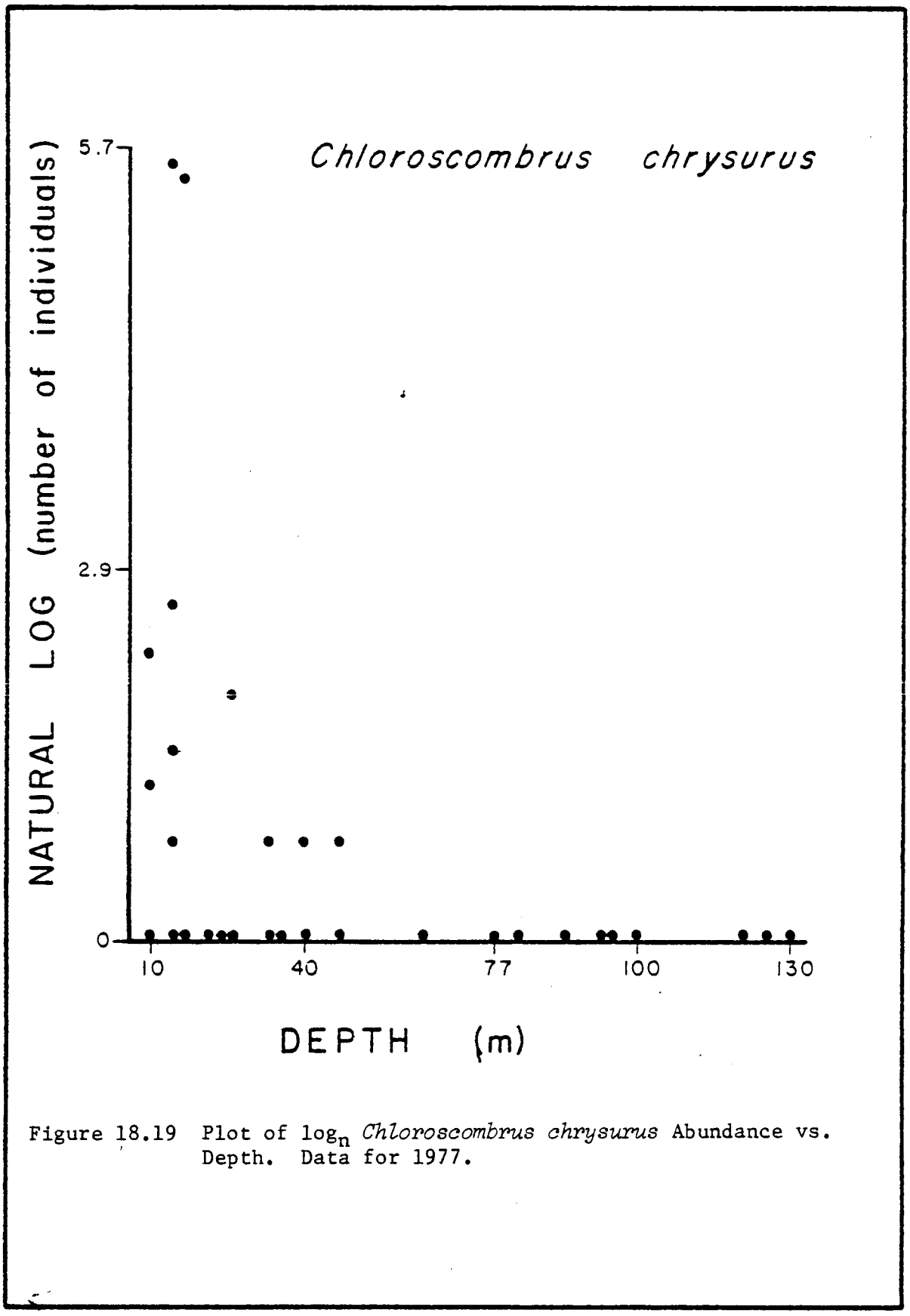

Figure 18.19 Plot of $\log_n$ *Chloroscombrus chrysurus* Abundance vs. Depth. Data for 1977.

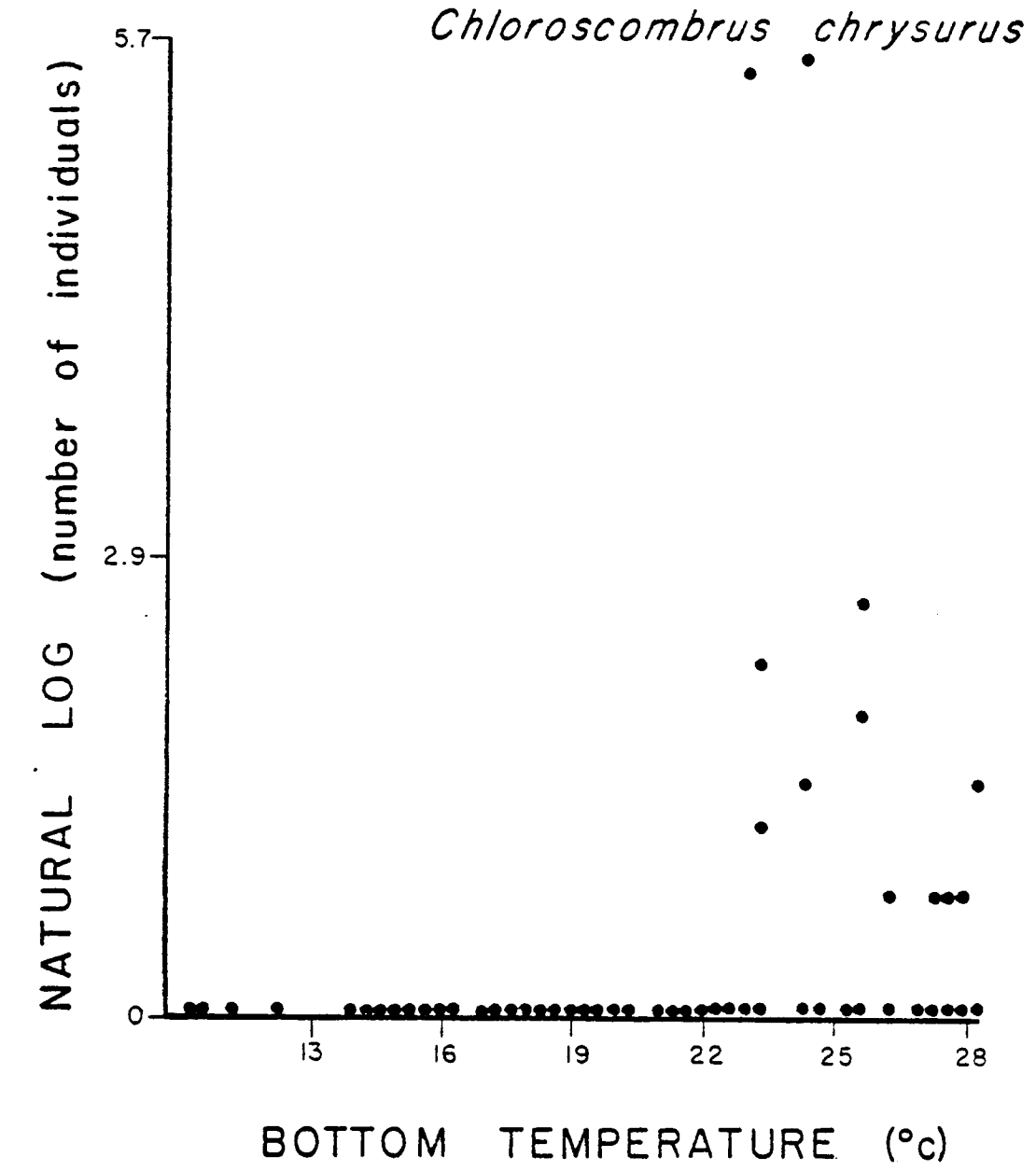

Figure 18.20 Plot of $\log_n$ *Chloroscombrus chrysurus* Abundance vs. Bottom Temperature. Data for 1977.

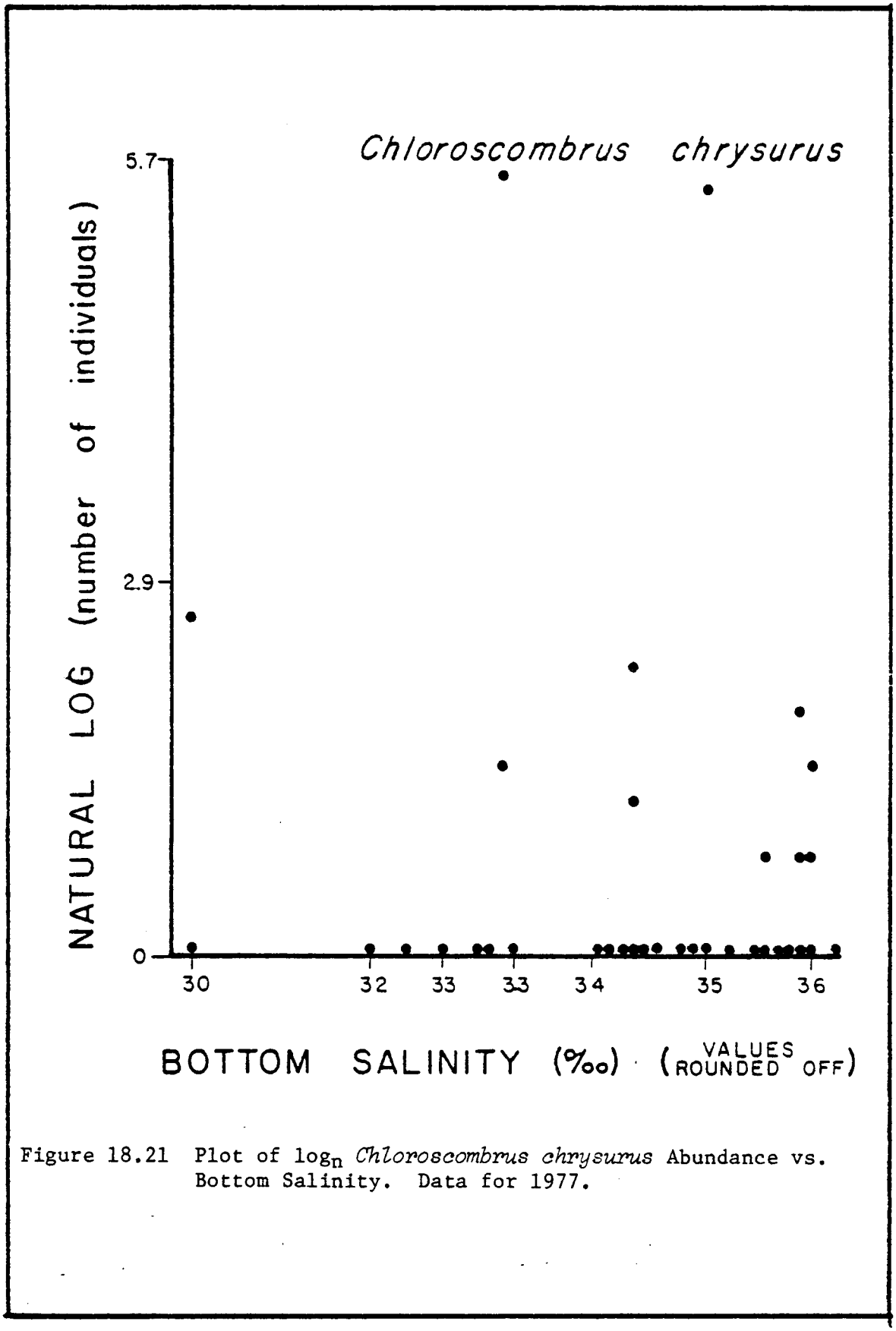

Figure 18.21 Plot of $\log_n$ *Chloroscombrus chrysurus* Abundance vs. Bottom Salinity. Data for 1977.

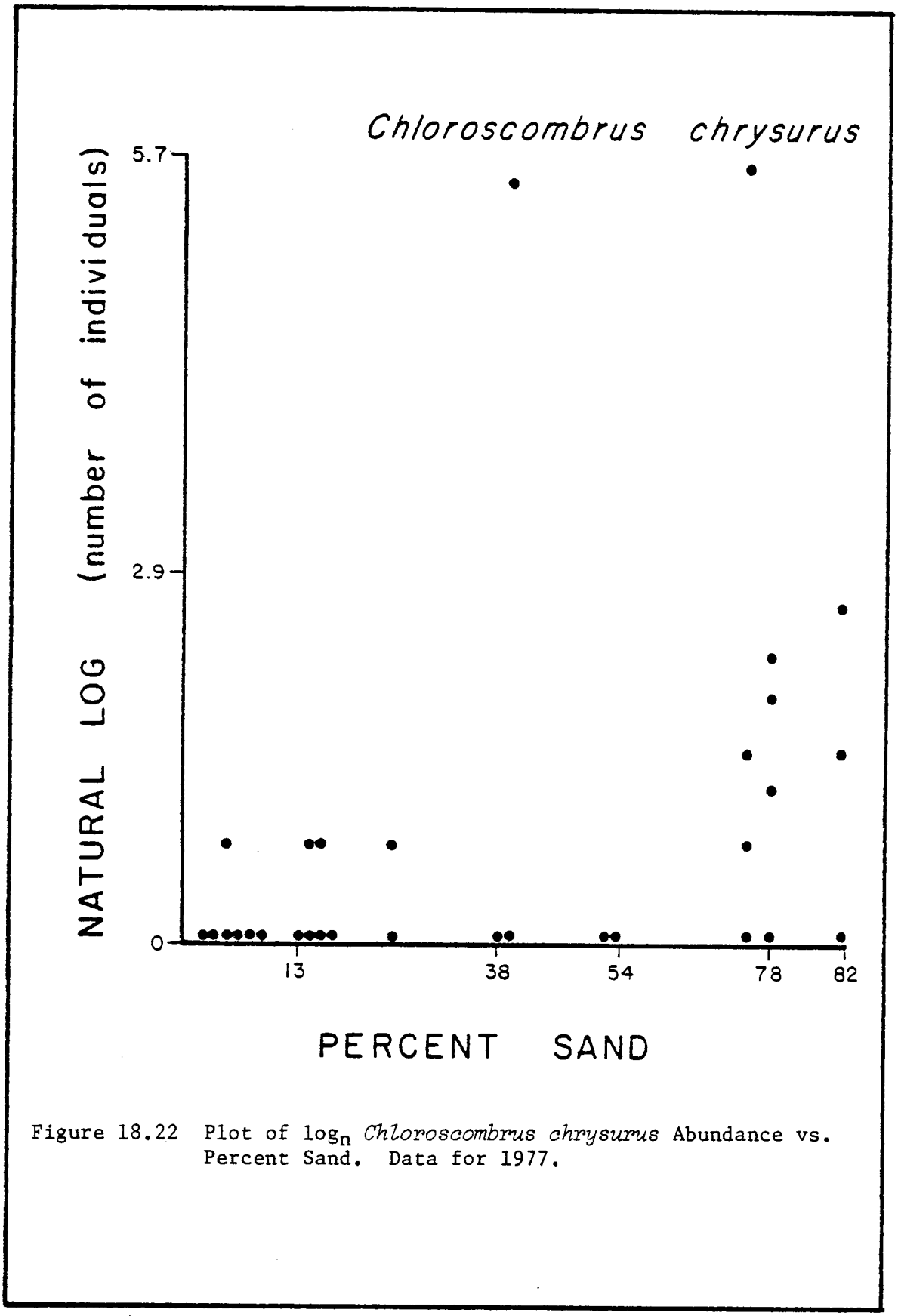

Figure 18.22 Plot of $\log_n$ *Chloroscombrus chrysurus* Abundance vs. Percent Sand. Data for 1977.

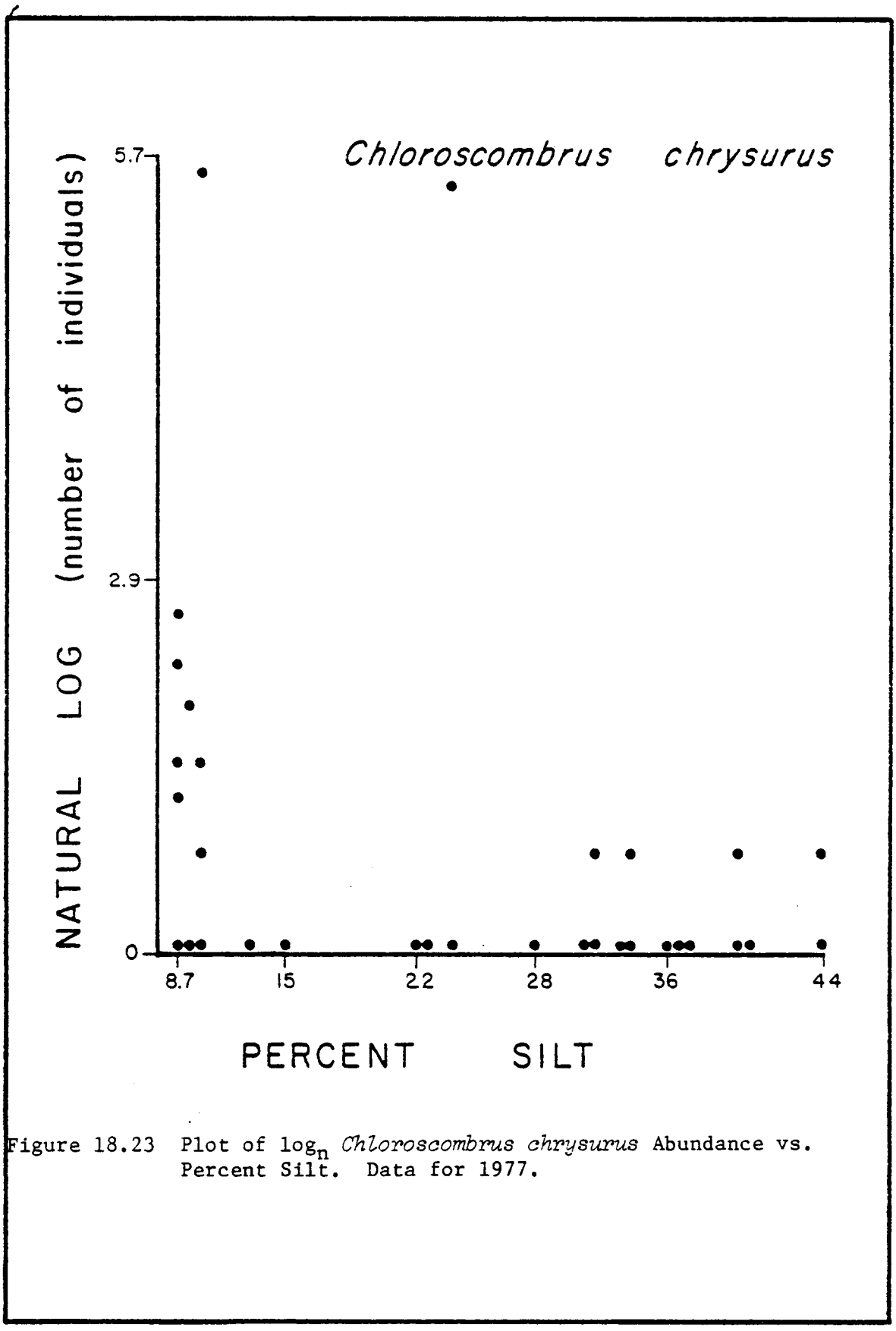

Figure 18.23 Plot of $\log_n$ *Chloroscombrus chrysurus* Abundance vs. Percent Silt. Data for 1977.

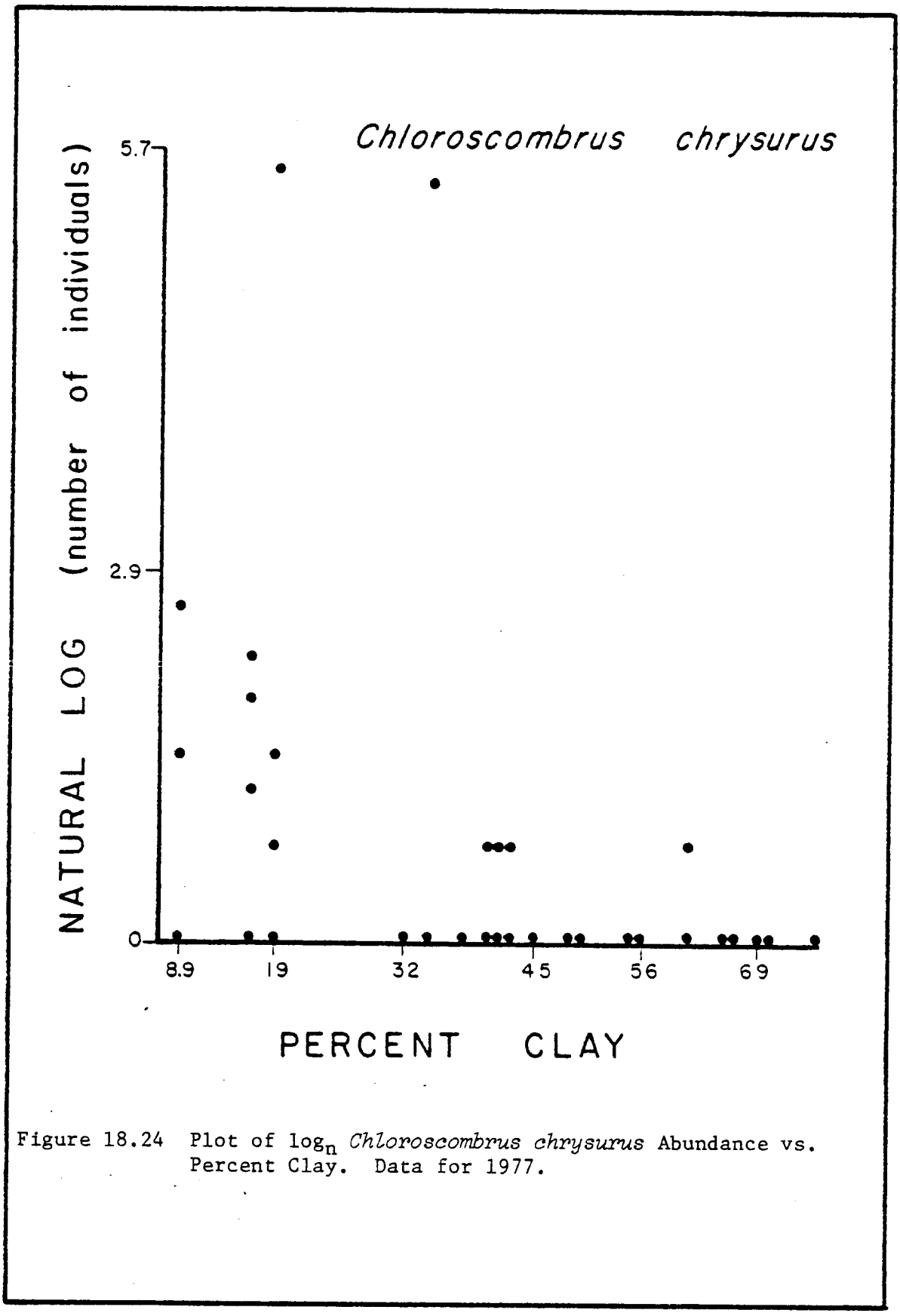

Figure 18.24 Plot of $\log_n$ *Chloroscombrus chrysurus* Abundance vs. Percent Clay. Data for 1977.

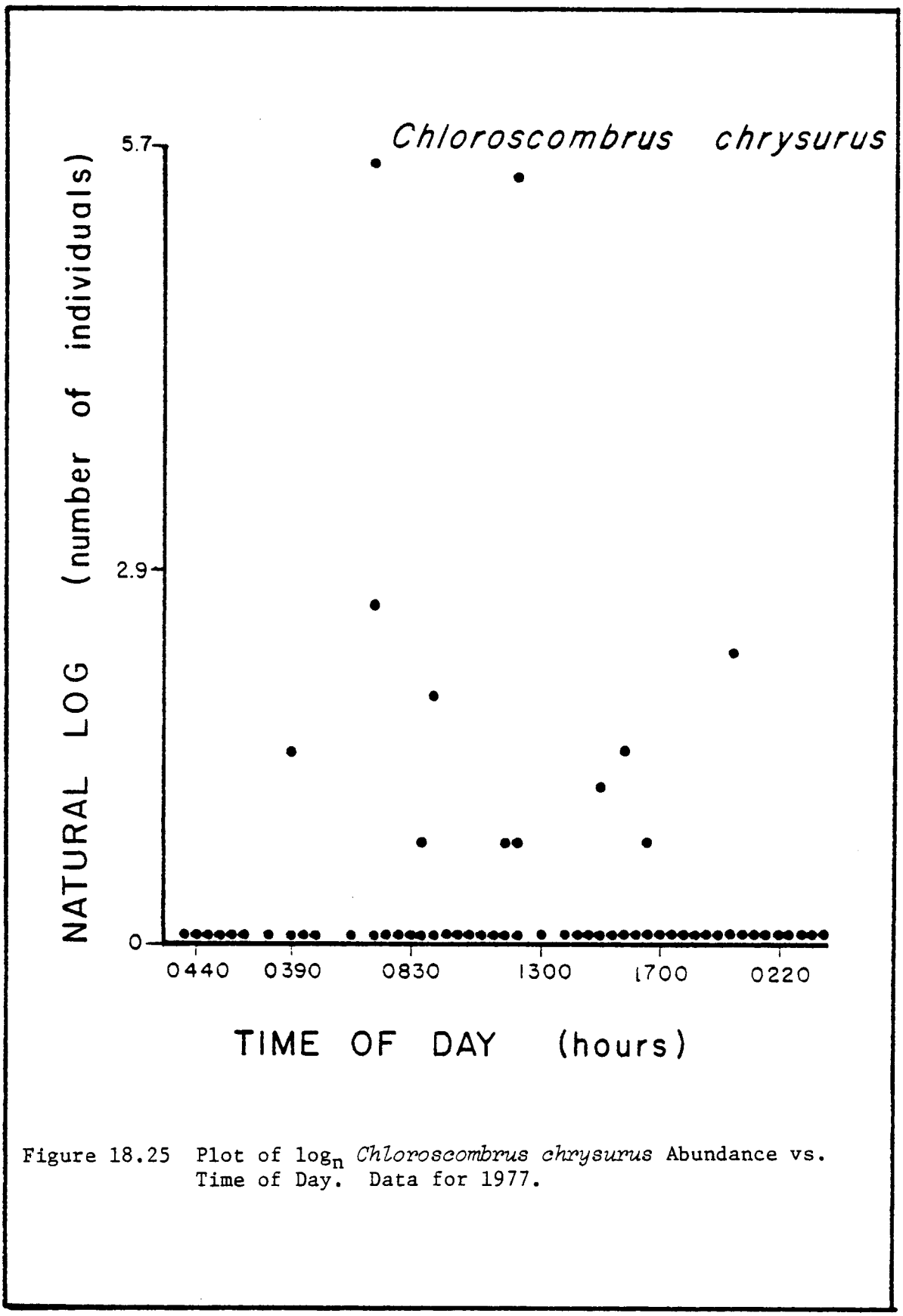

Figure 18.25 Plot of $\log_n$ *Chloroscombrus chrysurus* Abundance vs. Time of Day. Data for 1977.

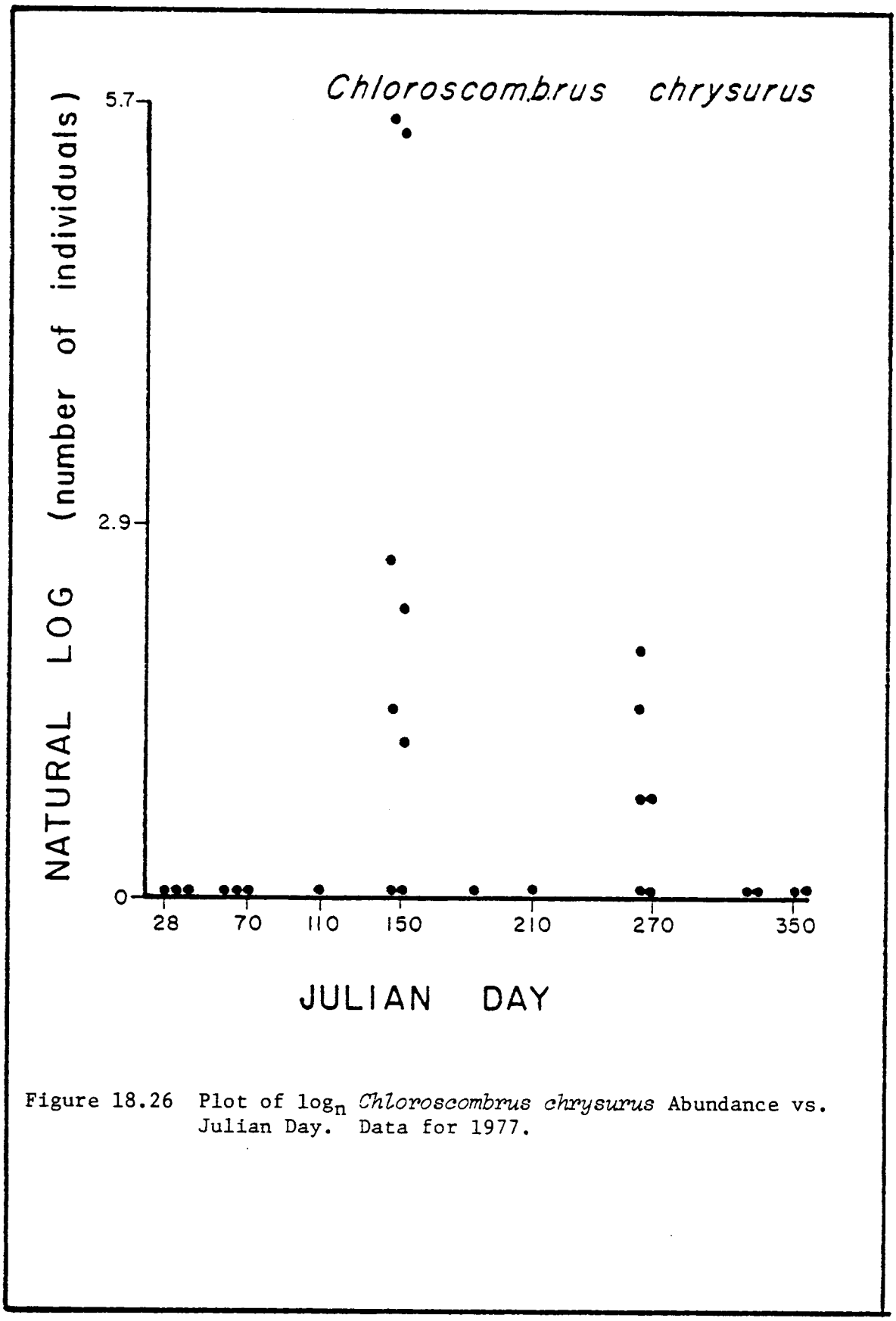

Figure 18.26 Plot of $\log_n$ *Chloroscombrus chrysurus* Abundance vs. Julian Day. Data for 1977.

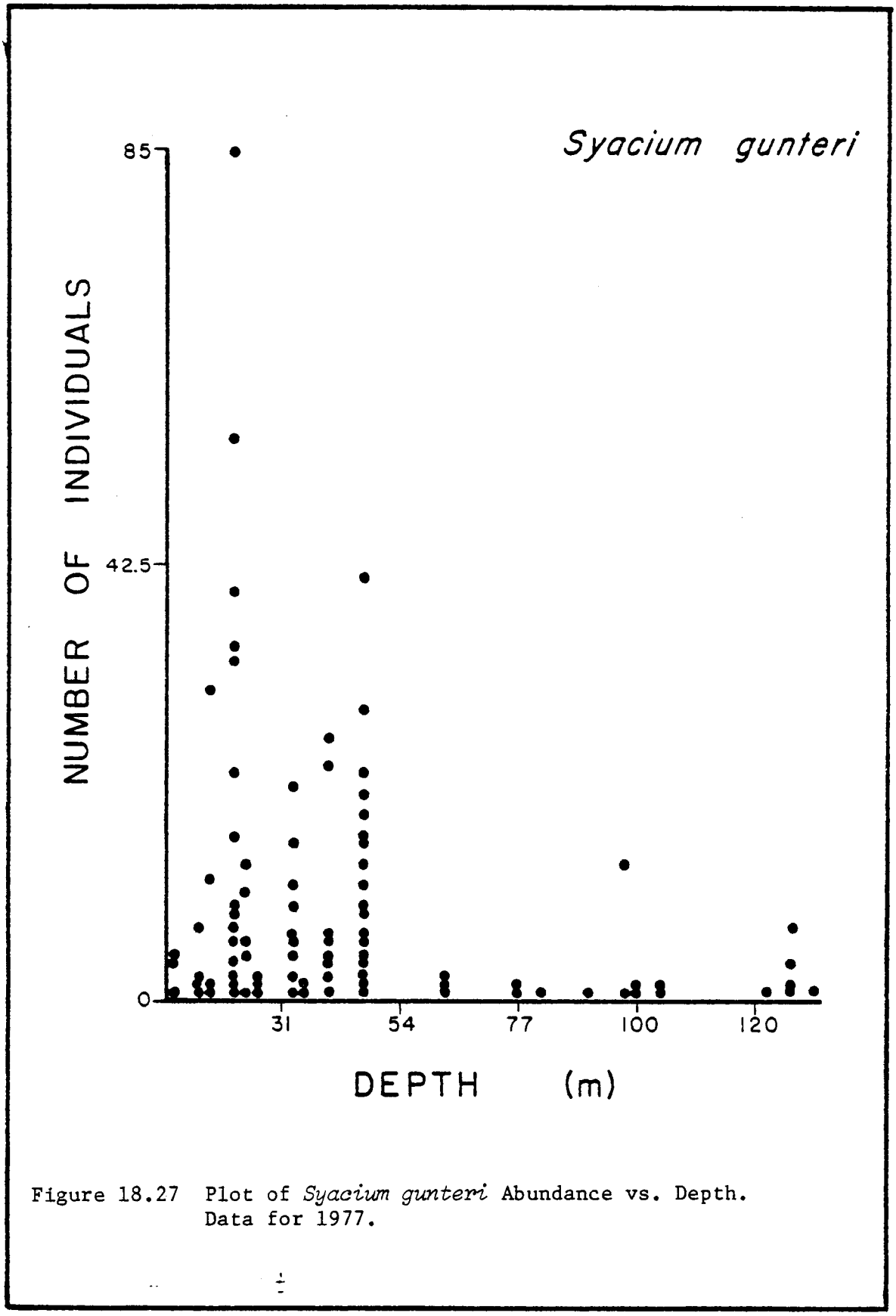

Figure 18.27 Plot of *Syacium gunteri* Abundance vs. Depth. Data for 1977.

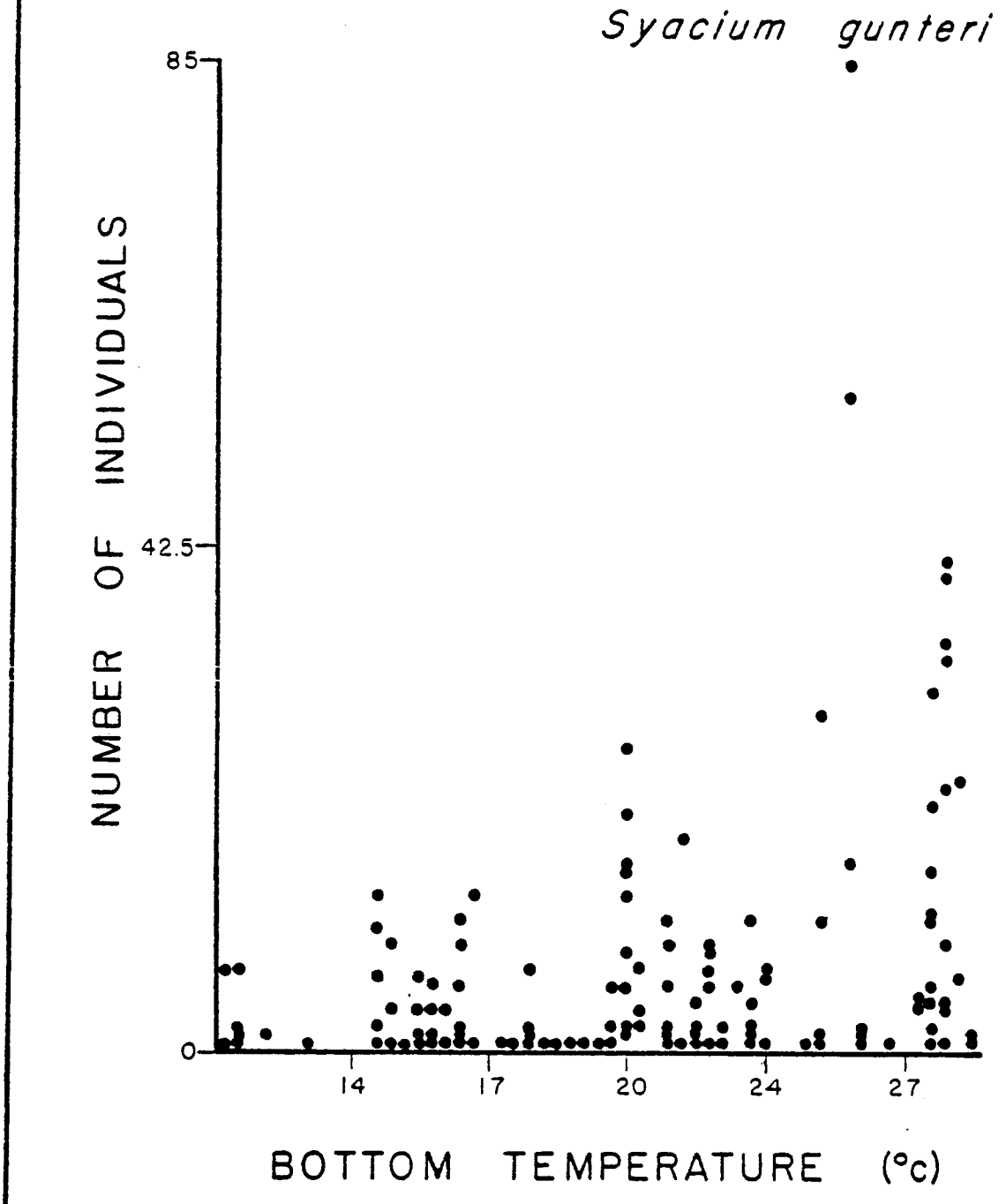

Figure 18.28 Plot of *Syacium gunteri* Abundance vs. Bottom Temperature. Data for 1977.

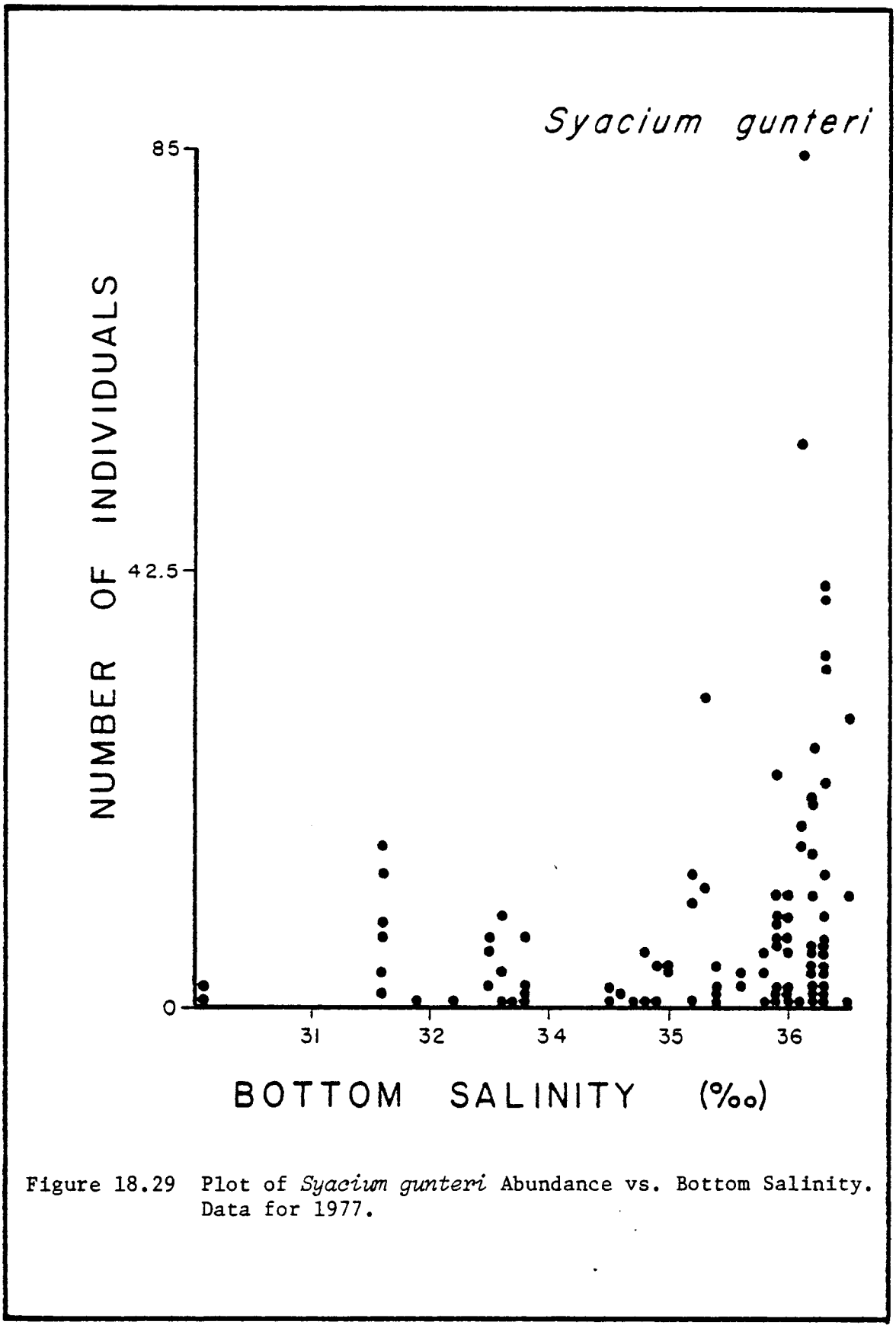

Figure 18.29 Plot of *Syacium gunteri* Abundance vs. Bottom Salinity. Data for 1977.

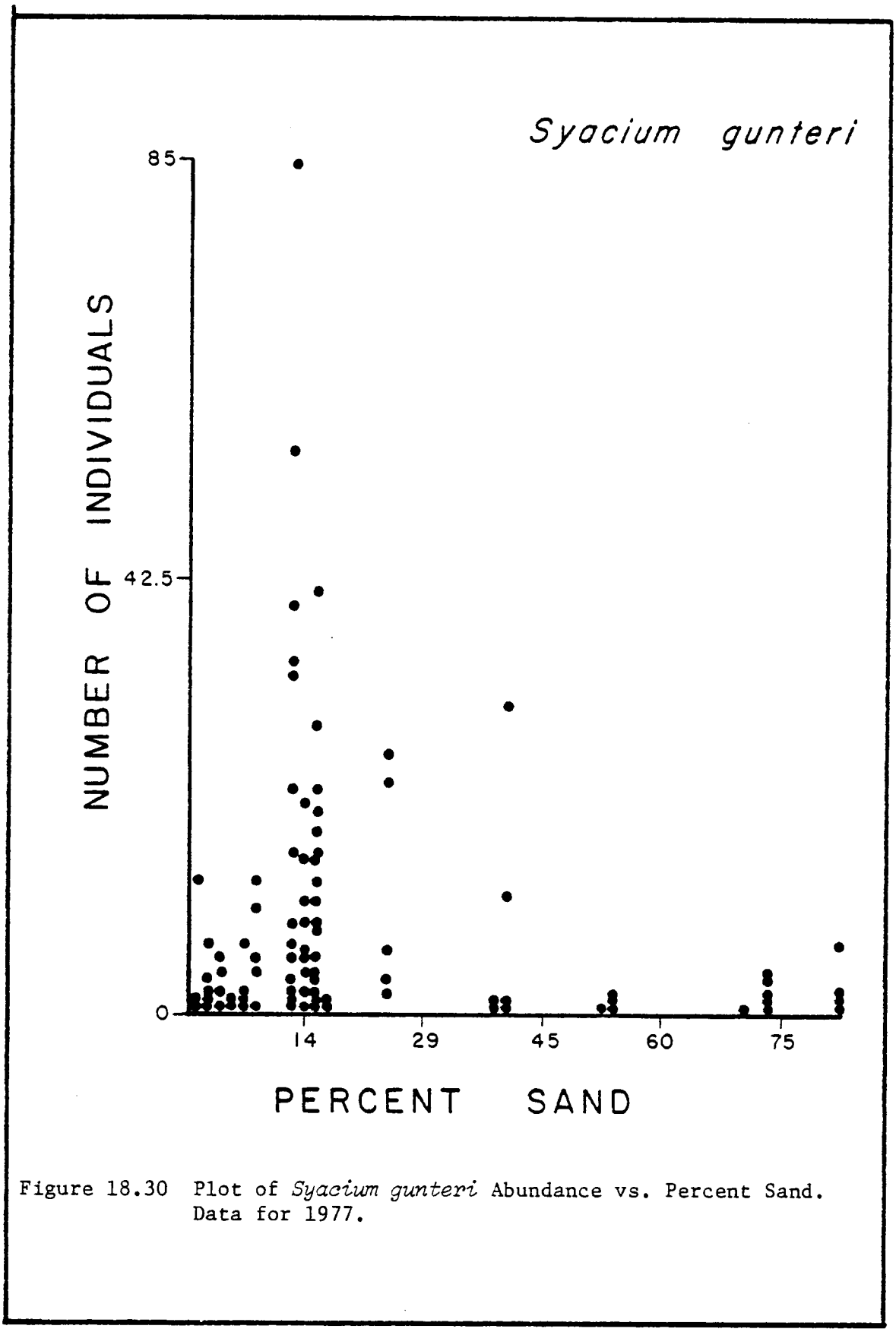

Figure 18.30 Plot of *Syacium gunteri* Abundance vs. Percent Sand. Data for 1977.

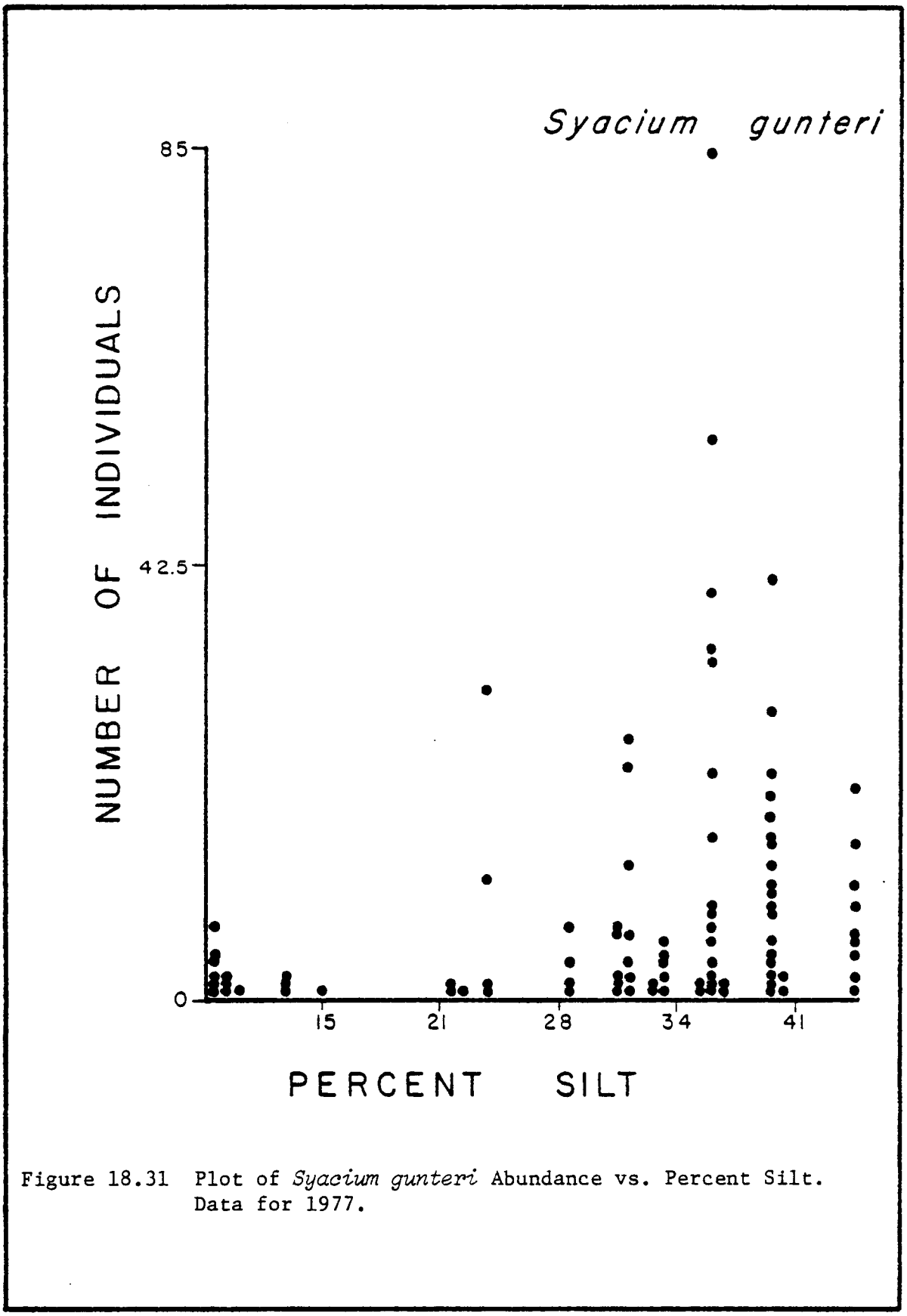

Figure 18.31 Plot of *Syacium gunteri* Abundance vs. Percent Silt. Data for 1977.

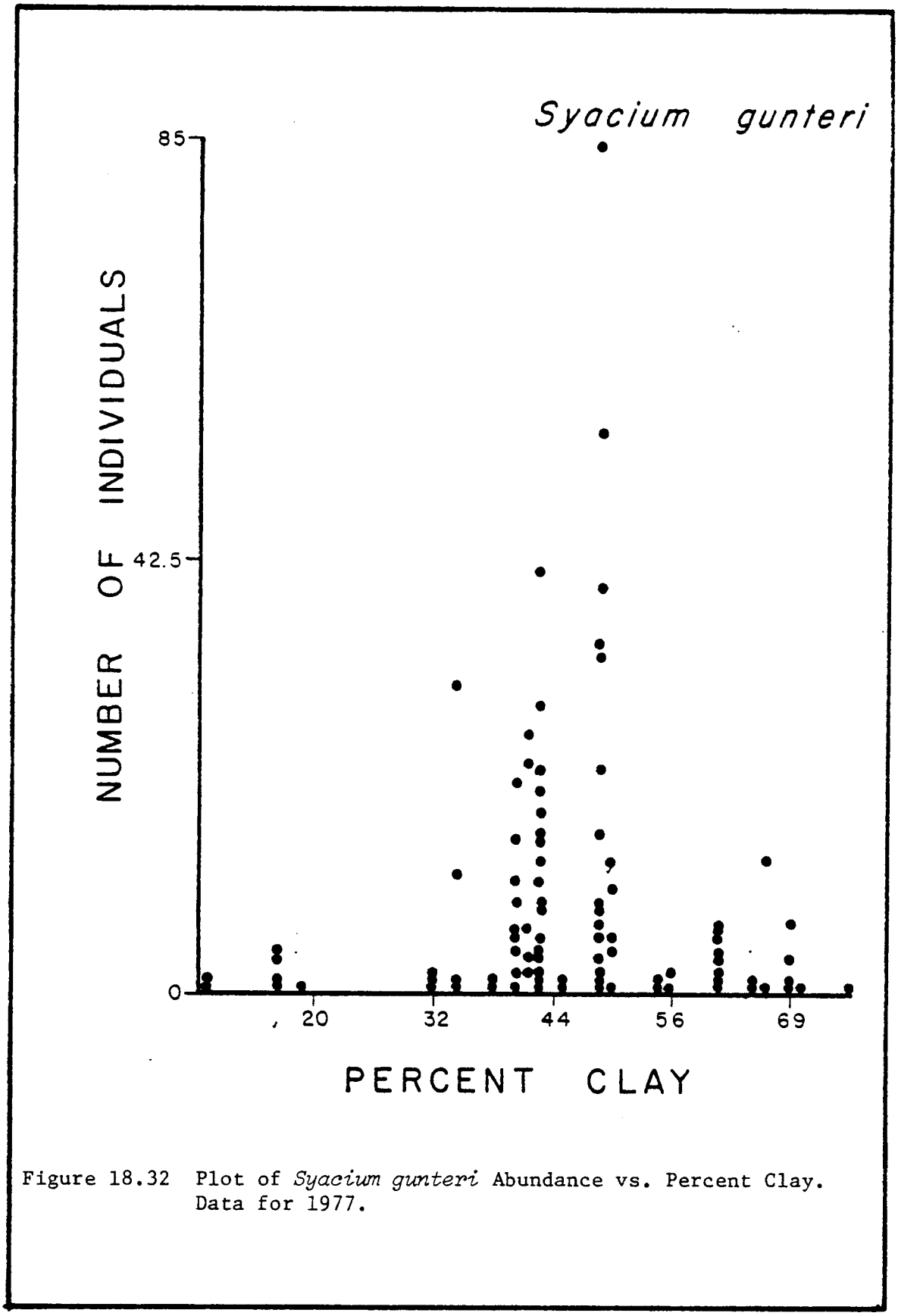

Figure 18.32 Plot of *Syacium gunteri* Abundance vs. Percent Clay. Data for 1977.

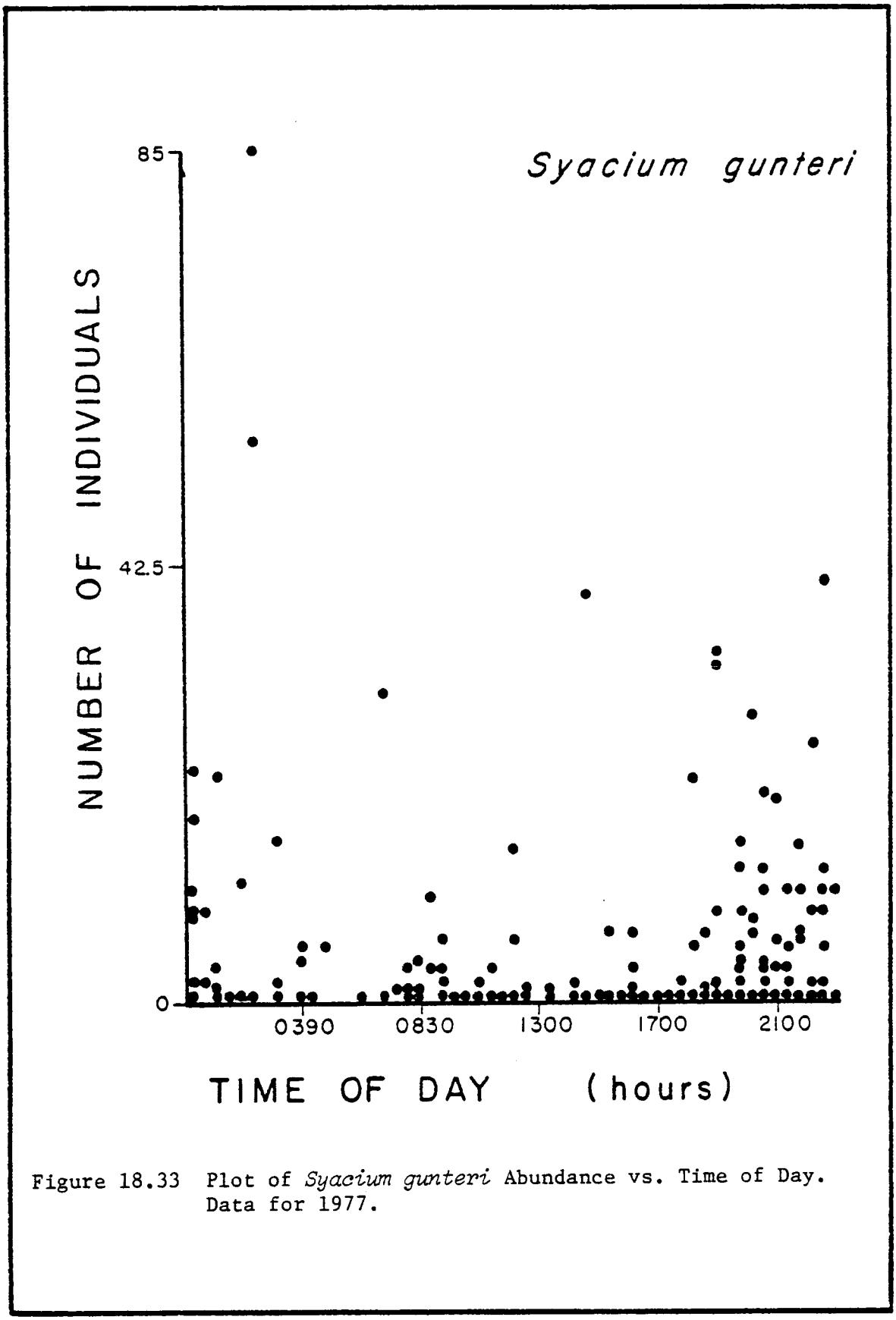

Figure 18.33 Plot of *Syacium gunteri* Abundance vs. Time of Day. Data for 1977.

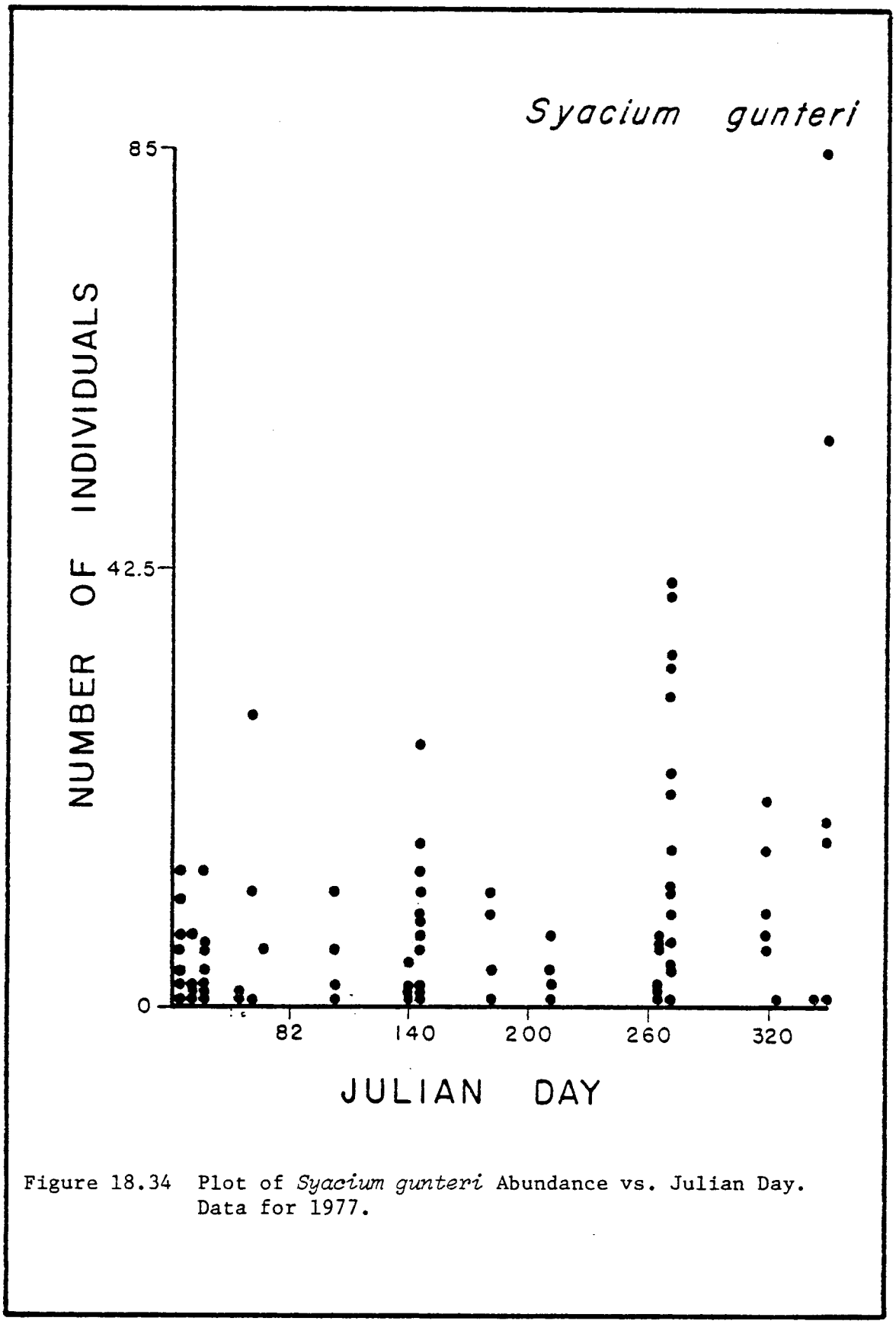

Figure 18.34 Plot of *Syacium gunteri* Abundance vs. Julian Day. Data for 1977.

years 1975, 1976 and 1977 in Figures 18.35 to 18.43. It can be seen that the highest abundances and frequencies of captures occurred in the 17-29°C temperature range in 1975, within the 18-28°C range in 1976, and the 26-28°C range in 1977. Highest abundances and frequencies of captures occurred in the salinity ranges ~ 29.5 - 37 ppt in 1975, ~ 32.5 - 36.5 ppt in 1976, and ~ 36.5 - 37 ppt in 1977. The sediment composition which corresponded to the highest abundances and frequencies of capture of *L. campechanus* ranged from 1-70% sand in 1975, 10-75% sand in 1976 and 14-72% sand in 1977. It was evident that noticeable differences in the presumably preferred ranges of various physical parameters existed (*e.g.* percent sand composition of the sediment). The message which emerges is that statements on the preferred ranges of various physical variables for the different species which are based on data from a single year must be viewed only as approximations.

That the preferred ranges of certain variables differ between years is possibly an indication that the manner in which these variables affect the abundance of some species may be influenced by the action of other variables, which themselves differ between years. Of course, it may also be that some variables are simply unimportant to a particular species, and plots of the abundance of the species against these variables would not necessarily be expected to show consistency between years. If it is assumed, however, that most of the factors chosen for study do have at least some effect on the abundance of fishes, it becomes of interest to determine just how these factors interact in influencing fish abundances. It is expected that in some cases these interactions between variables are complex and subtle, and there are certainly correlations between a number of variables. Techniques for studying the interactions between factors and their effects on the abundances of species are presently

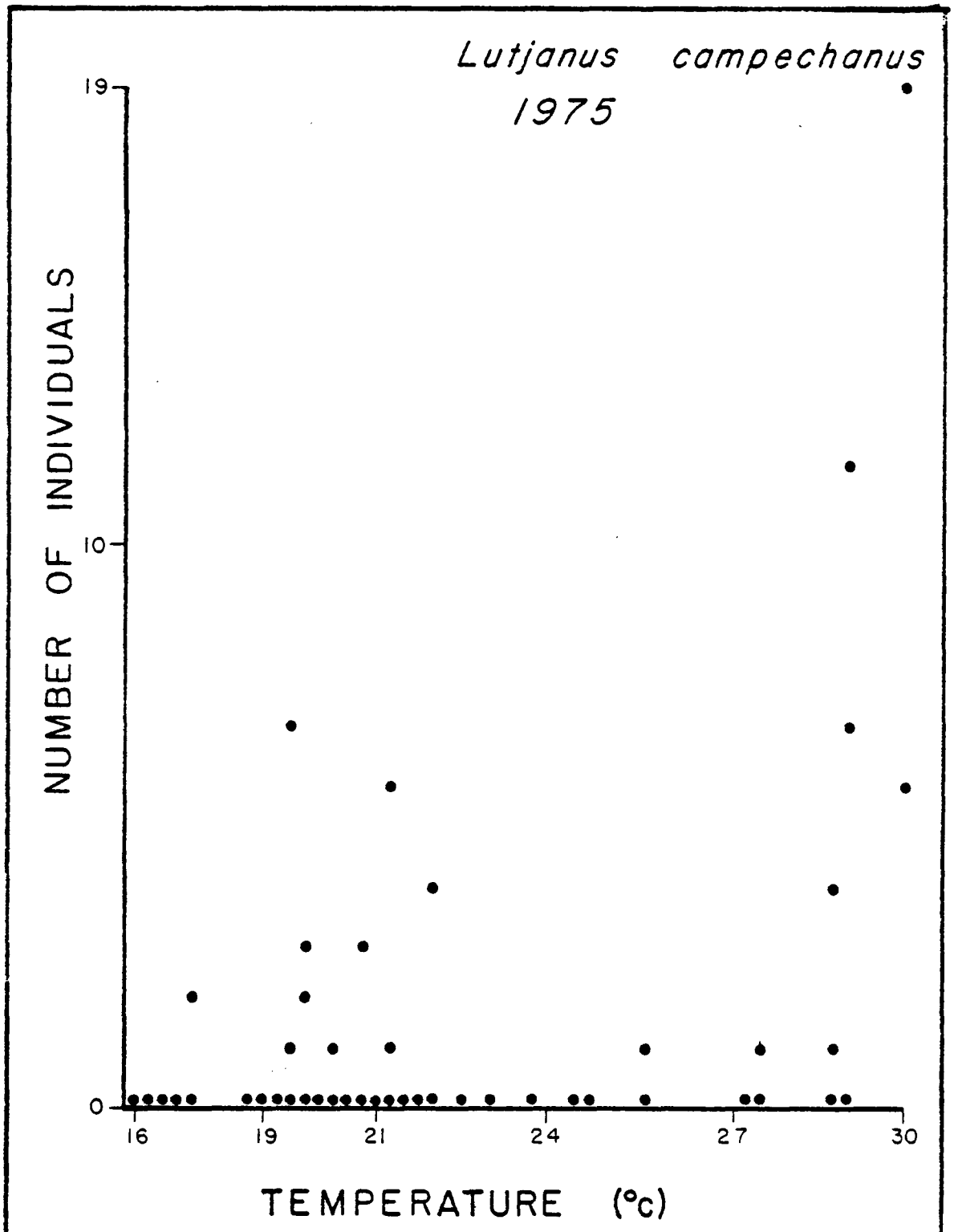

Figure 18.35 Plot of *Lutjanus campechanus* Abundance vs. Temperature. Data for 1975.

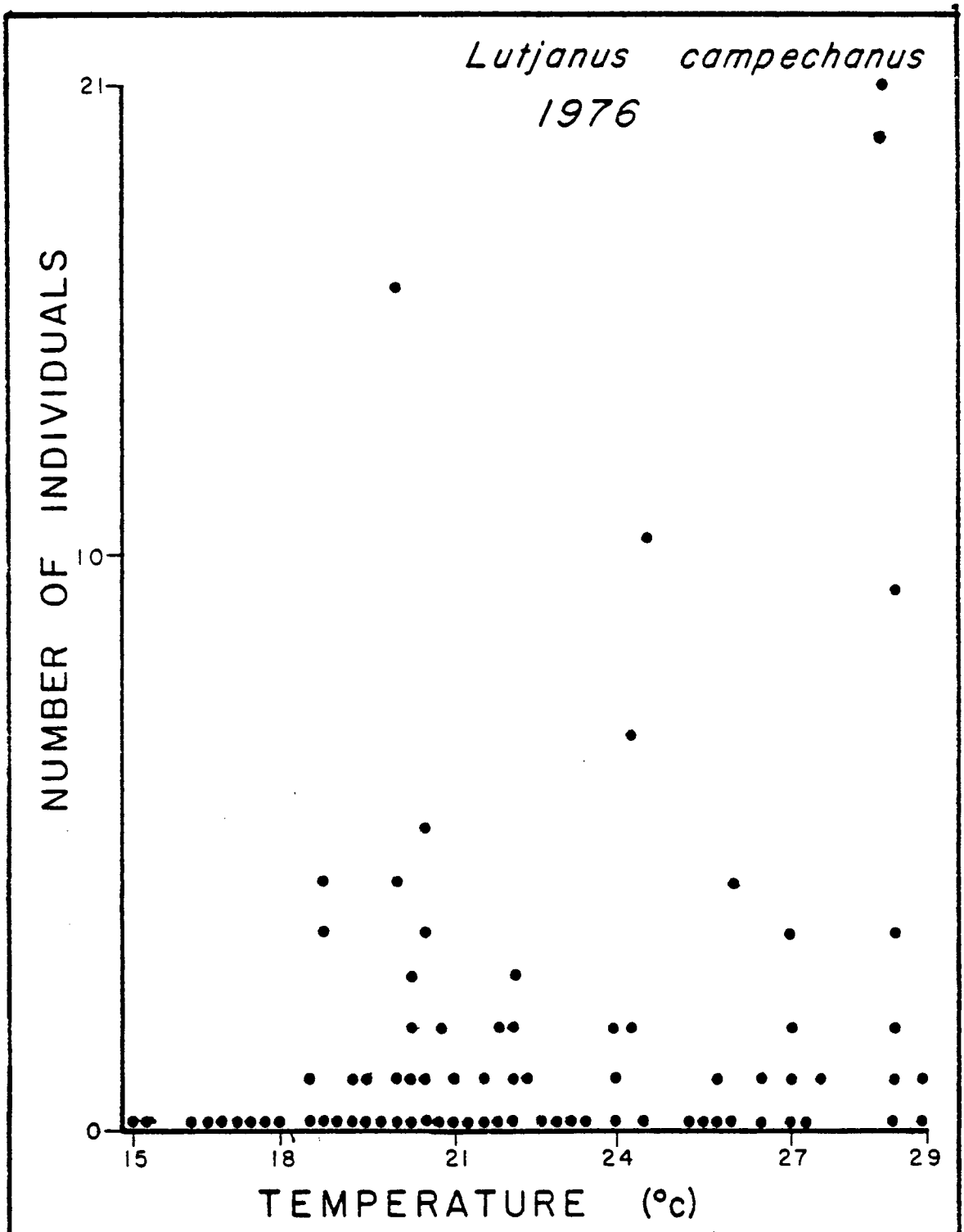

Figure 18.36 Plot of *Lutjanus campechanus* Abundance vs. Temperature. Data for 1976.

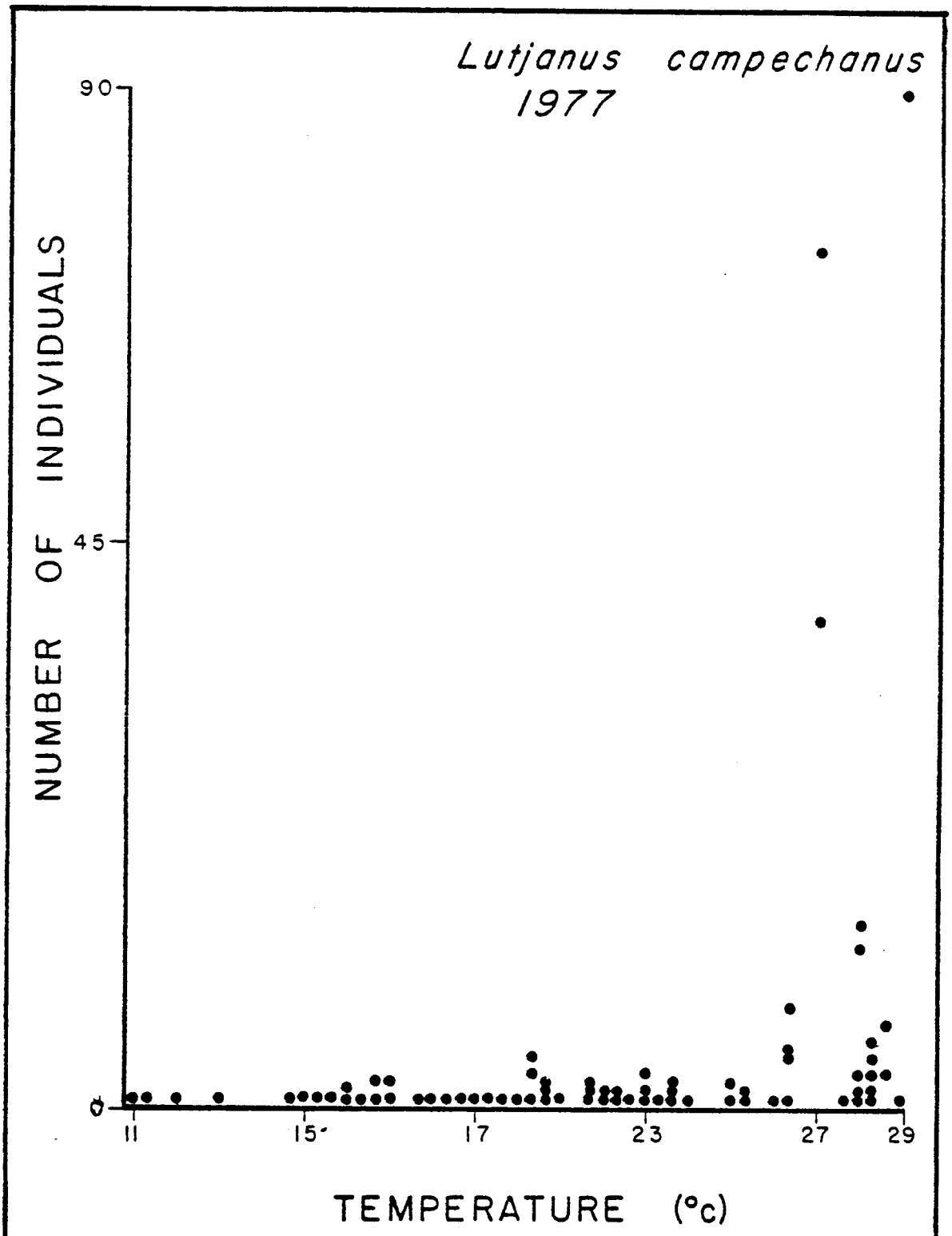

Figure 18.37 Plot of *Lutjanus campechanus* Abundance vs. Temperature. Data for 1977.

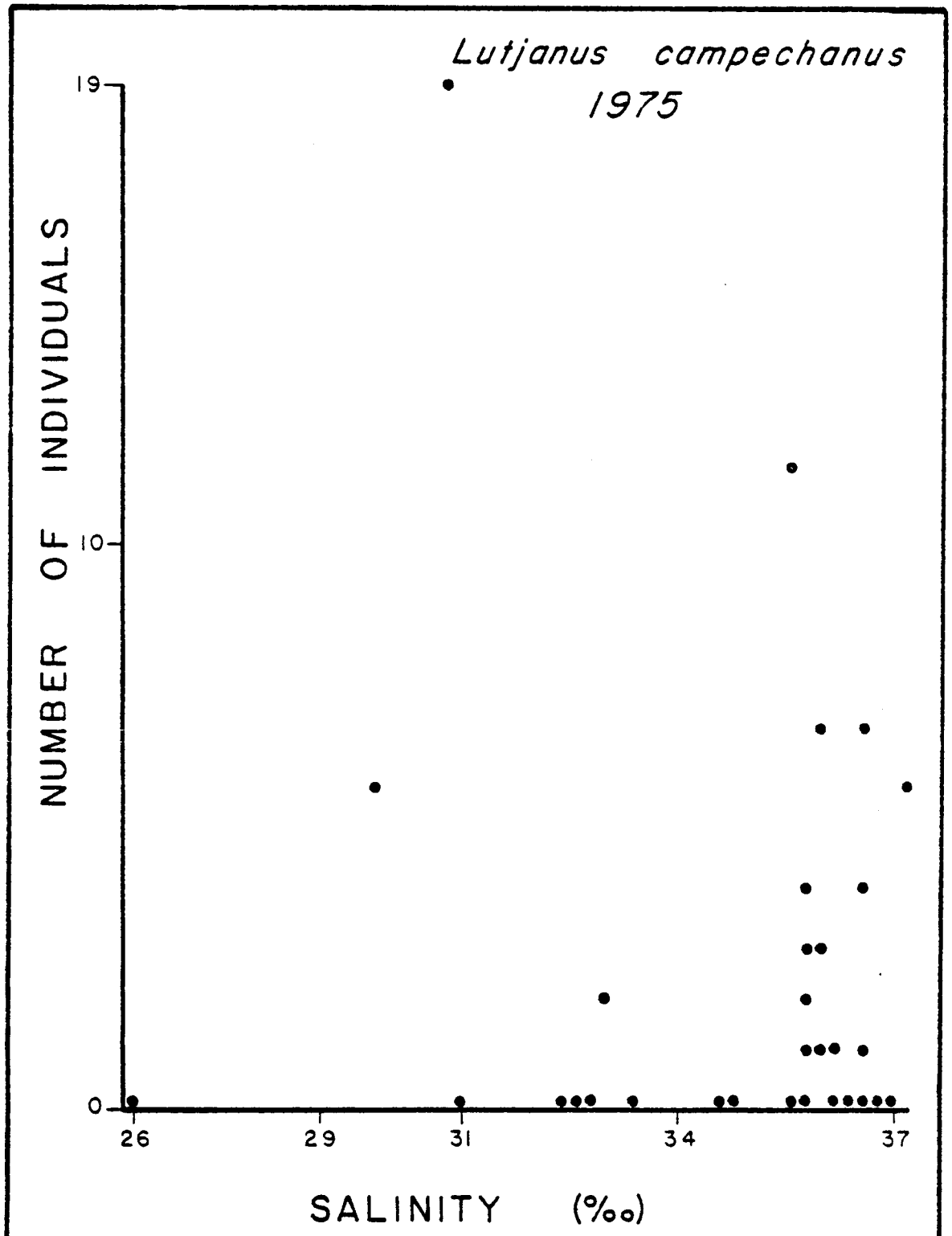

Figure 18.38 Plot of *Lutjanus campechanus* Abundance vs. Salinity. Data for 1975.

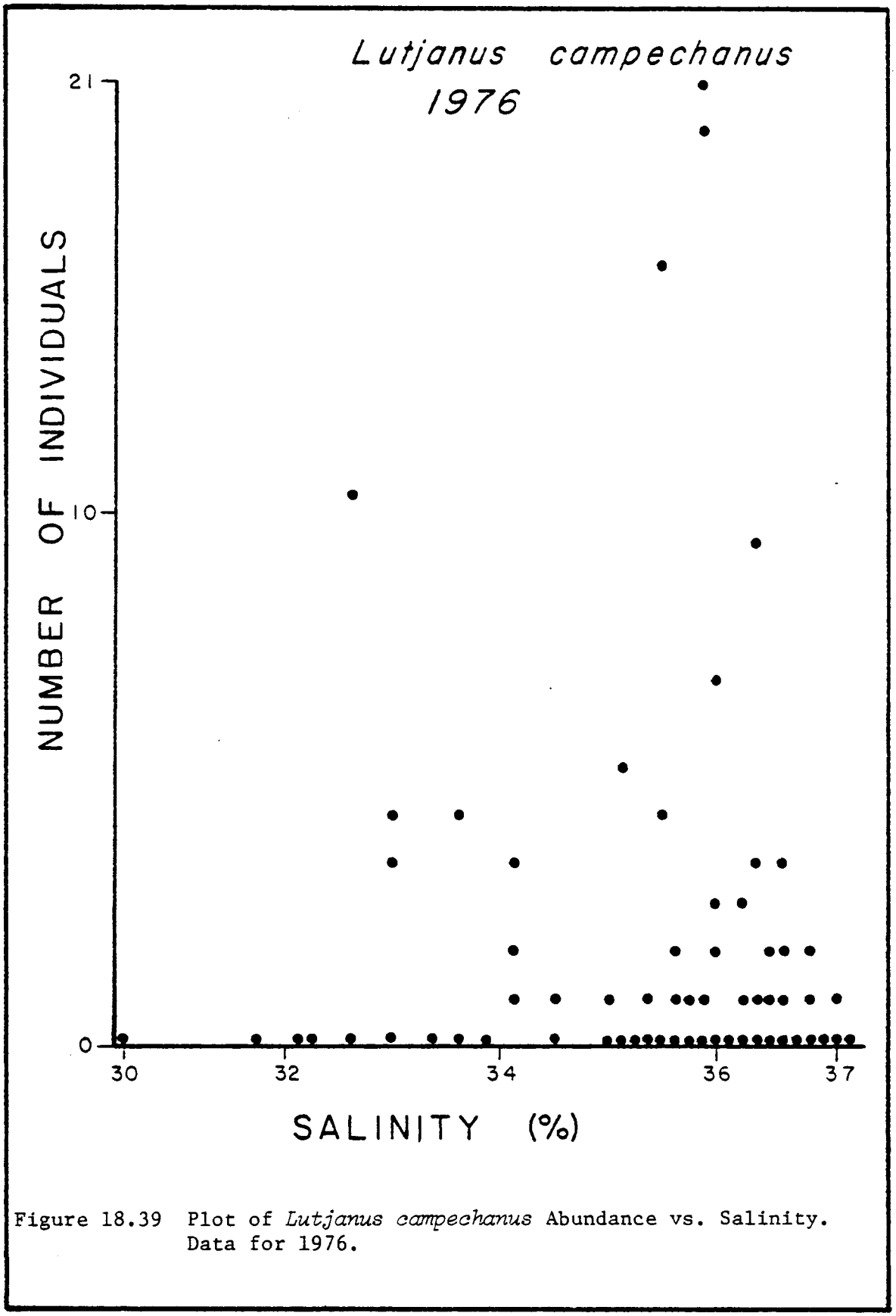

Figure 18.39 Plot of *Lutjanus campechanus* Abundance vs. Salinity. Data for 1976.

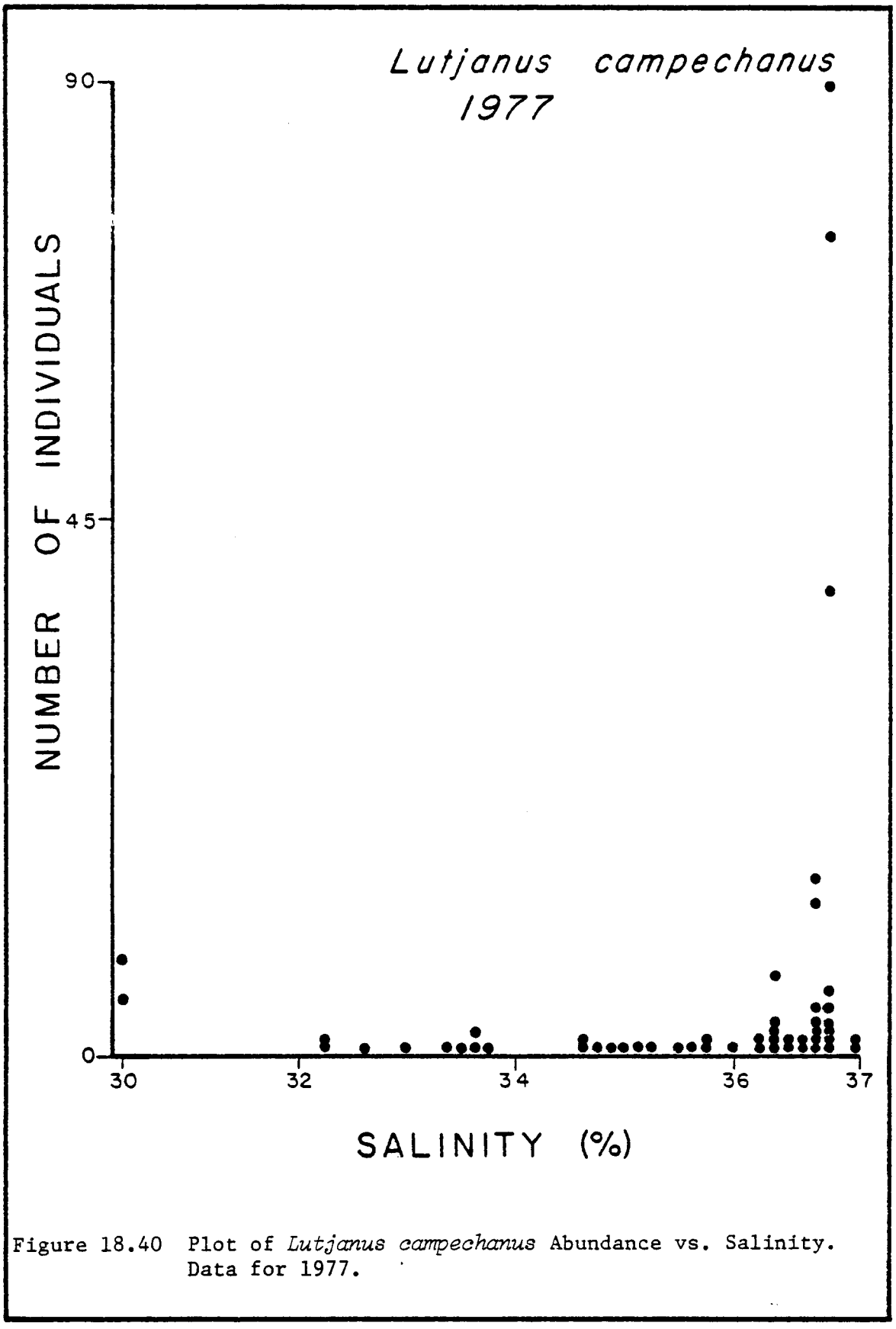

Figure 18.40 Plot of *Lutjanus campechanus* Abundance vs. Salinity. Data for 1977.

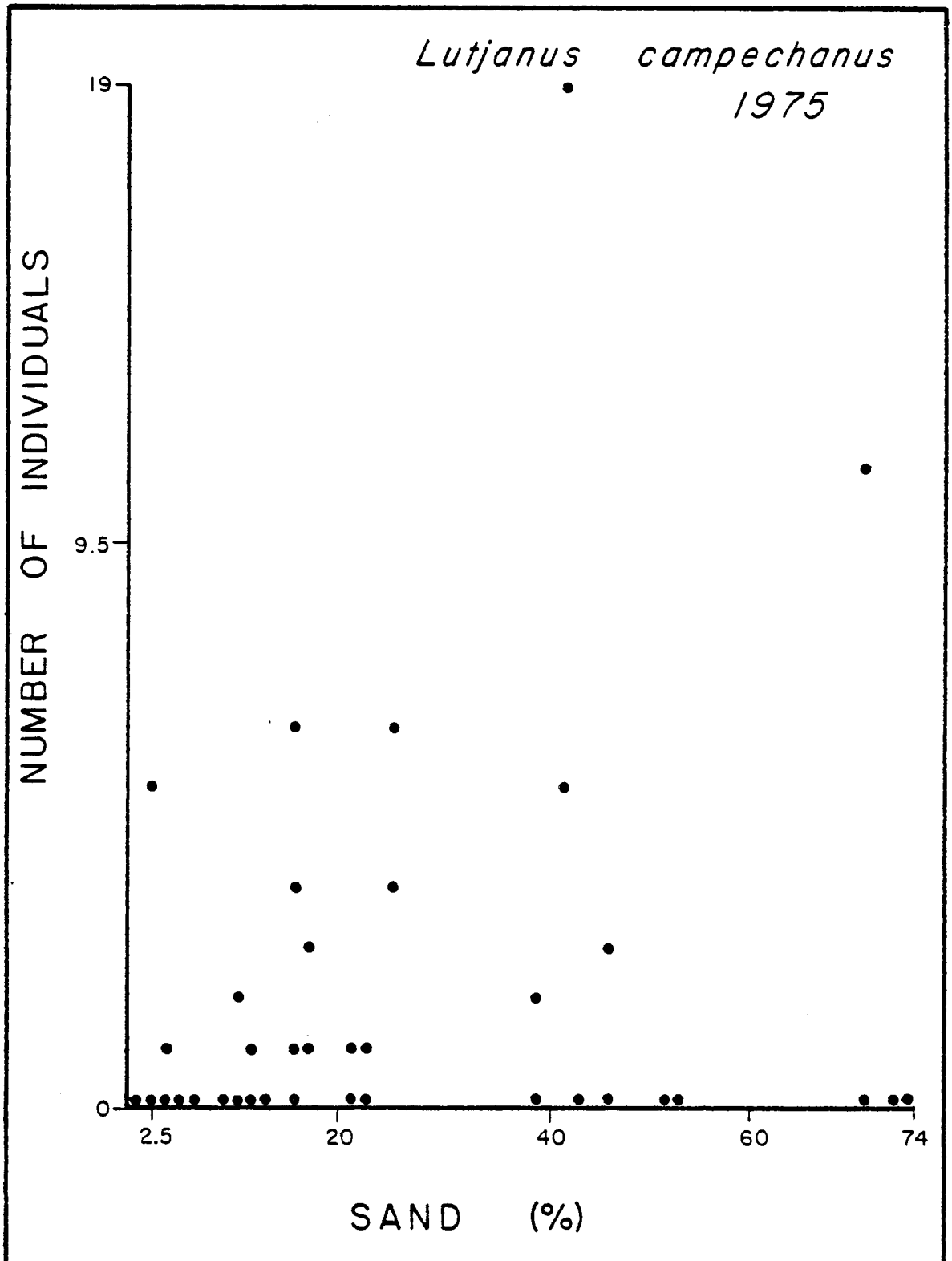

Figure 18.41 Plot of *Lutjanus campechanus* Abundance vs. Sand. Data for 1975.

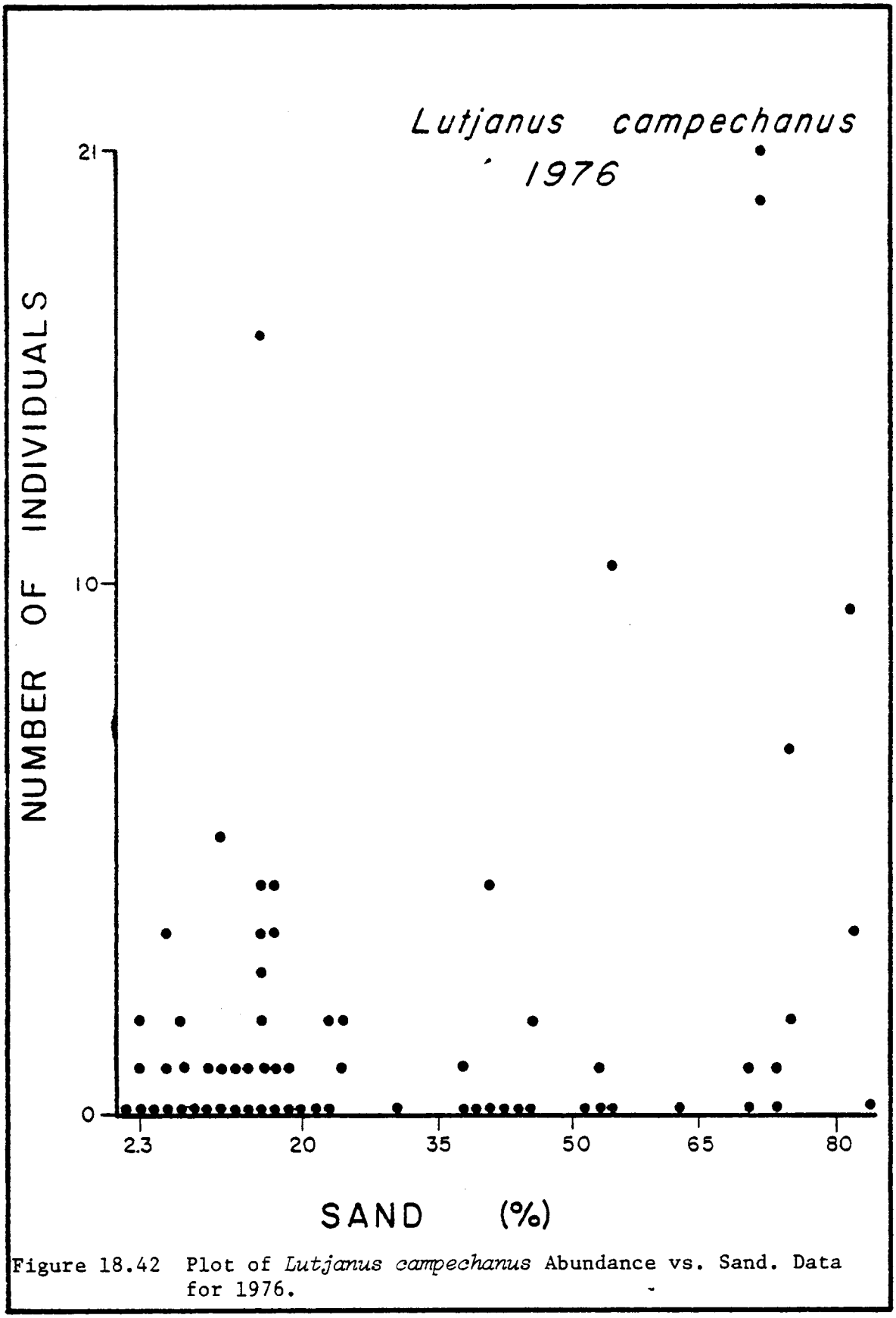

Figure 18.42 Plot of *Lutjanus campechanus* Abundance vs. Sand. Data for 1976.

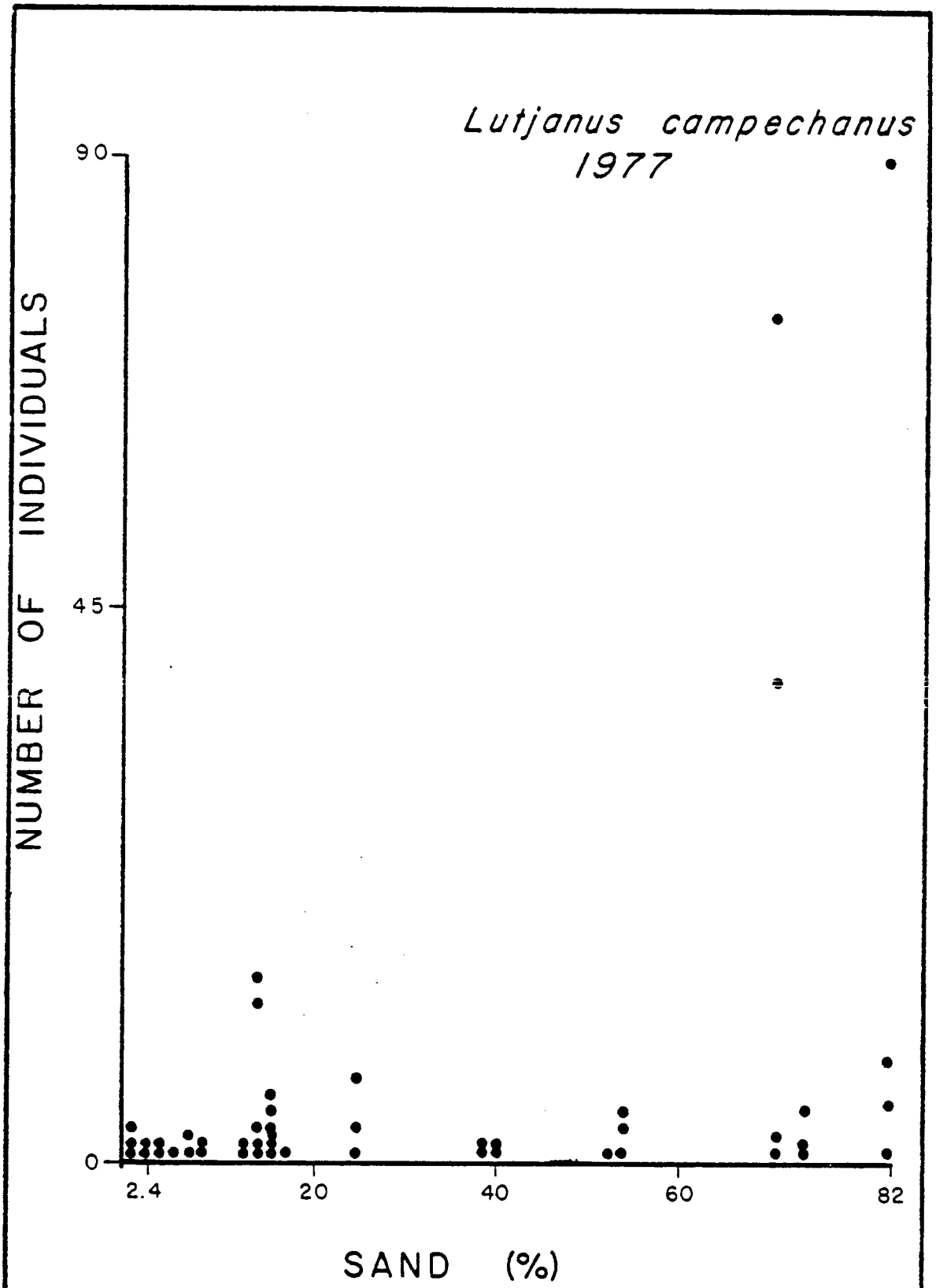

Figure 18.43 Plot of *Lutjanus campechanus* Abundance vs. Sand. Data for 1977.

under study and it is planned that these techniques will be applied to the data on demersal fishes.

Data from all three years of sampling of the BLM-STOCS program can be combined to construct plots of fish abundance against values of physical variables. This was done for *Lutjanus campechanus*, and representative plots for temperature, salinity and percent sand composition of the sediment are given in Figures 18.44 to 18.46. These plots of three years of data are of course more accurate in displaying the correlative relationships between fish abundance and physical variables than are plots based only on a single year's data. We plan to construct more of these plots for all of the major fish species that have been encountered.

It has been recognized by several workers on Gulf fishes (Gunter, 1945; Wohlschlag, *In* Groover, 1977) that some differences in spatial distribution exist between sizes of certain species. These differences in distribution presumably reflect differences between sizes of fish in the preferred range of various physical parameters. With this in mind, a number of major species encountered in this study were divided into size classes and their abundances plotted against values of selected variables. *Lutjanus campechanus* has again been used as an example, and plots of abundance versus temperature, salinity, percent sand composition of the sediment, time of day and Julian day are shown for two size classes ($\leq$ 30 grams and > 30 grams) of this species in Figures 18.47 to 18.58. (These plots are based on the combined 1975, 1976 and 1977 data.)

It was apparent from comparison of the corresponding plots for the two size classes of *L. campechanus* that small ($\leq$ 30 gram) fish occurred exclusively in water depths of 50 m while larger individuals (> 30 grams) showed a broader distribution, ranging from 15 to 97 m. Small fish had

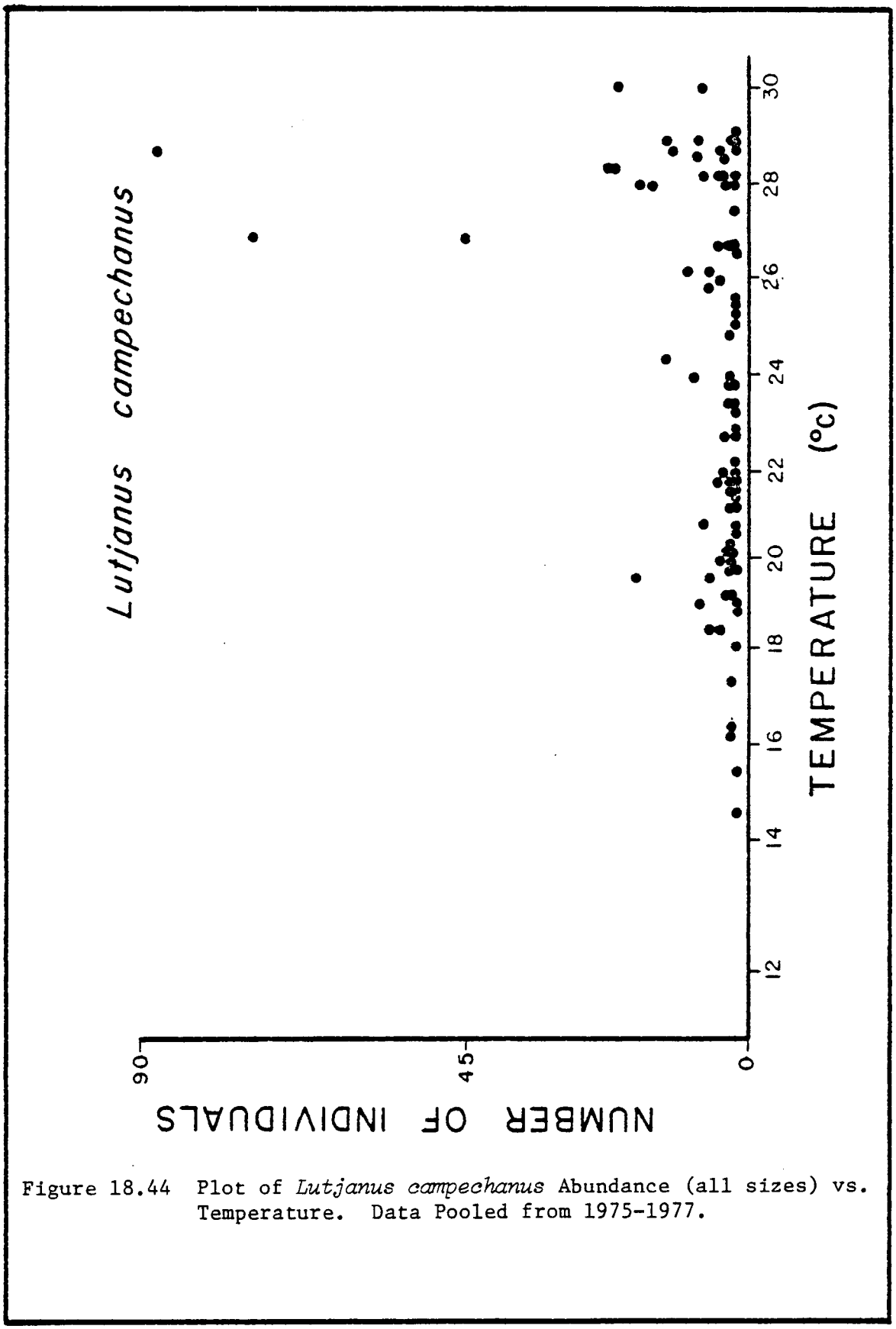

Figure 18.44 Plot of *Lutjanus campechanus* Abundance (all sizes) vs. Temperature. Data Pooled from 1975-1977.

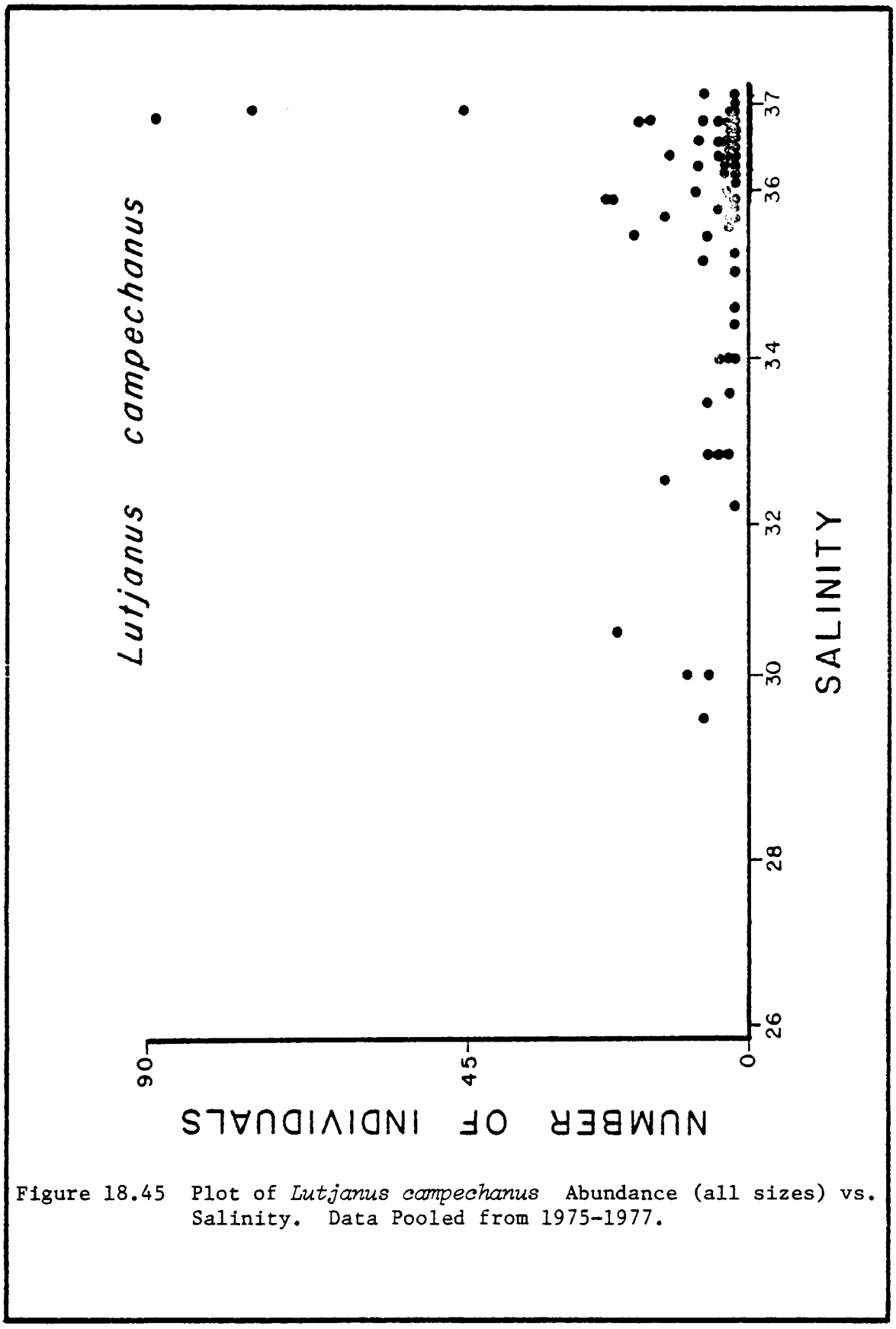

Figure 18.45 Plot of *Lutjanus campechanus* Abundance (all sizes) vs. Salinity. Data Pooled from 1975-1977.

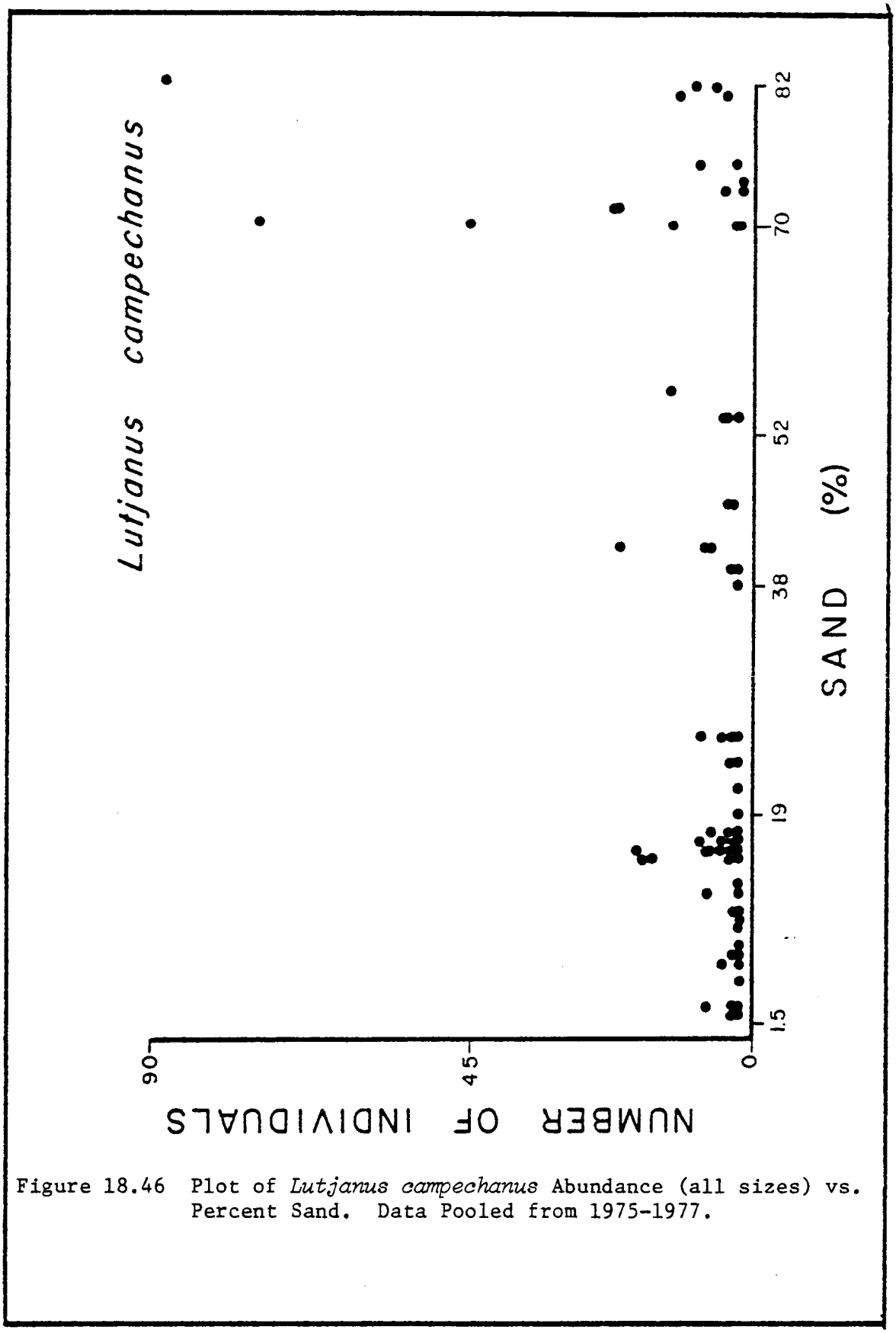

Figure 18.46 Plot of *Lutjanus campechanus* Abundance (all sizes) vs. Percent Sand. Data Pooled from 1975-1977.

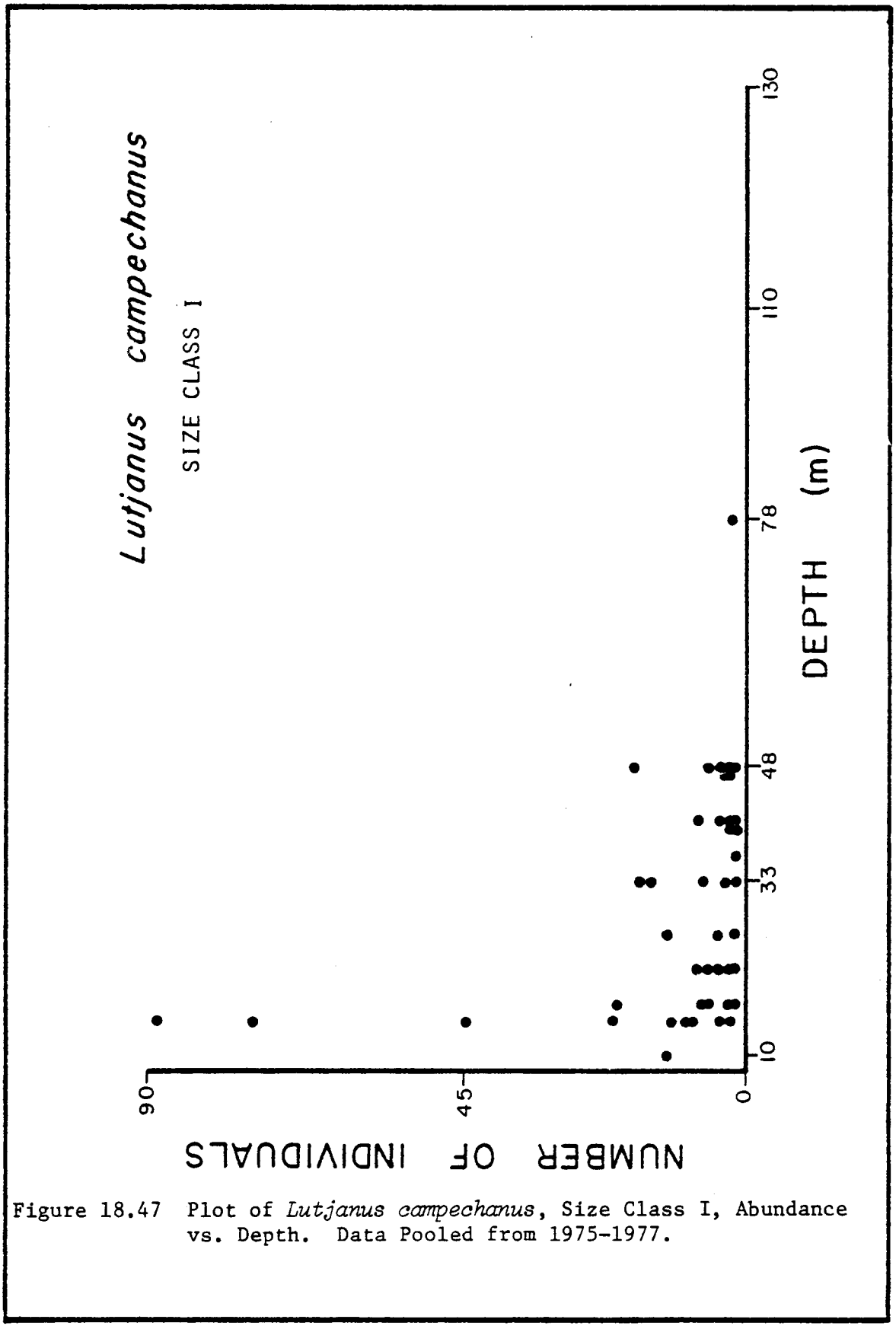

Figure 18.47 Plot of *Lutjanus campechanus*, Size Class I, Abundance vs. Depth. Data Pooled from 1975-1977.

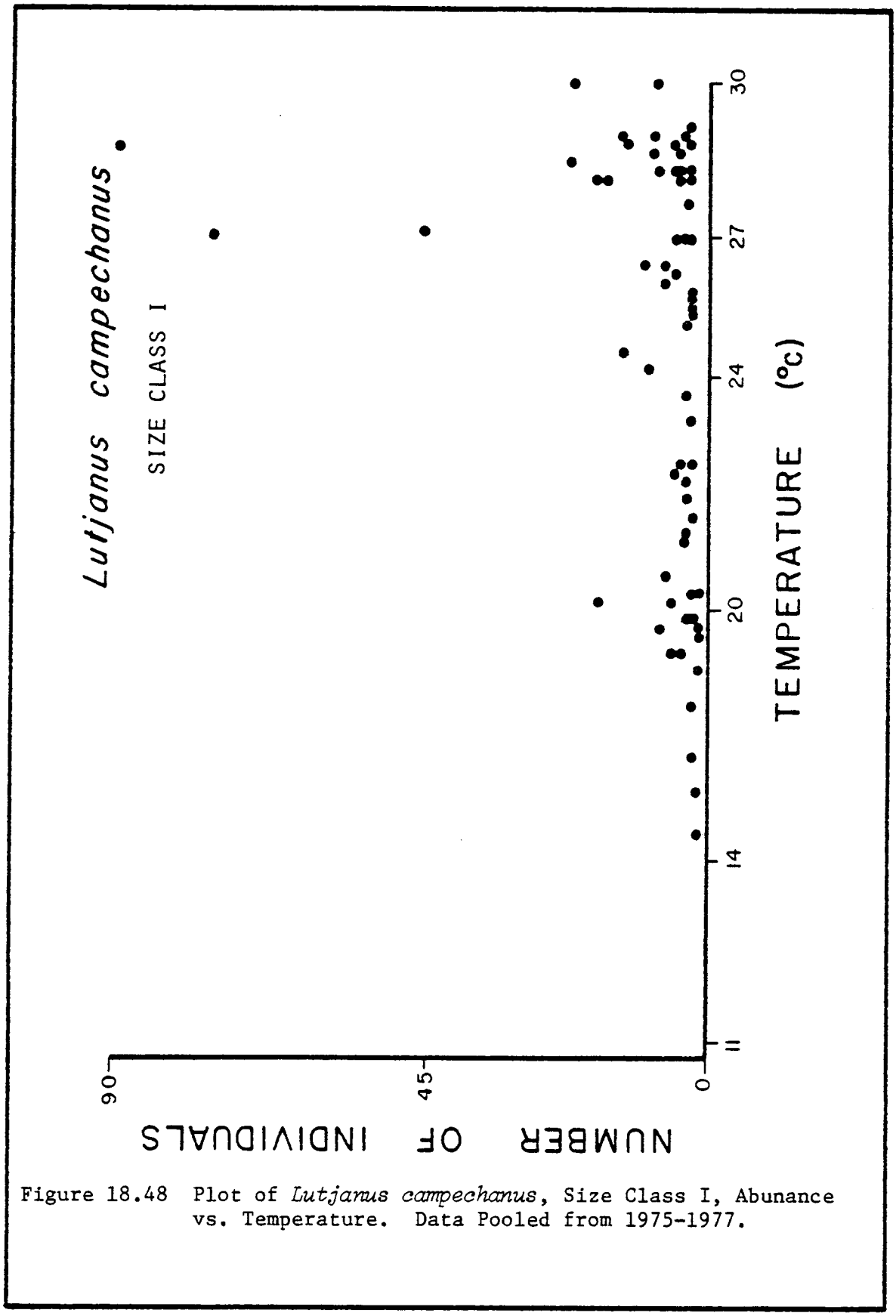

Figure 18.48 Plot of *Lutjanus campechanus*, Size Class I, Abunance vs. Temperature. Data Pooled from 1975-1977.

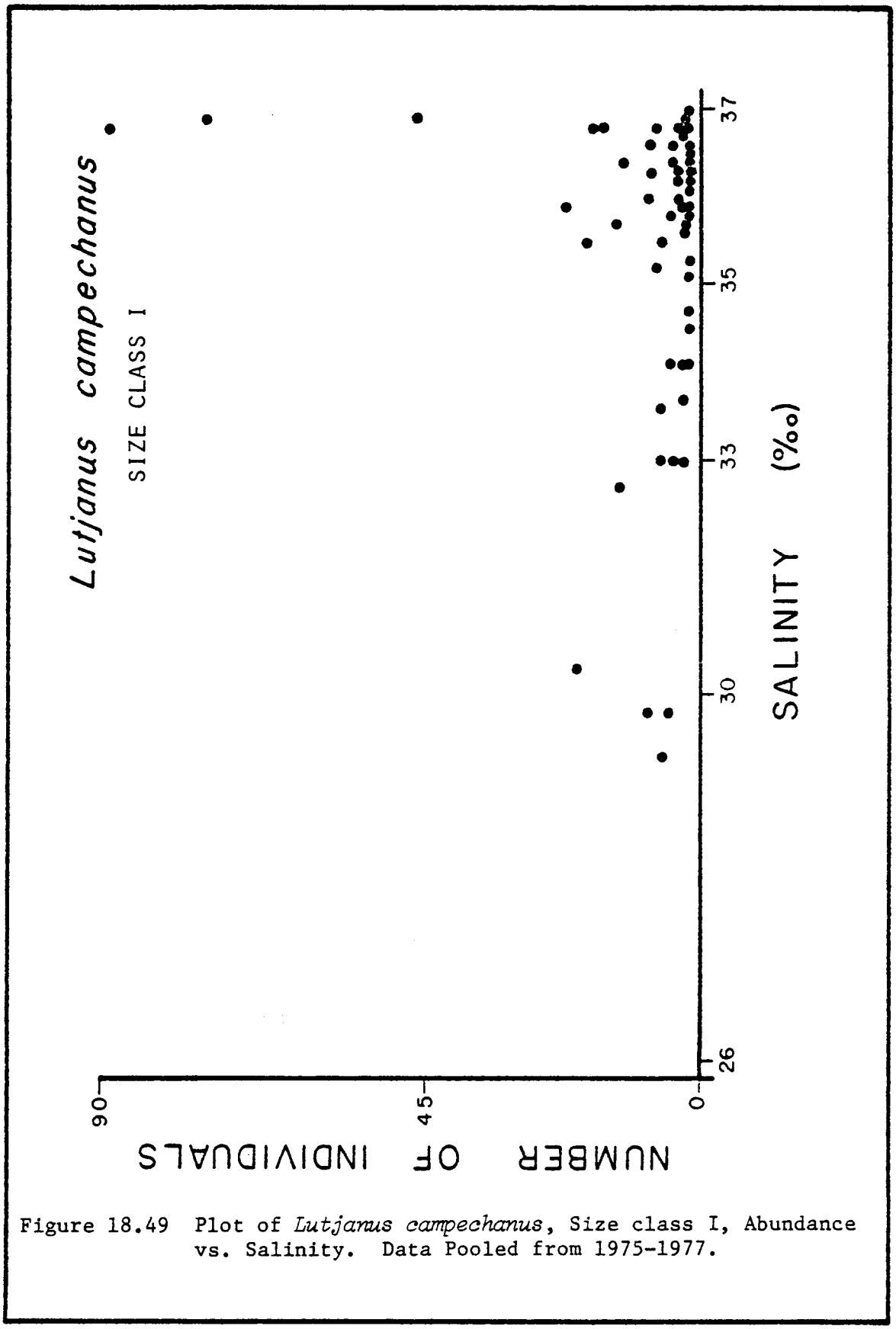

Figure 18.49 Plot of *Lutjanus campechanus*, Size class I, Abundance vs. Salinity. Data Pooled from 1975-1977.

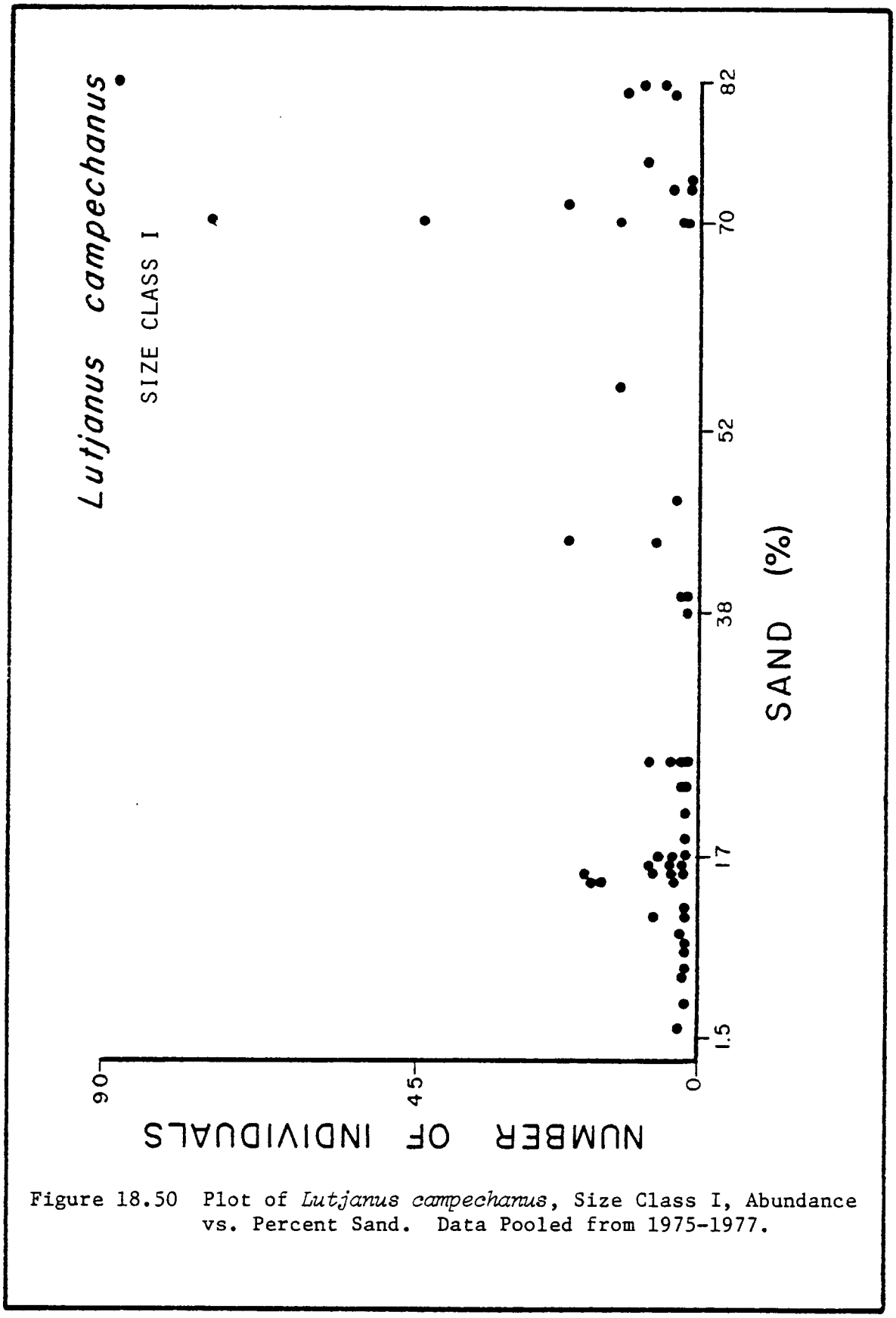

Figure 18.50 Plot of *Lutjanus campechanus*, Size Class I, Abundance vs. Percent Sand. Data Pooled from 1975-1977.

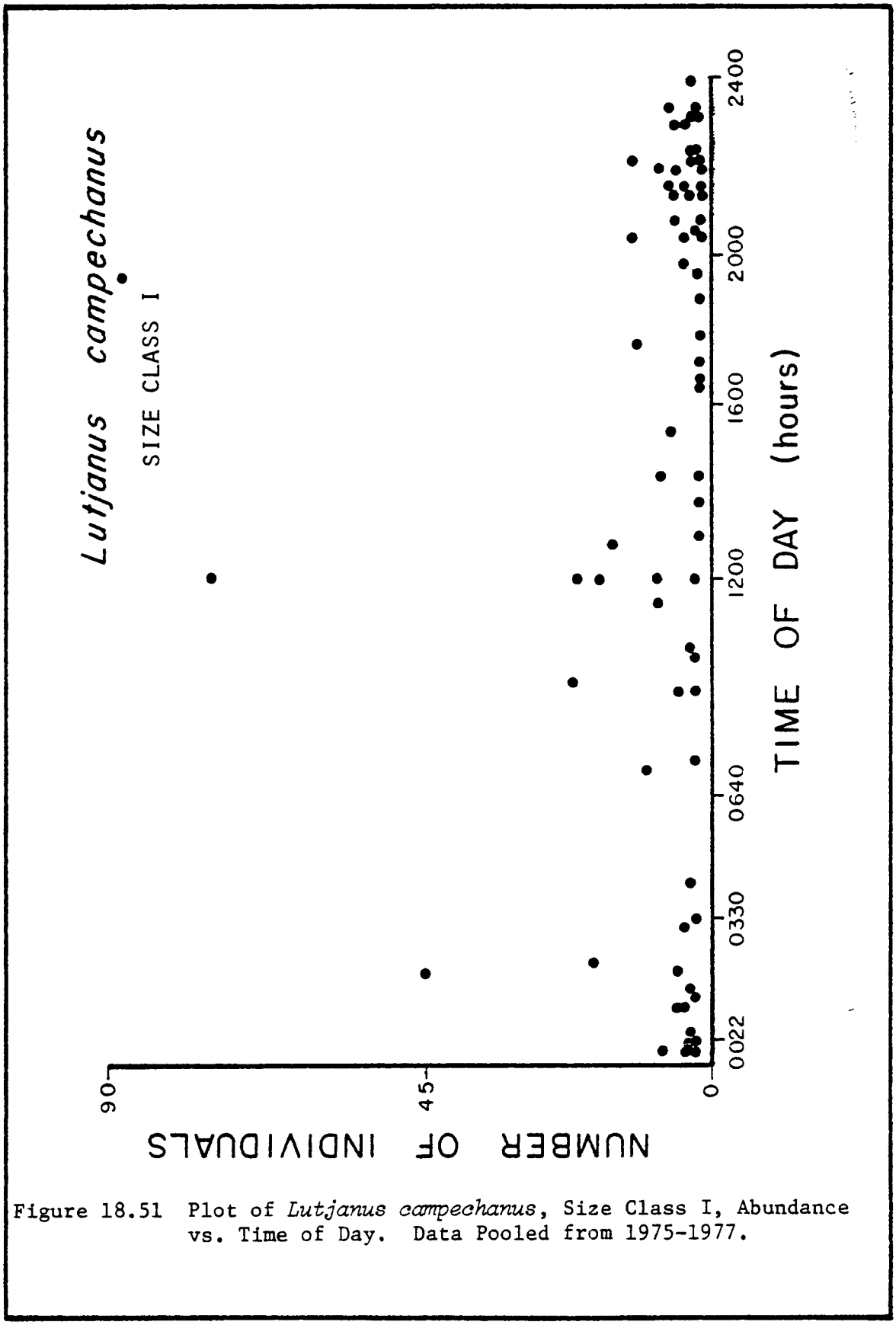

Figure 18.51 Plot of *Lutjanus campechanus*, Size Class I, Abundance vs. Time of Day. Data Pooled from 1975-1977.

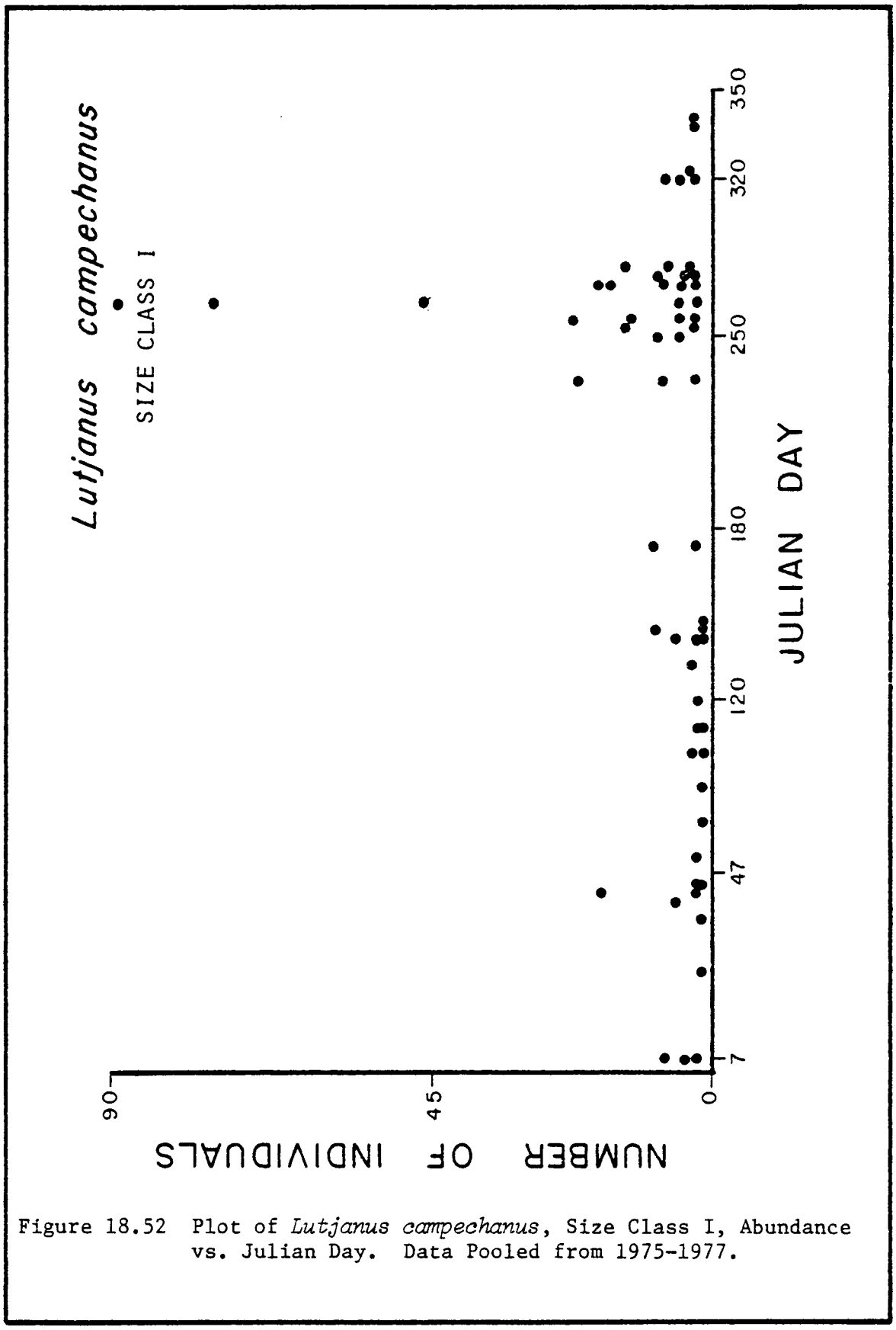

Figure 18.52 Plot of *Lutjanus campechanus*, Size Class I, Abundance vs. Julian Day. Data Pooled from 1975-1977.

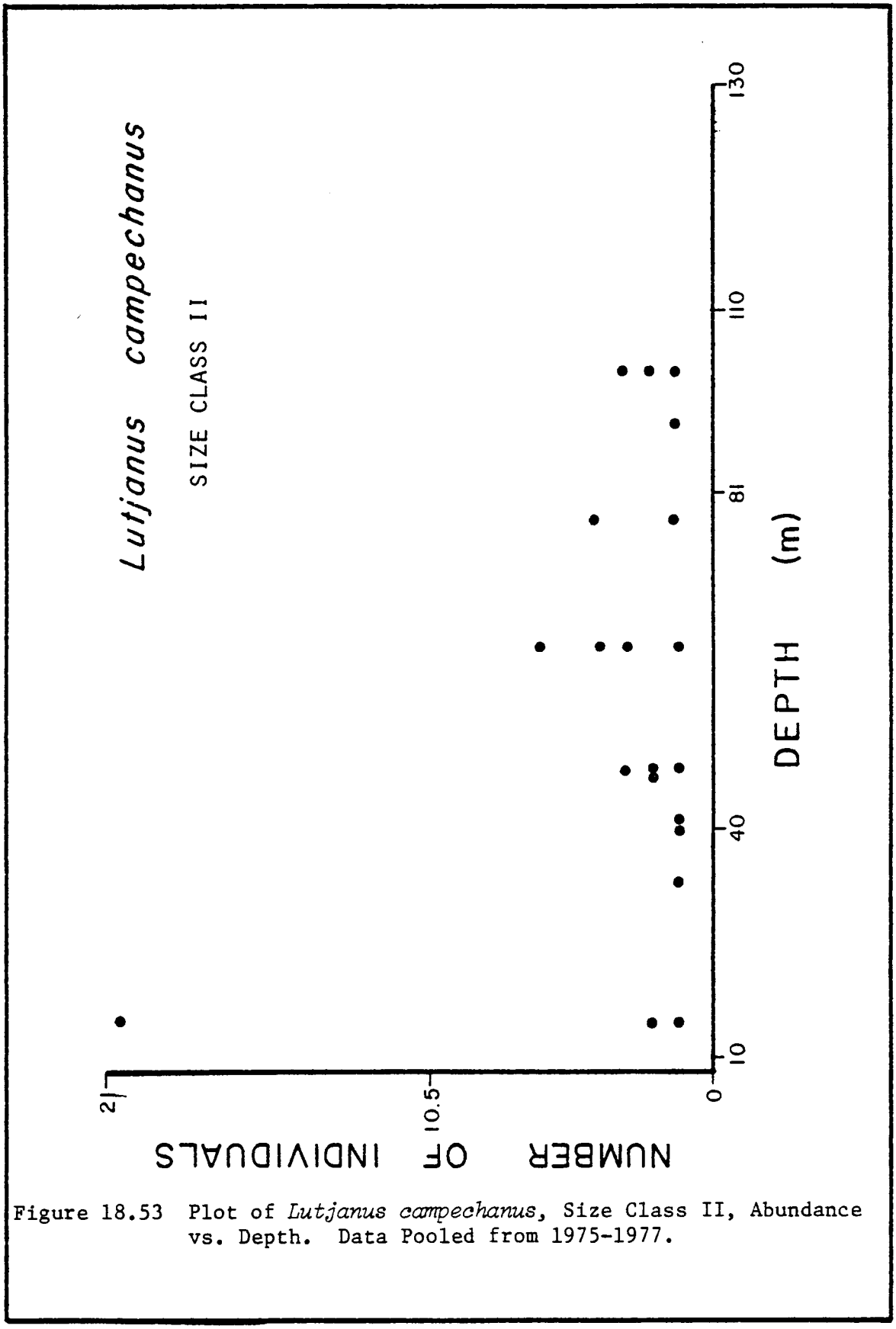

Figure 18.53 Plot of *Lutjanus campechanus*, Size Class II, Abundance vs. Depth. Data Pooled from 1975-1977.

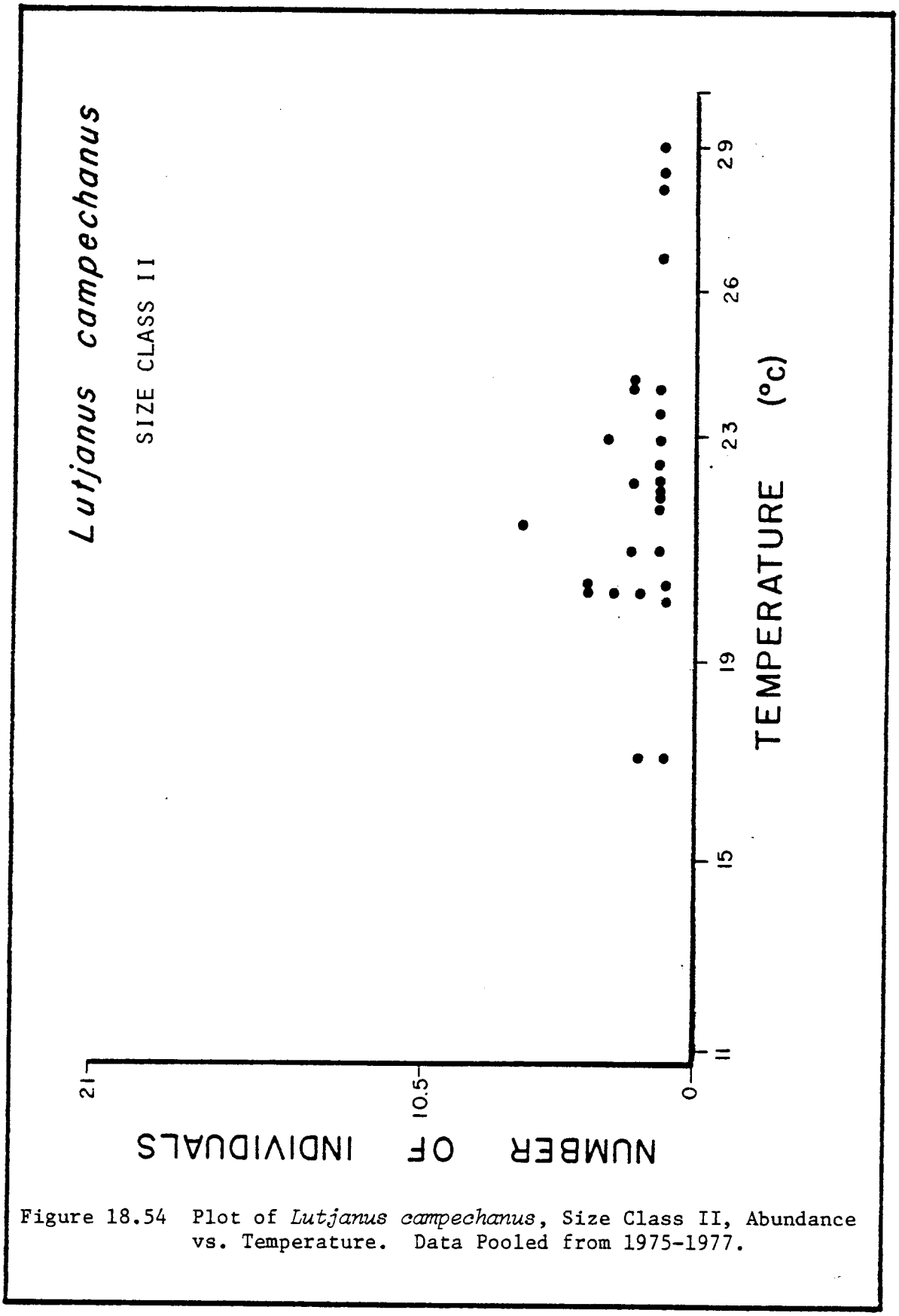

Figure 18.54 Plot of *Lutjanus campechanus*, Size Class II, Abundance vs. Temperature. Data Pooled from 1975-1977.

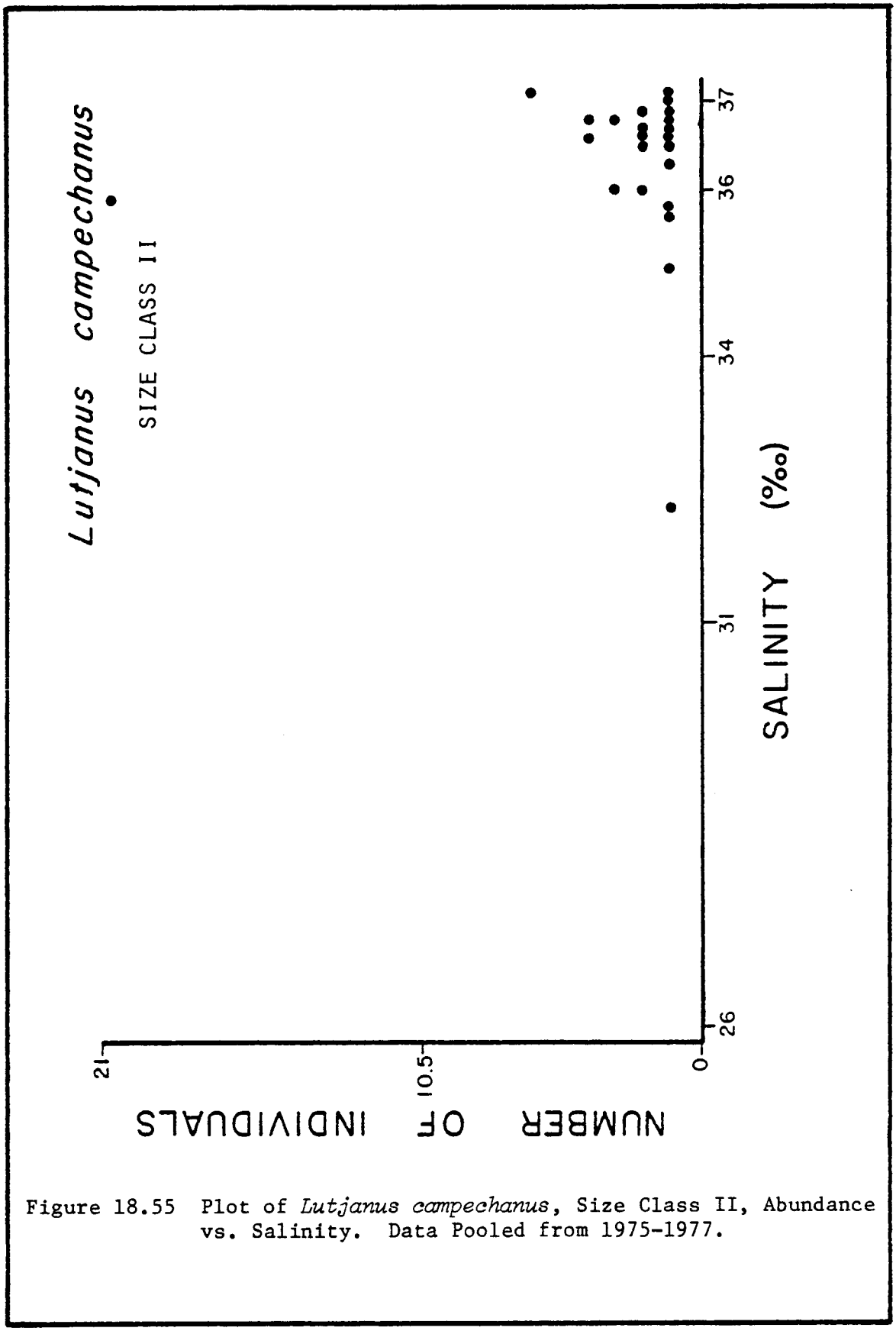

Figure 18.55 Plot of *Lutjanus campechanus*, Size Class II, Abundance vs. Salinity. Data Pooled from 1975-1977.

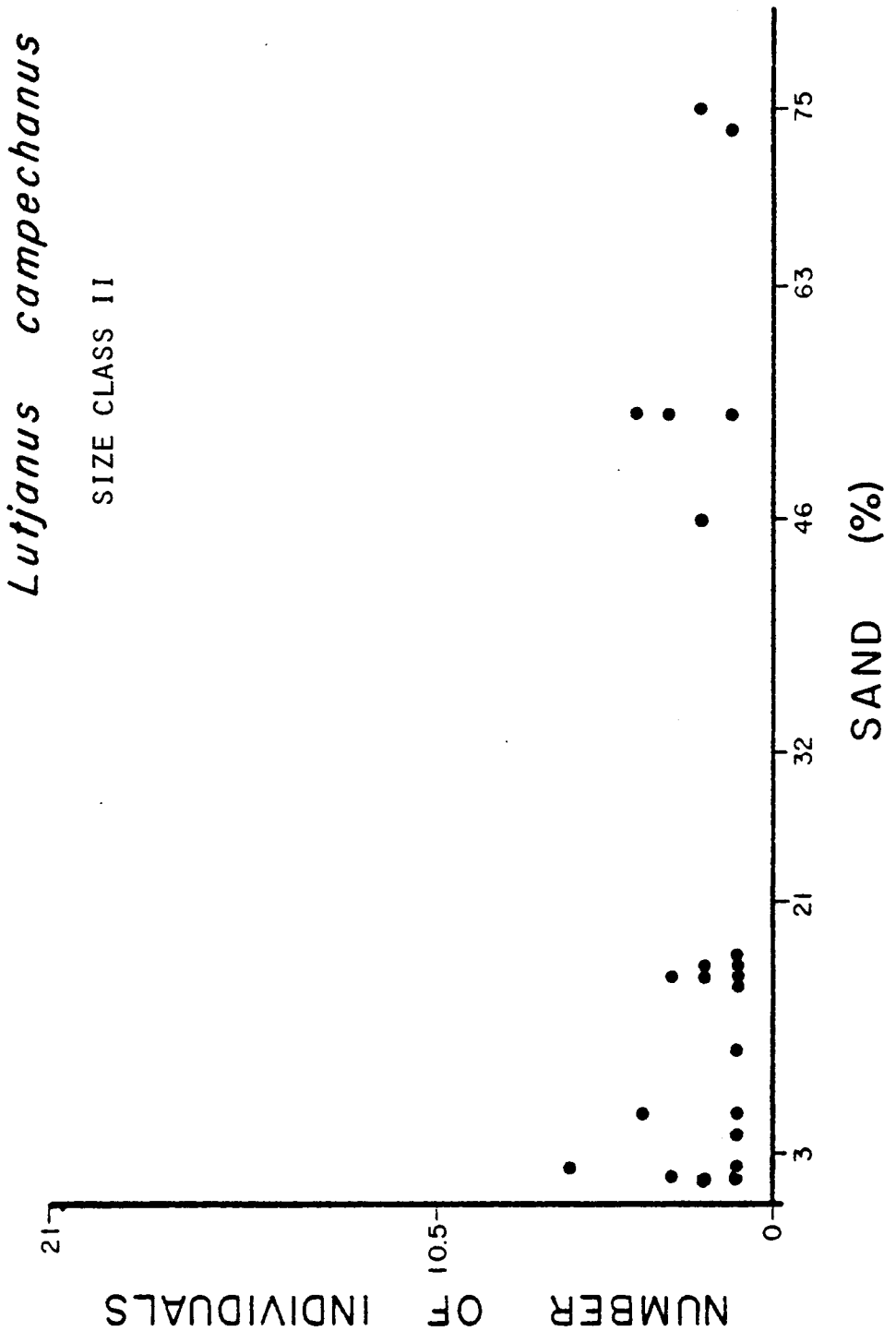

Figure 18.56 Plot of *Lutjanus campechanus*, Size Class II, Abundance vs. Percent Sand. Data Pooled From 1975-1977.

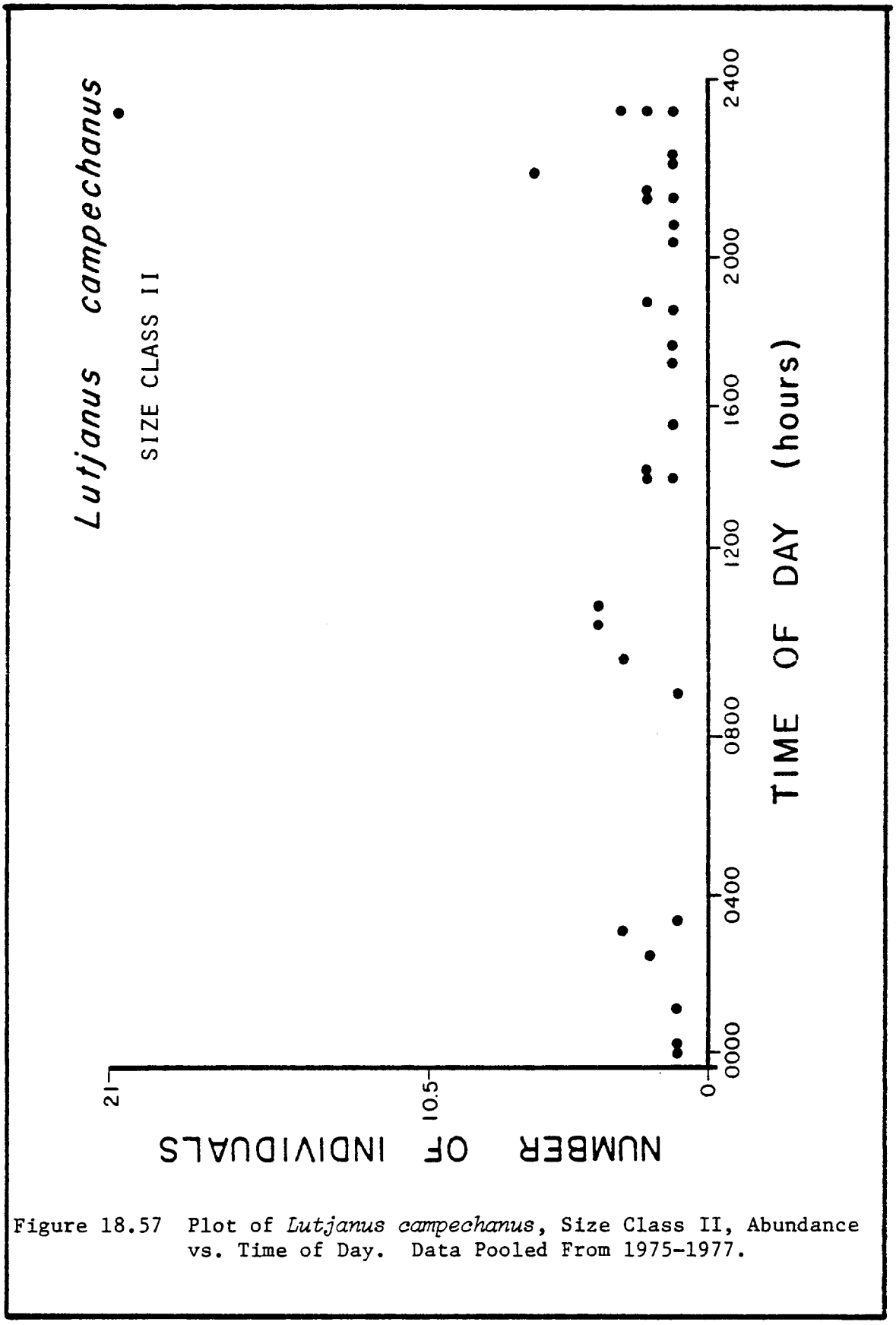

Figure 18.57 Plot of *Lutjanus campechanus*, Size Class II, Abundance vs. Time of Day. Data Pooled From 1975-1977.

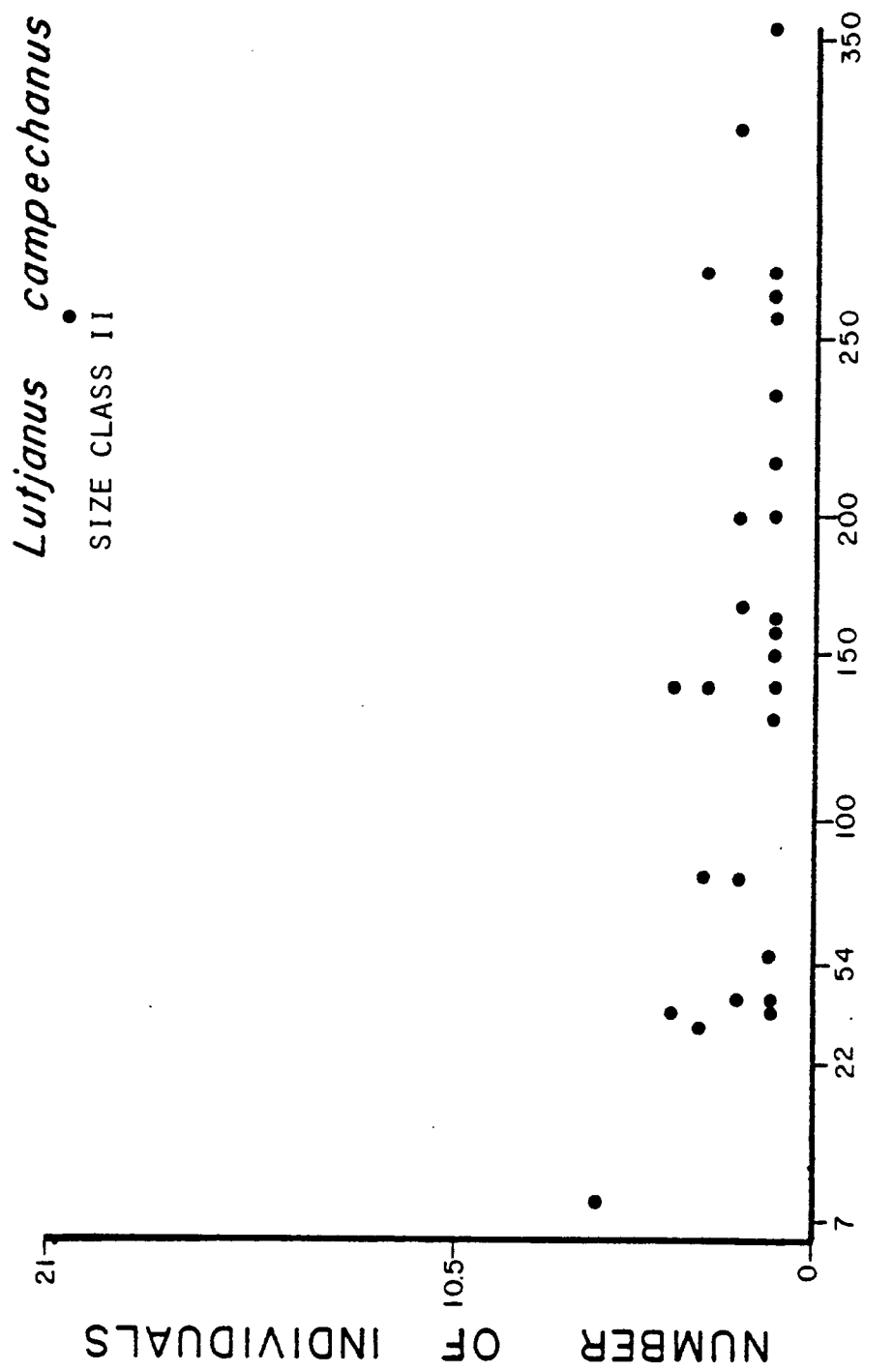

Figure 18.58 Plot of *Lutjanus campechanus*, Size Class II, Abundance vs. Julian Day. Data Pooled from 1975-1977.

high frequencies of capture in the 19-30°C temperature range, while most captures of larger fish occurred in the 20-24°C range. Fish of all sizes were more frequently caught at salinities ≥ 35 ppt, although a significant number of captures of small individuals were made at salinities down to 29 ppt. Both small and larger fish were captured over a wide range of percent sand composition of the sediment, showing no difference in this respect. There also appeared to be no difference between small and large fish in the time of day at which captures occurred. Fish of all sizes were caught throughout the 24-hr day at fairly uniform frequencies and abundances. However, there appeared to be a difference between small and large fish with respect to the time of year at which they were caught. Large fish showed a generally uniform frequency of capture over the entire year. Small fish, although caught throughout the year, showed a marked increase in abundance and in the frequency of capture during the fall. This probably corresponded with the time when the bulk of the young *L. campechanus* first became susceptible to capture with the gear employed in this study.

It is evident from the comparisons of the two size classes of *L. campechanus* with respect to correlations with selected physical parameters that, within a given species, different sizes of fish may respond differently to some environmental variables. The implication clearly is that further studies on the relationships between the abundance of the species and environmental variables should consider the possible effects of individual size on the relations of the fish to environmental conditions. In particular, if more plots such as those presented here are to be constructed, it may be best to divide each species into appropriate numbers of size classes before attempting the correlative analyses.

The point to be obtained from the plots and foregoing discussion is that correlative relationships between the abundance of each fish species

and selected physical parameters may be drawn. These relationships do not necessarily represent actual functional (cause and effect) relationships, but they nonetheless offer a starting point for ascertaining what functional relationships may exist. These correlative relationships also provide some degree of predictive capability of fish abundances, although in its present form this capability is somewhat crude. It is hoped that the predictive capability will eventually be refined to the point where reasonably accurate statements on the distribution and abundances of species can be made based on knowledge of the prevailing environmental conditions. Such work will inevitably lead to some understanding of the biological importance of certain environmental variables. For instance, the existence of appropriate temperatures and sediment composition may explain why certain species show highest abundance at or are restricted to particular depths, transects, or seasons. This approach is admittedly purely inferential, but it is felt that by proceeding in a systematic and cautious fashion, much can be learned from such correlative studies of the data at hand.

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CHAPTER NINETEEN

HISTOPATHOLOGY OF DEMERSAL FISHES

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Texas A&M University

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Associate Investigator:
JoAnn C. Eurell

ABSTRACT

This report is concerned with the histopathologic analyses of 15 species of demersal fishes. Observations pertain to nine cruises: three seasonal (February, June and October) and six monthly (March, April, July, August, November and December). All samples were collected at Stations 1, 2 and 3, along Transect II and at Southern Bank. The minimum sampling effort was five specimens of two species of fish at each station. The organ sampling effort included heart, stomach, kidney, muscle and liver. Organ samples were prepared for histologic examination by routine histologic procedures.

Parasitism, both protozoan and helminthic, was the primary cause of lesions in all organs. Lesions consisted of free and encapsulated parasites with varying degrees of inflammation and necrosis. The integrity of the tissues adjacent to the lesions was maintained.

Quantitative analyses of the percentages of lesions between and within various groups demonstrated that the lesions of stomach and liver were significantly more frequent throughout the study than were those of kidney, muscle and heart, while kidney lesions occurred with significantly greater frequency than did heart and muscle lesions. Cardiac lesions were significantly more frequent in the vermilion snapper (*Rhomboplites aurorubens*) and the red snapper (*Lutjanus campechanus*) than in the 13 other species.

Lesion percentages that did not differ significantly were as follows: between species, except between red snapper and Atlantic threadfin (*Polydactylus octonemus*); between cruises within stations; between stations; between cruises within seasonal effort; between cruises within monthly effort; and between seasonal and monthly cruises.

INTRODUCTION

This annual report is concerned with the histopathologic analyses of demersal fishes. Qualitative and quantitative observations pertain to fish samples collected on nine cruises: three seasonal (February, June and October) and six monthly (March, April, July, August, November and December). All samples were collected at Stations 1, 2 and 3, Transect II and at Southern Bank. The minimum sampling effort for this study was five specimens of two fish species at the Transect II stations. An additional effort was made to collect five specimens of two fish species at Southern Bank.

The organ sampling effort for each specimen within each species included the heart, stomach, kidney, muscle and liver. Samples of gill tissue were also collected on the first four cruises. Fish organ samples were collected by the Principal and Associate Investigators on all cruises.

MATERIALS AND METHODS

Fish were collected in a 35 ft (10.7 m) otter trawl at Stations 1, 2 and 3, and by hook and line at Southern Bank. Trawl time was approximately 30 minutes, with two to four trawls per station. Fish from each trawl were sorted, identified by species, and placed in a live holding tank. Fish caught at Southern Bank were also placed in a live holding tank.

Organ sample processing began immediately aboard ship in an effort to prevent postmortem changes. Samples of each organ no greater than five millimeters in all directions were placed in a fixative solution in tissue capsules with identification information. Two fixatives were employed: buffered neutral formalin and Helly solution (Appendix R, Table 1). Cardiac tissue, predominantly from the ventricle, was fixed primarily in Helly solution and occasionally in formalin. Organ samples were fixed

for 24 hours.

Following fixation, the organ samples were washed in running tap water for 24 hours and placed in 70% ethyl alcohol. While in 70% alcohol, the tissues were trimmed to remove unnecessary connective tissue remnants and for blocking purposes. Kidney tissue, collected *in situ*, was placed in ethylene-diamine-tetra-acetic acid (EDTA) for eight hours to decalcify adjacent bone structures. All organ samples were then dehydrated with ethyl alcohol in increasing concentrations, cleared in xylene, infiltrated with paraffin[1] in a vacuum oven at 58° for three hours and embedded in paraffin[1].

Organs were sectioned at six micrometers on a rotary microtome[2]. The sections, cut from organs fixed in both Helly solution and formalin, were mounted on glass microscope slides. Section size permitting, six sections of formalin fixed tissue were mounted per slide. Two sections of Helly-fixed tissue were mounted per slide. A minimum of two slides was prepared for each organ with each fixative. The basic staining procedure employed was hematoxylin and eosin (Appendix R, Tables 2 and 3). Additional sections fixed in Helly solution were also stained with Verhoeff and Van Gieson connective tissue stain (Appendix R, Tables 4 and 5). All slides were mounted with synthetic mounting media[3].

Fish were coded aboard ship. Each fish species was given a single Arabic letter, followed by a number to indicate the sequence of the specimens within each species. This is referred to as the Haensly code and will be used throughout this report. A computer code was also provided for each species, each specimen within each species, and each organ within each

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[1]TISSUE PREP, Fisher Scientific Co., Houston, Texas 77001
[2]AMERICAN OPTICAL 820
[3]HISTOCLAD, Clay Adams, Parsipany, New Jersey 07054

specimen, by the Data Management staff at the UTMSI/PAML.

RESULTS AND DISCUSSION

Organ samples for the 1977 sampling effort were collected from the species of fish listed in Table 19.1.

Qualitative Evaluation

The lesions observed in each of the organs were predominantly related to parasitism.

Muscle

Histology

The muscle sections, sampled from blocks of tissue collected from the left dorsal trunk musculature, demonstrated striated muscle fibers cut obliquely and/or in cross-section. The individual fibers were large and surrounded by small amounts of collagenous connective tissue fibers. Occasionally, nerve ganglia and nerve fibers were observed between the muscle fibers. Blood vessels were also present in the interstitial connective tissue.

Histopathology

All of the muscular lesions observed were related to parasitism. The majority were protozoan cysts, with and without prominent capsules, located either between or within the muscle fibers. These were classified as myxosporidian infections. A few of the parasitic lesions were encysted helminths. None of the lesions were associated with inflammatory reactions or accumulation of unusual cell types.

TABLE 19.1

SPECIES LIST OF FISH COLLECTED DURING THE 1977 SAMPLING EFFORT

Scientific Name	Common Name	Haensly Code
Pristipomoides aquilonaris	Wenchman	A
Stenotomus caprinus	Longspine porgy	B
Cynoscion arenarius	Sand seatrout	C
Micropogon undulatus	Atlantic croaker	D
Peprilus burti	Butter fish	E
Centropristis philadelphica	Rock sea bass	F
Lutjanus campechanus	Red snapper	G
Trachurus lathami	Rough scad	H
Serranus atrobranchus	Blackear bass	K
Lagodon rhomboides	Pinfish	L
Leiostomus xanthurus	Spot croaker	M
Harengula pensacolae	Scaled sardine	N
Chloroscombrus chrysurus	Atlantic bumper	P
Polydactylus octonemus	Atlantic threadfin	R
Rhomboplites aurorubens	Vermilion snapper	SN

Kidney

Histology

Renal tissue was morphologically the same for all species, that is, nephrons were embedded in varying amounts of hemopoietic tissue. Glomeruli were located peripherally, both dorsally and laterally, within the main renal mass. Renal tubules were numerous and appeared structurally similar to mammalian renal tubules, composed of a layer of simple cuboidal epithelial cells with round, central basophilic nuclei surrounded by an eosinophilic cytoplasm. Wandering lymphocytes penetrated the tubular epithelium only occasionally.

Scattered through the kidney sections were areas of pigment-containing cells. The pigmented areas varied in number from kidney to kidney and appeared to be associated with the hemopoietic tissue. Delicate strands of collagenous fibers supported the renal parenchyma. Connective tissue was not conspicuous in the kidney except adjacent to large blood vessels. Acidophil cells were occasionally observed in the renal interstitium.

Histopathology

The lesions observed in the kidney samples were varied: protozoa in duct lumens and between duct epithelial cells or thickly encapsulated in the parenchyma as xenomas, remnants of helminth parasites, and an apparent deposition of large amounts of lipid in tubule epithelial cells. Protozoa, free or encysted, were observed to be the most numerous parasite. A cardiac protozoa, observed only in fish sampled at Southern Bank, was also detected within the lumen of renal vessels. Adenomas were observed in two kidney samples.

Heart

Histology

Sections of cardiac ventricular muscle revealed bundles of striated muscle fibers cut in cross section, obliquely or longitudinally. Small amounts of collagenous connective tissue fibers supported the muscle cells and the abundant interstitial vascular supply. Occasional clumps of lightly pigmented cells were present, predominantly in the pericardium. Acidophil cells were occasionally observed in the pericardial region.

Histopathology

Encysted helminth parasites or their remnants were infrequently observed. The predominant cardiac lesions were circular and measured about 24 μm in diameter. The outer wall of these lesions were cellular and surrounded a central region varying structure which was apparently degenerative. In the same hearts that contained these lesions, there were protozoa-like cells aligned in rows along the cardiac muscle fibers or arranged in aggregates between muscle fibers. An extensive myocarditis was associated with these lesions. These protozoa-like cells were present only in the cardiac tissue of fish sampled at Southern Bank.

Stomach

Histology

The basic structure of the stomach wall was similar to that of carnivorous animals and exhibited a well-developed mucosa with columnar epithelial cells, gastric glands and muscularis mucosa, a well-developed submucosa, and tunica muscularis. No parietal cells were observed in the glandular epithelium in any of the species examined. Occasionally, striated muscle fibers were present in the muscle tunic.

Histopathology

Most of the histopathologic observations were lesions associated with parasitism. Helminth parasites were occasionally seen in the mucosa or attached to the mucosal surface. The most common mucosal parasites were protozoa, located among the gastric epithelial cells either as single cells or in small groups.

Protozoa were also observed in the submucosa, although less frequently than helminths. Helminth parasites in the submucosa represented the most intensive gastric infection, with sections of encysted trematodes, cestodes and nematodes. In addition, many encapsulated areas of degenerating parasitic foci could be detected in the submucosa. Helminth parasites were occasionally observed in the tunica muscularis.

The submucosa of all stomachs exhibited varying amounts of inflammatory reactions. Usually these were scattered foci of inflammatory cells, predominantly lymphocytes, plasma cells or mixtures of these two cell types. Lymph nodules were not observed.

Acidophil cells were commonly observed in the gastric tissue. While they were predominantly located in the submucosa, they were also present in the other two wall types. In this study, the presence and numbers of acidophil cells in the stomach appeared to be directly correlated with the degree of parasitism.

Liver

Histology

Liver cell arrangement was generally either tubular or muralium. In the tubular pattern, six to eight hepatocytes surrounded a central sinusoid. In the muralium arrangement, there were interweaving sheets of hepatocytes two cells thick, marginated by sinusoids.

Hepatocytes were large cuboidal cells with prominent nuclei and nucleoli. The cytoplasm ranged from non-vacuolated to extremely vacuolated. Vacuolation of the hepatocytes may have been due to glycogen and/or lipid accumulation.

Sinusoids were lined by discontinuous endothelium and Kupffer cells. The sinusoids were either dilated or closed. Sinusoid dilation may have been a shock reaction to trawl entrapment and rapid decompression.

Hepatopancreas (exocrine pancreas) units were scattered through the hepatic parenchyma in all species observed except the rock sea bass (F) and the rough scad (H). With hematoxylin and eosin stain, hepatopancreatic cells were basophilic, showing prominent eosinophilic zymogen granules at the apical end of the columnar cells.

Groups of yellow to gold pigmented cells were also found in the hepatic parenchyma.

In the perihepatopancreatic space, cells with acidophilic granules and basophilic nuclei (acidophil cells) were sometimes observed.

Histopathology

Pathologic lesions were primarily parasitic in nature. Three types of protozoa were observed. Encysted biconcave discs and nucleated protozoa were present in the hepatic parenchyma. A third type of protozoa was observed between epithelial cells of the bile ducts. This type was oval with an eosinophilic cytoplasm and basophilic nuclei.

Cross sections of helminths were observed in the liver parenchyma. One bile duct contained a trematode.

Necrosis was frequently observed in the liver parenchyma, bile ducts and blood vessels. Granulomas were observed occasionally.

Scattered areas of vacuolated hepatocytes were present in some liver samples.

Gill

Gill tissue samples were not routinely collected. Except for one sample that contained an ectoparasite, no histopathology was observed.

Quantitative Evaluation

Duncan's new multiple range test (Steel and Torrie, 1960) was used to detect possible significant differences between means. Percentages of lesions found in various groups of fish were used to interpret data from this testing. Gill tissues were not included in the analyses because they were not routinely collected. The results from this study are recorded in Tables 19.2 through 19.17.

Table 19.2 is a summary of the entire investigation according to species of fish and organs within each species. Forty-two percent of 1591 organ samples showed lesions. Among species, lesions present varied from 16% (threadfin, R) to 69% (red snapper, G). This variation may have little meaning because species sample size varied widely. In only one comparison, red snapper (G) versus threadfin (R), was there a significant difference in the percentages of lesions observed. This absence of significant differences between species was due to the large variation which existed within each species.

For the overall study, Table 19.2 also summarizes the percentages of lesions found in each organ. Regardless of species, the stomach and liver had consistently more lesions than did other organs, perhaps because the functions of stomach and liver make them more susceptible to infection. Lesion percentages in heart, kidney and muscle were smaller and more variable, with the overall percentage of kidney lesions significantly higher than were the percentages of heart and muscle lesions. Compared with the

TABLE 19.2

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS WITHIN EACH SPECIES SAMPLED ON THE FEBRUARY, MARCH, APRIL, JUNE, JULY, AUGUST, OCTOBER, NOVEMBER, AND DECEMBER CRUISES, 1977, SOUTH TEXAS OCS MONITORING STUDY

Organ	Species A	B	C	D	E	F	G	H	K	L	M	N	P	R	SN	TOTAL
Heart	4*(9)** / 44	3(5) / 55	0(0) / 45	3(9) / 35	0(0) / 20	0(0) / 14	16(80) / 20	0(0) / 5	0(0) / 14	0(0) / 5	1(7) / 15	0(0) / 5	1(20) / 5	0(0) / 5	19(63) / 30	47(15) / 317
Stomach	45(100) / 45	37(67) / 55	43(96) / 45	14(40) / 35	14(70) / 20	11(73) / 15	20(100) / 20	2(40) / 5	9(64) / 14	2(40) / 5	6(40) / 15	3(60) / 5	0(0) / 5	4(80) / 5	26(87) / 30	236(76) / 319
Kidney	11(26) / 43	13(24) / 55	33(73) / 45	9(26) / 35	0(0) / 20	1(7) / 15	14(70) / 20	4(80) / 5	0(0) / 14	1(20) / 5	5(33) / 15	0(0) / 5	0(0) / 5	0(0) / 5	9(30) / 30	100(32) / 317
Muscle	2(4) / 45	3(5) / 55	15(33) / 45	2(6) / 35	0(0) / 20	0(0) / 15	0(0) / 20	2(40) / 5	0(0) / 14	1(20) / 5	12(80) / 15	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 30	37(12) / 319
Liver	41(91) / 45	55(100) / 55	29(64) / 45	15(43) / 35	12(60) / 20	11(73) / 15	19(95) / 20	4(80) / 5	8(57) / 14	3(60) / 5	12(80) / 15	2(40) / 5	4(80) / 5	0(0) / 5	28(93) / 30	243(76) / 319
Gill	0(0) / 20	0(0) / 30	0(0) / 25	0(0) / 5	0(0) / 15	0(0) / 10	1(20) / 5	0(0) / 0	0(0) / 4	0(0) / 5	0(0) / 5	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 10	1(1) / 134
TOTAL	103(43) / 242	111(36) / 305	120(48) / 250	43(24) / 180	26(23) / 115	23(27) / 84	70(67) / 105	14(48) / 25	17(23) / 74	7(23) / 30	36(45) / 80	5(20) / 25	5(20) / 25	4(16) / 25	82(51) / 160	664(38) / 1725

*Numerator: number of organs containing histopathologic condition.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.3

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS WITHIN STATION 1, TRANSECT II, ON THE MONTHLY AND SEASONAL CRUISES, 1977, SOUTH TEXAS OCS MONITORING STUDY

Cruise Dates

Organ/Species	Feb. E,K	March C,E	April C,E	June C,D	July C,H	Aug. N,P	Oct. D,R	Nov. C,D	Dec. C,D	TOTAL
Heart	0*(0)** / 9	0(0) / 10	0(0) / 10	0(0) / 10	0(0) / 10	1(10) / 10	1(10) / 10	0(0) / 10	0(0) / 10	2(2) / 89
Stomach	3(33) / 9	9(90) / 10	9(90) / 10	5(50) / 10	7(70) / 70	3(30) / 10	6(60) / 10	9(90) / 10	6(60) / 10	57(64) / 89
Kidney	0(0) / 9	5(50) / 10	4(40) / 10	6(60) / 10	7(70) / 10	0(0) / 10	1(1) / 10	4(40) / 10	3(30) / 10	30(34) / 89
Muscle	0(0) / 9	4(40) / 10	2(20) / 10	2(20) / 10	2(20) / 10	0(0) / 10	0(0) / 10	1(10) / 10	1(10) / 10	12(13) / 89
Liver	7(78) / 9	8(80) / 10	7(70) / 10	3(30) / 10	0(0) / 10	6(60) / 10	5(50) / 10	5(50) / 10	2(20) / 10	43(48) / 89
Gill	0(0) / 9	0(0) / 10	0(0) / 10	0(0) / 10	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 0	0(30) / 39
TOTAL	10(19) / 54	26(43) / 60	22(37) / 60	16(27) / 60	24(48) / 50	10(20) / 50	13(26) / 50	19(38) / 50	12(24) / 50	152(31) / 484

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.4

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS WITHIN STATION 2, TRANSECT II, ON THE MONTHLY AND SEASONAL CRUISES, 1977, SOUTH TEXAS OCS MONITORING STUDY

	Cruise Dates									
	Feb.	March	April	June	July	Aug.	Oct.	Nov.	Dec.	
Organ/Species	B,F	B,L	C,M	A,F	E,K	F,K	D,M	C,D	D,M	TOTAL
Heart	0*(0)** / 10	0(0) / 10	0(0) / 10	0(0) / 10	0(0) / 10	0(0) / 9	1(10) / 10	1(10) / 10	1(10) / 10	3(3) / 89
Stomach	7(70) / 10	6(60) / 10	8(80) / 10	9(90) / 10	7(70) / 10	6(60) / 10	5(50) / 10	7(70) / 10	2(20) / 10	57(63) / 90
Kidney	1(10) / 10	1(10) / 10	8(80) / 10	0(0) / 10	0(0) / 10	0(0) / 10	3(30) / 10	8(80) / 10	1(10) / 10	22(24) / 90
Muscle	0(0) / 10	1(10) / 10	7(70) / 10	0(0) / 10	0(0) / 10	0(0) / 10	4(40) / 10	3(30) / 10	3(30) / 10	18(20) / 90
Liver	9(90) / 10	8(80) / 10	8(80) / 10	10(100) / 10	5(50) / 10	5(50) / 10	8(80) / 10	4(40) / 10	3(30) / 10	60(67) / 90
Gill	0(0) / 10	0(0) / 10	0(0) / 10	0(0) / 10	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 40
TOTAL	17(28) / 60	16(26) / 60	31(52) / 60	19(32) / 60	12(24) / 50	11(22) / 49	21(42) / 50	23(46) / 50	10(20) / 50	160(33) / 489

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.5

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS WITHIN STATION 3, TRANSECT II, ON THE MONTHLY AND SEASONAL CRUISES, 1977, SOUTH TEXAS OCS MONITORING STUDY

Cruise Dates

Organ/Species	Feb. B,C	March A,B	April A,B	June A,B	July A,B	Aug. A,B	Oct. A,B	Nov. A,B	Dec. A,B	TOTAL
Heart	2*(20)** / 10	0(0) / 9	0(0) / 10	1(10) / 10	1(10) / 10	1(10) / 10	1(10) / 10	0(0) / 10	1(10) / 10	7(8) / 89
Stomach	9(90) / 10	8(80) / 10	9(90) / 10	9(90) / 10	10(100) / 10	9(90) / 10	6(60) / 10	8(80) / 10	8(80) / 10	76(84) / 90
Kidney	3(30) / 10	4(50) / 8	3(30) / 10	1(10) / 10	3(30) / 10	4(40) / 10	4(40) / 10	0(0) / 10	3(30) / 10	25(28) / 88
Muscle	4(40) / 10	1(10) / 10	1(10) / 10	0(0) / 10	1(10) / 10	0(0) / 10	0(0) / 10	0(0) / 10	0(0) / 10	7(8) / 90
Liver	9(90) / 10	10(10) / 10	10(100) / 10	10(100) / 10	10(100) / 10	8(80) / 10	10(100) / 10	10(100) / 10	8(80) / 10	85(94) / 90
Gill	0(0) / 10	0(0) / 10	0(0) / 10	0(0) / 10	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 40
TOTAL	27(45) / 60	23(40) / 57	23(38) / 60	21(35) / 60	25(50) / 50	22(44) / 50	21(42) / 50	18(36) / 50	20(40) / 50	200(41) / 487

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.6

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS WITHIN SOUTHERN BANK ON THE MONTHLY AND SEASONAL CRUISES, 1977, SOUTH TEXAS OCS MONITORING STUDY

	Cruise Dates							
	April	June	July	Aug.	Oct.	Nov.	Dec.	
Organ/Species	SN,G	SN,G	SN,G	SN,G	SN	G	SN	TOTAL
Heart	8*(89(** / 9	2(33) / 6	7(70) / 10	8(80) / 10	3(60) / 5	4(80) / 5	3(60) / 5	35(70) / 50
Stomach	8(89) / 9	6(100) / 6	10(100) / 10	10(100) / 10	4(80) / 5	5(100) / 5	3(60) / 5	46(92) / 50
Kidney	2(22) / 9	1(17) / 6	3(30) / 10	9(90) / 10	2(40) / 5	4(80) / 5	2(40) / 5	23(46) / 50
Muscle	0(0) / 9	0(0) / 6	0(0) / 10	0(0) / 10	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 50
Liver	9(100) / 9	6(100) / 6	9(90) / 10	10(100) / 10	3(60) / 5	5(100) / 5	5(100) / 5	47(94) / 50
Gill	1(11) / 9	0(0) / 6	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 0	1(7) / 15
TOTAL	28(52) / 54	15(42) / 36	29(58) / 50	37(74) / 50	12(48) / 25	18(72) / 25	13(52) / 25	152(57) / 265

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.7

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS
FOR THREE SEASONAL CRUISES, 1977,
SOUTH TEXAS OCS MONITORING STUDY

	Seasonal Cruises			
	February	June	October	
Organ/Species	E.K.B.F.B,C	D,C,A,F,B,SN,G	D,R,M,A,B,SN	TOTAL
Heart	2*(6)** / 29	3(8) / 36	6(17) / 35	11(11) / 100
Stomach	19(65) / 29	29(81) / 36	21(60) / 35	69(69) / 100
Kidney	4(13) / 29	8(22) / 36	10(29) / 35	22(22) / 100
Muscle	4(13) / 29	2(6) / 36	4(11) / 35	10(10) / 100
Liver	25(86) / 29	29(81) / 36	26(24) / 35	80(80) / 100
Gill	0(0) / 29	0(0) / 36	0(0) / 0	0(0) / 65
TOTAL	54(31) / 174	71(33) / 216	67(38) / 175	192(34) / 565

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.8

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS FOR SIX MONTHLY CRUISES, 1977, SOUTH TEXAS OCS MONITORING STUDY

Monthly Cruises

Organ/Species	March	April	July	Aug.	Nov.	Dec.	TOTAL
	C,E,B,L, A,B	C,E,M,A, B,SN,G	C,H,E,K, A,B,SN,G	N,P,K,F, A,B,SN,G	C,D,A, B,G	C,D,M, A,B,SN	
Heart	0*(0)** / 29	8(21) / 39	8(20) / 40	10(26) / 39	5(14) / 35	5(14) / 35	36(17) / 217
Stomach	23(76) / 30	34(87) / 39	34(85) / 40	28(70) / 40	29(83) / 35	19(54) / 35	167(76) / 219
Kidney	10(35) / 28	17(44) / 39	13(32) / 40	13(32) / 40	16(46) / 35	9(26) / 35	78(40) / 217
Muscle	6(20) / 30	10(26) / 39	3(8) / 40	0(0) / 40	4(11) / 35	4(11) / 35	27(12) / 219
Liver	26(86) / 30	34(87) / 39	32(80) / 40	29(72) / 40	24(69) / 35	18(51) / 35	163(74) / 219
Gill	0(0) / 30	1(3) / 39	0(0) / 0	0(0) / 0	0(0) / 0	0(0) / 0	1(1) / 69
TOTAL	65(36) / 177	104(44) / 234	90(45) / 200	80(40) / 199	78(45) / 175	55(31) / 175	472(41) / 1160

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.9

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS PER NUMBER OF ORGANS SAMPLED ON THE FEBRUARY, 1977, CRUISE, SOUTH TEXAS OCS MONITORING STUDY

	Station 1		Station 2		Station 3		
Organ/Species:	E	K	B	F	B	C	TOTAL
Heart	0*(0)** / 5	0(0) / 4	0(0) / 5	0(0) / 5	2(40) / 5	0(0) / 5	2(6) / 29
Stomach	2(40) / 5	1(25) / 4	2(40) / 5	5(100) / 5	4(80) / 5	5(100) / 5	19(65) / 29
Kidney	0(0) / 5	0(0) / 4	0(0) / 5	1(20) / 5	2(40) / 5	1(20) / 5	4(13) / 29
Muscle	0(0) / 5	0(0) / 4	0(0) / 5	0(0) / 5	2(40) / 5	2(40) / 5	4(13) / 29
Liver	4(80) / 5	3(75) / 4	5(100) / 5	4(80) / 5	5(100) / 5	4(80) / 5	25(86) / 29
Gill	0(0) / 5	0(0) / 4	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 29
Subtotal	6(20) / 30	4(16) / 24	7(23) / 30	10(33) / 30	15(50) / 30	12(40) / 30	
TOTAL	10(18) / 54		17(28) / 60		27(45) / 60		54(31) / 174

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.10

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS PER NUMBER OF ORGANS SAMPLED ON THE MARCH, 1977, CRUISE, SOUTH TEXAS OCS MONITORING STUDY

	Station 1		Station 2		Station 3		
Organ/Species:	C	E	B	L	A	B	TOTAL
Heart	0*(0)** / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 4	0(0) / 5	0(0) / 29
Stomach	5(100) / 5	4(80) / 5	4(80) / 5	2(40) / 5	5(100) / 5	3(60) / 5	23(76) / 30
Kidney	5(100) / 5	0(0) / 5	0(0) / 5	1(20) / 5	1(33) / 3	3(60) / 5	10(35) / 28
Muscle	4(80) / 5	0(0) / 5	0(0) / 5	1(20) / 5	1(20) / 5	0(0) / 5	6(20) / 30
Liver	5(100) / 5	3(60) / 5	5(100) / 5	3(60) / 5	5(100) / 5	5(100) / 5	26(86) / 30
Gill	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 30
Subtotal	19(63) / 30	7(23) / 30	9(30) / 30	7(23) / 30	12(44) / 27	11(36) / 30	
TOTAL	26(43) / 60		16(26) / 60		23(40) / 57		65(36) / 177

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.11

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS
PER NUMBER OF ORGANS SAMPLED ON THE APRIL, 1977,
CRUISE, SOUTH TEXAS OCS MONITORING STUDY

	Station 1		Station 2		Station 3		Southern Bank		
Organ/Species:	C	E	M	C	A	B	SN	G	TOTAL
Heart	0*(0)** / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	4(80) / 5	4(100) / 4	8(21) / 39
Stomach	4(80) / 5	5(100) / 5	3(60) / 5	5(100) / 5	5(100) / 5	4(80) / 5	4(80) / 5	4(100) / 4	34(87) / 39
Kidney	4(80) / 5	0(0) / 5	3(60) / 5	5(100) / 5	1(20) / 5	2(40) / 5	0(0) / 5	2(50) / 4	17(44) / 39
Muscle	2(40) / 5	0(0) / 5	5(100) / 5	2(40) / 5	0(8) / 5	1(20) / 5	0(0) / 5	0(0) / 4	10(26) / 39
Liver	5(100) / 5	2(40) / 5	4(80) / 5	4(80) / 5	5(100) / 5	5(100) / 5	5(100) / 5	4(100) / 4	34(87) / 39
Gill	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	1(25) / 4	1(3) / 39
Subtotal	15(50) / 30	7(23) / 30	15(50) / 30	16(53) / 30	11(37) / 30	12(40) / 30	13(43) / 30	15(62) / 24	
TOTAL	22(37) / 60		31(52) / 60		23(38) / 60		28(52) / 54		104(44) / 234

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.12

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS
PER NUMBER OF ORGANS SAMPLED ON THE JUNE,1977,
CRUISE, SOUTH TEXAS OCS MONITORING STUDY

	Station 1		Station 2		Station 3		Southern Bank		
Organ/Species	D	C	A	F	A	B	SN	G	TOTAL
Heart	0*(0)** / 5	0(0) / 5	0(0) / 5	0(0) / 5	1(20) / 5	0(0) / 5	2(40) / 5	0(0) / 1	3(8) / 36
Stomach	0(0) / 5	5(100) / 5	5(100) / 5	4(80) / 5	5(100) / 5	4(80) / 5	5(100) / 5	1(100) / 1	29(81) / 36
Kidney	1(20) / 5	5(100) / 5	0(0) / 5	0(0) / 5	0(0) / 5	1(20) / 5	1(20) / 5	0(0) / 1	8(22) / 36
Muscle	0(0) / 5	2(40) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 1	2(6) / 36
Liver	1(20) / 5	2(40) / 5	5(100) / 5	5(100) / 5	5(100) / 5	5(100) / 5	5(100) / 5	1(100) / 1	29(81) / 36
Gill	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 1	0(0) / 36
Subtotal	2(7) / 30	14(47) / 30	10(33) / 30	9(30) / 30	11(37) / 30	10(33) / 30	13(43) / 30	2(33) / 6	
TOTAL	16(27) / 60		19(32) / 60		21(35) / 60		15(42) / 36		71(33) / 216

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.13

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS
PER NUMBER OF ORGANS SAMPLED ON THE JULY, 1977,
CRUISE, SOUTH TEXAS OCS MONITORING STUDY

	Station 1		Station 2		Station 3		Southern Bank		
Organ/Species:	C	H	E	K	A	B	SN	G	TOTAL
Heart	0/5*(0)**	0/5(0)	0/5(0)	0/5(0)	1/5(20)	0/5(0)	4/5(80)	3/5(60)	8/40(20)
Stomach	5/5(100)	2/5(40)	3/5(60)	4/5(80)	5/5(100)	5/5(100)	5/5(100)	5/5(100)	34/40(85)
Kidney	3/5(60)	4/5(80)	0/5(0)	0/5(0)	3/5(60)	0/5(0)	0/5(0)	3/5(60)	13/40(32)
Muscle	0/5(0)	2/5(40)	0/5(0)	0/5(0)	1/5(20)	0/5(0)	0/5(0)	0/5(0)	3/40(8)
Liver	4/5(80)	4/5(80)	3/5(60)	2/5(40)	5/5(100)	5/5(100)	5/5(100)	4/5(80)	32/40(80)
Subtotal	12/25(48)	12/25(48)	6/25(24)	6/25(24)	15/25(60)	10/25(40)	14/25(56)	15/25(60)	
TOTAL	24/50(48)		12/50(24)		25/50(50)		29/50(58)		90/200(45)

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.14

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS PER NUMBER OF ORGANS SAMPLED ON THE AUGUST, 1977, CRUISE, SOUTH TEXAS OCS MONITORING STUDY

	Station 1		Station 2		Station 3		Southern Bank		
Organ/Species:	N	P	K	F	A	B	SN	G	TOTAL
Heart	0*(0)** / 5	1(20) / 5	0(0) / 5	0(0) / 4	1(20) / 5	0(0) / 5	3(60) / 5	5(100) / 5	10(26) / 39
Stomach	3(60) / 5	0(0) / 5	4(80) / 5	2(40) / 5	5(100) / 5	4(80) / 5	5(100) / 5	5(100) / 5	28(70) / 40
Kidney	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	3(60) / 5	1(20) / 5	4(80) / 5	5(100) / 5	13(32) / 40
Muscle	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 5	0(0) / 40
Liver	2(40) / 5	4(80) / 5	3(60) / 5	2(40) / 5	3(60) / 5	5(100) / 5	5(0) / 5	5(100) / 5	29(72) / 40
Subtotal	5(20) / 25	5(20) / 25	7(28) / 25	4(17) / 24	12(48) / 25	10(40) / 25	17(68) / 25	20(80) / 25	
TOTAL	10(20) / 50		11(22) / 49		22(44) / 50		37(74) / 50		80(40) / 199

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.15

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS PER NUMBER OF ORGANS SAMPLED ON THE OCTOBER, 1977, CRUISE, SOUTH TEXAS OCS MONITORING STUDY

	Station 1		Station 2		Station 3		Southern Bank	
Organ/Species	D	R	D	M	A	B	SN	TOTAL
Heart	1*(20)** / 5	0(0) / 5	0(0) / 5	1(20) / 5	1(20) / 5	0(0) / 5	3(60) / 5	6(17) / 35
Stomach	2(40) / 5	4(80) / 5	2(40) / 5	3(60) / 5	5(100) / 5	1(0) / 5	4(80) / 5	21(60) / 35
Kidney	1(20) / 5	0(0) / 5	1(20) / 5	2(40) / 5	2(40) / 5	2(40) / 5	2(40) / 5	10(29) / 35
Muscle	0(0) / 5	0(0) / 5	0(0) / 5	4(80) / 5	0(0) / 5	0(0) / 5	0(0) / 5	4(11) / 35
Liver	5(100) / 5	0(0) / 5	3(60) / 5	5(100) / 5	5(100) / 5	5(100) / 5	3(60) / 5	26(74) / 35
Subtotal	9(36) / 25	4(16) / 25	6(24) / 25	15(60) / 25	13(52) / 25	8(32) / 25		
TOTAL	13(26) / 50		21(42) / 50		21(42) / 50		12(48) / 25	67(38) / 175

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.16

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS PER NUMBER OF ORGANS SAMPLED ON THE NOVEMBER, 1977, CRUISE, SOUTH TEXAS OCS MONITORING STUDY

	Station 1		Station 2		Station 3		Southern Bank	
Organ/Species	C	D	C	D	A	B	G	TOTAL
Heart	0*(0)** / 5	0(0) / 5	0 / 5	1(20) / 5	0(0) / 5	0(0) / 5	4(80) / 5	5(14) / 35
Stomach	5(100) / 5	4(80) / 5	5 / 5	2(40) / 5	5(100) / 5	3(60) / 5	5(100) / 5	29(83) / 35
Kidney	2(40) / 5	2(40) / 5	5 / 5	3(60) / 5	0(0) / 5	0(0) / 5	4(80) / 5	16(46) / 35
Muscle	0(0) / 5	1(20) / 5	2 / 5	1(20) / 5	0(0) / 5	0(0) / 5	0(0) / 5	4(11) / 35
Liver	2(40) / 5	3(60) / 5	2 / 5	2(40) / 5	5(100) / 5	5(0) / 5	5(100) / 5	24(69) / 35
Subtotal	9(36) / 25	10(40) / 25	14(56) / 25	9(36) / 25	10(40) / 25	8(32) / 25		
TOTAL	19(38) / 50		23(46) / 50		18(36) / 50		18(72) / 25	78(45) / 175

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

TABLE 19.17

NUMBER OF ORGANS CONTAINING HISTOPATHOLOGIC CONDITIONS PER NUMBER OF ORGANS SAMPLED ON THE DECEMBER, 1977, CRUISE, SOUTH TEXAS OCS MONITORING STUDY

	Station 1		Station 2		Station 3		Southern Bank	
Organ/Species	D	C	D	M	A	B	SN	TOTAL
Heart	0*(0)** / 5	0(0) / 5	1(20) / 5	0(0) / 5	0(0) / 5	1(20) / 5	3(60) / 5	5(14) / 35
Stomach	2(40) / 5	4(80) / 5	2(40) / 5	0(0) / 5	5(100) / 5	3(0) / 5	3(60) / 5	19(54) / 35
Kidney	0(0) / 5	3(60) / 5	1(20) / 5	0(0) / 5	1(20) / 5	2(40) / 5	2(40) / 5	9(26) / 35
Muscle	0(0) / 5	1(20) / 5	0(0) / 5	3(60) / 5	0(0) / 5	0(0) / 5	0(0) / 5	4(11) / 35
Liver	1(20) / 5	1(20) / 5	0(0) / 5	3(60) / 5	3(60) / 5	5(100) / 5	5(100) / 5	18(51) / 35
Subtotal	3(12) / 25	9(36) / 25	4(16) / 25	6(24) / 25	9(36) / 25	11(44) / 25	13(52) / 25	
TOTAL	12(24) / 50		10(20) / 50		20(40) / 50		13(52) / 25	55(31) / 175

*Numerator: number of organs containing histopathologic conditions.
Denominator: number of organs sampled.

**Percentage of lesions.

other 13 species, vermilion snapper (SN) and red snapper (G) showed significantly more cardiac lesions, an observation which may be related to the environment of these two species (Southern Bank). Kidney and muscle lesions were more numerous in sand sea trout (C), rough scad (H), and spot croaker (M) than in all other species. Red snapper (G) also had numerous kidney lesions.

Tables 19.3 - 19.6 summarize lesion percentages observed at the various stations: 1, 2 and 3, Transect II, and Southern Bank, respectively. No significant differences in overall lesion frequency was found in organ samples taken from monthly cruises and those taken from seasonal cruises. Again, however, within each station gastric and hepatic lesions were significantly more frequent than cardiac, renal and muscular lesions, and renal lesions were significantly more frequent than lesions of heart and muscle. There was a consistent increase in the overall number of lesions observed from Stations 1 to 2 to 3 to Southern Bank.

A comparison of the lesions found in each organ at each station gave the following results: cardiac lesions were significantly more frequent at Southern Bank than at the other stations; hepatic lesions were significantly more frequent at Southern Bank than at Stations 1 and 2; and hepatic lesions were more frequent at Station 3 than at Station 1. Liver lesion percentages increased from Station 1 to 2 to 3, with the highest percentage at Southern Bank.

Table 19.7 presents a summary of percentages of lesions observed during the seasonal sampling effort. These percentages did not differ significantly among the seasonal cruises. During these cruises, however, both liver lesions and stomach lesions were observed with significantly

greater frequency than were muscle, heart and kidney lesions.

Table 19.8 summarizes lesion percentage data gathered from the monthly cruises and, again, the overall percentages from these cruises showed no significant difference. Percentages of both liver and stomach lesions were significantly larger than the percentages of muscle, heart and kidney lesions, and the kidney percentage was significantly larger than those for muscle and heart.

Between seasonal and monthly cruises (Tables 19.7 and 19.8), overall lesion percentages were not significantly different, nor were the percentages of liver, stomach, muscle, kidney or heart lesions.

Tables 19.9 through 19.17 present histopathologic detail of each seasonal and monthly sampling effort as well as the data summarized in Tables 19.2 through 19.8.

SUMMARY

The qualitative information obtained in the histopathologic study of demersal fish demonstrated that parasitism was the major cause of lesions. Lesions that may be related to other pathologic agents were not observed. Parasitism caused varying degrees of necrosis, especially in the liver and stomach. Adjacent to such lesions, however, the general integrity of the tissues was maintained.

Quantitative analyses of the percentages of lesions between and within various groups demonstrated the following:

1. Approximately two-fifths of the organ samples collected had lesions.

2. Among species, aside from significant differences between red snapper (G) and threadfin (R), overall lesion percentages did not differ significantly.

3. Hepatic and gastric lesions were significantly more frequent throughout the study than heart, kidney and muscle lesions.

4. Overall, kidney lesions occurred with significantly greater frequency than did heart and muscle lesions.

5. Cardiac lesion percentages in vermilion snapper (SN) and red snapper (G) were significantly higher than in the 13 other species sampled.

6. Within each station, lesion percentages did not differ significantly according to month or season.

7. Within each station, gastric and hepatic lesions were observed with significantly greater frequency than were heart, kidney and muscle lesions. Kidney lesions were significantly more frequent than heart or muscle lesions.

8. Overall lesion percentages did not differ significantly according to station.

9. Cardiac lesions were observed with significantly greater frequency at Southern Bank than at Stations 1, 2 or 3.

10. Gastric, renal and muscular lesion percentages did not differ significantly according to station.

11. Hepatic lesions were significantly more frequent at Southern Bank than at Stations 1 and 2 and significantly more frequent at Station 3 than at Station 1.

12. Among the seasonal cruises, overall lesion percentages were not significantly different.

13. During the seasonal cruises, gastric and hepatic lesions were significantly more frequent than were muscular, cardiac and renal lesions.

14. During the monthly cruises, gastric and hepatic lesions were significantly more frequent than were muscular, cardiac and renal lesions, while kidney lesions were significantly more frequent than those for

muscle and heart.

15. Overall lesion percentages did not differ significantly according to month or season.

16. Percentages of cardiac, gastric, hepatic, renal and muscular lesions did not differ significantly according to month or season.

CONCLUSIONS

Parasitism caused most of the histopathologic conditions observed in fish taken from the stations of Transect II and Southern Bank, and was randomly distributed between species, stations and time of year. Aside from the parasitism, the fish sampled appeared to be in good health and free from lesions that could be attributed to other etiological agents. Monitoring studies should be much enhanced, since other types of lesions can be readily contrasted with this baseline information.

LITERATURE CITED

Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Co., Inc.

CHAPTER TWENTY

HISTOPATHOLOGY OF INVERTEBRATE EPIFAUNA

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ABSTRACT

A histopathological study of epifaunal invertebrates was carried out on animals collected at Stations 1, 2 and 3, Transect II each month of 1977 except for January, May and September. A total of 2265 organs were used from 453 specimens. Crustaceans were the most common specimens obtained. There were 6 species of shrimp totaling 214 specimens, 5 species of crabs totaling 129 specimens and 2 species of stomatopods totaling 26 specimens. Molluscs collected consisted of 3 species of bivalves totaling 55 specimens and 1 species of squid totaling 29 specimens.

The total number of pathologies in the gills almost equaled that in internal organs. Shrimp had the highest percent and variety of symbionts in the gills, most of which were parasitic ciliates. The total percent of other types of pathological conditions in the gills was higher than the total percent of symbionts. Crabs had by far the largest number of such conditions and molluscs had very few gill pathologies of any kind.

Internal organs, as opposed to the gills, had a much higher total percent of symbionts than other types of pathologies. Crabs were the exception, with less symbionts than other pathologies. Bivalves had many more symbionts in their internal organs than other animals.

All pathological conditions other than symbionts in the gills and internal organs could have been caused by parasites, bacteria, viruses or injuries. Most of these conditions in the internal organs, however, appeared to be related to the host's reaction to parasites. The largest percent of all pathologies in the internal organs were found in the gastro-intestinal tract of the animals studied.

INTRODUCTION

The purpose of this study was the continuation of the development of a data base of histopathologies of invertebrate epifauna of the South Texas Outer Continental Shelf (STOCS). Such a study is necessary for environmental monitoring purposes, as such surveys have not been performed previously. It is also a very useful study to the general scientific community, as knowledge of the normal histology as well as histopathology of these animals is meager (Couch *et al.*, 1974).

Most reports of histopathological conditions in the literature concerned commercial species (Cheng, 1967; Sparks, 1972). Only two such species, *Penaeus aztecus* and *P. setiferus* (the brown and white shrimp, respectively), were collected as part of this study. Many of the pathological conditions found in this study had not been reported in the literature for either the animals studied or for closely related animals (Johnson, 1968). The majority of the pathological conditions were due to parasites, particularly nematodes, cestodes and trematodes. These could not be specifically identified from sectioned material, but had to be obtained whole from their hosts by dissection. The only parasitological survey of Gulf invertebrates found in the literature was on shrimp by Hutton *et al.*, (1959), and only dissection, no sectioning, was used for identifying the parasites. In almost all reports concerning parasites in the literature, the parasites were identified to at least the genus level. Since no parasitology was conducted in the STOCS study, the identification beyond general classification of the majority of the symbionts found in the animals used in this study was impossible. In a few cases, *i.e. Nematopsis* sps. and *Pseudoklossia* sps., comparison of the morphology of the parasite, its histopathological effects on the host and its presence in closely related

host species, resulted in identification at least to the genus level.

The etiologies of various hyperplastic conditions observed in this study are unknown. Such pathologies may be caused by viruses (Rosenfield, 1976), which can only be diagnosed with the use of live material or electron microscopy; bacterial diseases, which can only be identified from living material; or protozoans and fungi, which also require living material for identification.

This report shows the general types of pathological conditions found in several different kinds of marine invertebrates of the region studied. Differences between the various pathological conditions in the different types of animals, *i.e.*, shrimp and crabs, are presented as well as differences between the different species of each type, *i.e.* the two shrimp *Penaeus aztecus* and *Trachypenaeus similis*. Some pathological conditions were shown to differ with change in seasons and some were found only at certain depths of the Gulf.

MATERIALS AND METHODS

Collections were made at Stations 1, 2 and 3, Transect II each month in 1977 except for January, May and September. A 35-ft (10.7 m) otter trawl was used with trawl times generally of 30 minutes. Trawling efforts were generally performed until sufficient specimens were obtained, and ranged from one to six efforts per station. Collections were made between sunset and sunrise. The two instances when insufficient numbers of specimens were obtained, collections were performed during daylight (Station 3, April 18 and Station 1, July 29).

Three species per station, five specimens per species, and five organs per specimen were required by BLM for the study. Extra specimens and species were obtained when possible to provide supplemental material if needed. A total of 405 specimens and 2025 organs were required for

study while 453 specimens and 2265 organs were actually examined. BLM suggested that the brown shrimp, *Penaeus aztecus*, a bivalve, and any other species be used. *P. aztecus* was collected at least once every cruise, but bivalves were not available in February or October and only one specimen was collected in November (Table 20.1). An attempt was made to collect the same species studied in 1976, but this was not always possible. A total of 17 species was collected, some of which were extra species and others only obtained one time.

Animals were removed from the otter trawl net and sorted immediately. Usable specimens were placed in a tank with running sea water. One specimen at a time was brought into the dissecting area and measured, sexed (if possible) and various organs dissected out, if the animal was large enough. If the animal was too small to dissect properly, it was opened up to allow penetration of the fixative as discussed below. Shrimp abdomen were severed from the cephalothorax, a small central dorsal portion of the carapace of the cephalothorax removed, and the front of the head just behind the eyes cut off. Stomatopod abdomens were severed from the cephalothorax, sharp edges of abdominal segments as well as thoracic appendages were cut off and the front of the heads were removed just behind the eyes. Crab legs were removed and the carapace opened dorsally from the posterior end, leaving the anterior end attached. A cut was also made into the muscle mass just anterior to the fourth leg. Bivalves were carefully shucked. Squid mantles were cut along the ventral midline and the animal spread open. Organs not dissected on board ship were dissected with the aid of a dissecting microscope after returning to the laboratory when there was sufficient time to be careful. Small organs were easier to dissect after they had been fixed, as less damage occurred to fixative-hardened tissues than to soft, fresh ones. Bivalves, no matter

TABLE 20.1

NUMBER OF SPECIMENS STUDIED IN MONTHS, SEASONS AND STATIONS

Species	OCCURRENCE																											Total
	Feb.			March			April			June			July			Aug.			Oct.			Nov.			Dec.			
	Winter			Spring			Spring			Summer			Summer			Summer			Fall			Fall			Winter			
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Penaeus aztecus		5	5		6	7	6	6		6	6		5	5	5	5				5			6			6	5	89
Penaeus setiferus	6			7															5			5			5			28
Trachypenaeus similis	7				7		5									5			5		5	5				5		44
Sicyonia dorsalis		5			5						6						5			5			5					31
Sicyonia stimpsoni								6																				6
Solenocera vioscai																		5					5	6				16
Squilla chydaea	5					5													6									16
Squilla empusa	3			7																								10
Callinectes similis		6	5							7			2	6			5			5		6			5	5		52
Portunus spinicarpus								6	1			6			5			5			6			5			5	39
Portunus gibbesii				6			6																		6			18
Anasimus latus									1			7									5			6				19
Myropsis quinquespinosa									1																			1
Armatium papyraceus						7		3	1		5	6		5	5		5	5						1			6		49
Pecten gibbus					1																							1
Neopycnodonta cochlear									5																			5
Loligo pealiei			6						6	6			6			5												29
Total	21	16	16	20	19	19	17	21	15	19	17	19	13	16	15	15	15	15	16	15	16	16	16	18	16	16	16	453

what their size, were not dissected as they have a small coelomic cavity and most of their organs could not be dissected out without destroying the surrounding ones.

Different organs were studied in different types of animals as shown in Table 20.2. Since the organs of bivalves were not dissected out, sections were made in the areas of the desired organs.

Dissected organs as well as parts of or whole animals were placed in appropriate size tissue capsules, wrapped in cheese cloth or placed in perforated plastic bags with a label and immersed in Zenker's fixative for 12 to 24 hours. Then they were placed in 70% ethyl alcohol, in which they could remain indefinitely. At this time dissection was completed. Further dehydration, clearing and infiltration with paraffin were completed in an automatic tissue processor. Final paraffin embedding was done by hand.

Sections were cut at 6 µm, mounted on cleaned labeled slides and allowed to dry at 35°C for about 24 hours. If the sections were small enough six serial sections were mounted per slide, or six serial sections were mounted on the necessary number of slides. Each organ was stained with two different stains, two slides of each, or 12 sections per stain, making a total of four slides or 24 sections. Different stains were used for different tissues as follows: gills were stained with Chlorazol Black E and Alcian Blue-PAS; muscles were stained with Chlorazol Black E and Masson's Trichrome; all other tissues were stained with Alcian Blue-PAS and Masson's Trichrome. The Alcian Blue-PAS and Chlorazol Black E stains were performed by hand and the Masson's Trichrome stain was carried out in an automatic tissue stainer. Slides were cover slipped with "Permount" mounting media. Slides were read with the aid of a Leitz Ortholux microscope.

TABLE 20.2

ORGANS USED FOR HISTOPATHOLOGY OF INVERTEBRATES

	Gill	Digestive Organ	Intestine	Muscle	Kidney	Stomach	Heart	Caecum
Shrimp	x	x	x	x		x		
Stomatopods	x	x	x	x		x		
Crabs	x	x	x	x			x	
Squid	x		x	x	x			x
Bivalves	x	x	x	x	x			

Occasionally a tissue block would need to be recut. This occurred for example, when hard material was in the intestinal contents and caused the tissue section to shatter upon sectioning. Another example was an insufficient amount of a particular organ in a section, particularly in bivalve tissue blocks where the organs were not dissected and further sectioning deeper into the block provided sufficient material for examination. The total number of recuts was 262. The total number of slides studied was 9322.

A total of 15 organs was lost (9 intestines, 5 hearts, and 1 digestive gland). In all cases the tissue present was not the proper organ. Intestines of shrimp were very small and were usually left attached to muscle and/or gonadal tissue when dissected. During preparation of the tissue the intestines probably became detached and were lost. Crab hearts were very thin and fragile and were occasionally destroyed when opening the animal. The hearts may have partially adhered to the epidermis underlying the dorsal carapace. All of these blocks were recut several times in an attempt to find the wanted tissue.

Dr. John G. Mackin served as a consultant to aid in identifying parasites and other types of pathologies. Several pathological conditions of the paper shell scallop, *Amusium papyraceus*, were unknown to Dr. Mackin and nothing concerning them was available in the literature. An expert in molluscan pathology, Dr. Thomas C. Cheng, offered to identify these conditions. Slides containing these pathologies were sent to him in July, 1977, but he has been too busy to aid us as of this writing.

RESULTS AND DISCUSSION

General

Parasitic symbionts were responsible for most of the pathological

conditions observed in this study. Non-parasitic symbionts, found predominantely in the gills of decapods, generally were not pathological unless present in excessively high numbers. In such cases, blockage of normal function or mechanical damage may have resulted. Normally, pathological conditions caused by symbionts were obvious, but if the sectioned tissue did not contain the central portion of a lesion, such pathological conditions had to be described as having an unknown etiology. Viral diseases could not be identified in this study and were also classified as etiology unknown. There may have been more than one etiology for each type of pathological condition described in the same or different species.

The results are given in Tables 20.3 through 20.15. Results are given as percentages because the number of animals studied of each species was not the same. The percentages were obtained by dividing the number of animals of a given species with a particular pathological condition by the total number of animals of that species studied. Percentages higher than 100 indicate the pathological condition occurred in more than one organ. Each type of pathological condition was only counted once for a given organ. This was necessary as certain symbionts, such as nematodes, are long and sinuous, and could pass in and out of the plane of section several times without the observer being able to identify the true number of nematodes present. Therefore, animals were identically recorded as having a particular condition, whether one or many such conditions were present in any one organ. Tables of original data are presented in Appendix S.

Symbionts, other pathological conditions, organs and locations of conditions in the gills were listed by number to conserve space in the tables herein and in Appendix S. These numbers are decoded in the two

Key to Table Codes

ORGANS

105 GONAD
106 HEART
107 HEPATOPANCREAS
108 INC SAC
110 INTESTINE
111 KIDNEY
112 LIVER
113 MUSCLE
114 OVARY
117 STOMACH
120 CAECUM
121 BRAIN GANGLION
122 MANTLE
125 SALIVARY GLAND
150 PANCREAS

LOCATIONS

201 IN GILL CHAMBER
202 IN GILL FILAMENT
203 BETWEEN GILL FILAMENTS
204 BRANCHIAL SINUS
205 INVOLVING FILAMENTS AND BRANCHIAL SINUS
209 EPITHELIUM

SYMBIONTS

301 ALGAE
302 CESTODE LARVA
303 COPEPOD
304 DEGENERATE PARASITE
305 ECTOCOMMENSAL
306 FUNGI
307 GREGARINE
308 LABRYINTHYLID
309 MYXOSPORIDIAN CYST
310 NEMATODE
311 NEMERTEAN
312 PSEUDOKLOSSIA SP.
313 PROTOZOA
314 AMUSIUM HP BACTERIA
315 SPORAZOAN
316 SMALL CILIATE
317 STALKED CILIATE
318 OTHER CILIATE
319 TREMATODE LARVA
320 SYNOPHRYA SP.
321 SUCTORIA
322 COELENTERATE
323 NEMATOPSIS SP.
324 UNKNOWN EGGS ATTACHED TO GILL TISSUE

Key to Table Codes
(cont.'d)

SYMBIONTS (cont.'d)

325 HELMINTHS

327 UNKNOWN DIGESTIVE GLAND DISEASE (GREEN DISEASE)

328 DORVILLID POLYCHAETE

329 FLATWORM

330 ANNELID

331 BARNACLE

332 PINNOTHERIDAE (PEA CRAB)

333 TUBULARIAN

334 POLYCHAETE

335 LARVAL CRAB

336 AMUSIUM HALO CELL

398 UNKNOWN

GILL PATHOLOGIES OTHER THAN SYMBIONTS

401 EXCESS CELLULARITY & ATROPHY

402 LARGE CELL AGGREGATE

403 T - SHAPED

404 Y - SHAPED

405 SMALL CELL AGGREGATE

406 SWOLLEN BRANCHIAL SINUS

407 SWOLLEN FILAMENTS

408 THICKENED CUTICLE

410 DISEASE CONDITION - GLANDS STAIN PAS POSITIVE

411 DEFORMED FILAMENT

PATHOLOGIES OTHER THAN SYMBIONTS

501 ARTRETIC EGGS

502 SWOLLEN SARCOLEMMA

503 HYPERPLASIA - ABNORMAL CELLS

504 HYPERPLASIA - NORMAL CELLS

505 GRAM NEGATIVE BACTERIA

506 GRAM POSITIVE BACTERIA

507 OTHER BACTERIA

520 CYST - PROBABLE DEGENERATE PARASITE

521 CYSTIC REACTION TO PARASITE

529 CYST - UNKNOWN

540 LEUCOCYTIC INFILTRATION BY CYST

541 LEUCOCYTIC INFILTRATION BY DEGENERATING PARASITE

542 LEUCOCYTIC INFILTRATION BY PARASITE

549 LEUCOCYTIC INFILTRATION BY UNKNOWN

550 GENERAL LEUCOCYTIC INFILTRATION

551 HYALINIZATION

TABLE 20.3

PERCENT OF SHRIMP WITH GILL SYMBIONTS

	SYMBIONT AND LOCATION																														
	301	303	305	308	308	308	308	310	310	310	311	315	316	317	318	319	319	320	320	321	322	323	324	328	329	330	331	334	335		
Species	202	203	203	202	203	204	205	202	203	204	203	202	203	203	203	202	204	202	205	202	203	202	209	201	203	203	202	203	203		
Penaeus aztecus		1	1				2						40			1	2	35	1			1									
Penaeus setiferus										4			46	4	4		14	50	4	4											
Trachypenaeus similis			2		5	2							91					32												
Sicyonia dorsalis								3	3	3			94	45				65			3									
Sicyonia stimpsoni													100																	
Solenocera vioscai													81					50											13	
Squilla chydaea													25							6										
Squilla empusa													50		10															

TABLE 20.4

PERCENT OF SHRIMP WITH GILL PATHOLOGIES OTHER THAN SYMBIONTS

Species	PATHOLOGY AND LOCATION																														
	401 202	401 204	401 205	402 202	402 205	403 & 404 202	405 202	406 204	406 & 407 205	407 202	407 204	408 202	410 202	410 204	411 202	503 202	503 205	504 202	505 202	507 202	529 202	529 204	529 205	540 202	557 202						
Penaeus aztecus	56									1		3	3								25	19			1						
Penaeus setiferus	86		11							4		7				4					39	46	4								
Trachypenaeus similis	57											2	5								39	16		2							
Sicyonia dorsalis	81						3	3		100		6				3					16	3	6								
Sicyonia stimpsoni	17									100								33				17									
Solenocera vioscai	75	6								6	6		19	6							31	6									
Squilla chydaea	19																				38	6									
Squilla empusa																					10										

TABLE 20.5

PERCENT OF SHRIMP WITH SYMBIONTS IN INTERNAL ORGANS

Species	SYMBIONT																		
	302	303	304	307	308	310	311	312	314	315	319	321	323	325	327	329	330	336	398
Penaeus aztecus	21		6	28		87					4								1
Penaeus setiferus	50			4		21					4								
Trachypenaeus similis	16			5		11													2
Sicyonia dorsalis			26	3		152													
Sicyonia stimpsoni				17		50										50			
Solenocera vioscai	13			13		13				6									
Squilla chydaea	13										13								6
Squilla empusa																			

TABLE 20.6

PERCENT OF SHRIMP WITH PATHOLOGIES OTHER THAN SYMBIONTS IN INTERNAL ORGANS

	PATHOLOGY																	
	501	502	503	504	505	506	507	520	521	529	540	541	542	549	550	551		
Penaeus aztecus	2		1	2				6	7	26	4	3	16	2				
Penaeus setiferus	7			4				14	11	71	29	7	18	7	7			
Trachypenaeus similis	2												2					
Sicyonia dorsalis								23		39	16	23	45					
Sicyonia stimpsoni										17								
Solenocera vioscai	6									6								
Squilla chydaea							6											
Squilla empusa																		

TABLE 20.7

PERCENT OF CRABS WITH GILL SYMBIONTS

Species	SYMBIONT AND LOCATION																																
	301	303	305	308	308	308	308	310	310	310	311	315	316	317	318	319	319	320	320	321	322	323	324	328	329	330	331	334	335				
	202	203	203	202	203	204	205	202	203	204	203	202	203	203	203	202	204	202	205	202	203	202	209	201	203	203	202	203	203				
Callinectes similis			13															10	2		12				4		4							
Portunus spinicarpus			5																		3				3		23							
Portunus gibbesii													6					11																
Anasimus latus	5		5			5					11							42	5		11			32		5		16					
Myropsis quinquespinosa																																	

TABLE 20.8

PERCENT OR CRABS WITH GILL PATHOLOGIES OTHER THAN SYMBIONTS

Species	PATHOLOGY AND LOCATION																															
	401 202	401 204	401 205	402 202	402 205	403 & 404 202	405 202	406 204	406 & 407 205	407 202	407 204	408 202	410 202	410 204	411 202	503 202	503 205	504 202	505 202	507 202	529 202	529 204	529 205	540 202	557 202						
Callinectes similis	63		46	56	13	12	71	8	40	37		15			6		2				10	52	15								
Portunus spinicarpus	5			38			74		6	21		15			5						3	33	3								
Portunus gibbesii	67		11	39		11	89	6	33	39		22									11	44	6								
Anasimus latus	58		32	16			58		5	11		21			11						5	11	11								
Myropsis quinquespinosa				100			100			100																					

TABLE 20.9

PERCENT OF CRABS WITH SYMBIONTS IN INTERNAL ORGANS

Species	SYMBIONT																		
	302	303	304	307	308	310	311	312	314	315	319	321	323	325	327	329	330	336	398
Callinectes similis	8					2					6			2					
Portunus spinicarpus	8					13								3					
Portunus gibbesii	6					6													6
Anasimus latus					5	37													
Myropsis quinquespinosa																			

TABLE 20.10

PERCENT OF CRABS WITH PATHOLOGIES OTHER THAN SYMBIONTS IN INTERNAL ORGANS

	PATHOLOGY																		
	501	502	503	504	505	506	507	520	521	529	540	541	542	549	550	551			
Callinectes similis	2									31	8			2					
Portunus spinicarpus										18	5		3	5	3				
Portunus gibbesii										12	6								
Anasimus latus										15									
Myropsis quinquespinosa																			

TABLE 20.11

PERCENT OF MOLLUSCS WITH GILL SYMBIONTS

Species	SYMBIONTS AND LOCATION																																
	301	303	305	308	308	308	308	310	310	310	311	315	316	317	318	319	319	320	320	321	322	323	324	328	329	330	331	334	335				
	202	203	203	202	203	204	205	202	203	204	203	202	203	203	203	202	204	202	205	202	203	202	209	201	203	203	202	203	203				
Amusium papyraceus				2																	4	59											
Pecten gibbus																																	
Neopycnodonta cochlear																																	
Loligo pealei				7								3																					

TABLE 20.12

PERCENT OF MOLLUSCS WITH GILL PATHOLOGIES OTHER THAN SYMBIONTS

Species	PATHOLOGY AND LOCATION																																	
	401 202	401 204	401 205	402 202	402 205	403 & 404 202	405 202	406 204	406 & 407 205	407 202	407 204	406 202	410 202	410 204	411 202	503 202	503 205	504 202	505 202	507 202	529 202	529 204	529 205	540 202	557 202								
Amusium papyraceus																		2			4													
Pecten gibbus																																		
Neopycnodonta cochlear																																		
Loligo pealei																7		3	3	3														

TABLE 20.13

PERCENT OF MOLLUSCS WITH SYMBIONTS IN INTERNAL ORGANS

Species	SYMBIONT 302	303	304	307	308	310	311	312	314	315	319	321	323	325	327	329	330	336	398
Amusium papyraceus	16	63	53		4	39	2	57	22		43		18	29	10		4	27	20
Pecten gibbus																			
Neopycnodonta cochlear		100																	
Loligo pealei	83										10			28					

TABLE 20.14

PERCENT OF MOLLUSCS WITH PATHOLOGIES OTHER THAN SYMBIONTS IN INTERNAL ORGANS

	PATHOLOGY																	
	501	502	503	504	505	506	507	520	521	529	540	541	542	549	550	551		
Amusium papyraceus	2			2				6	16	55	2	8	2	6		2		
Pecten gibbus																		
Neopycnodonta cochlear																		
Loligo pealei									7									

TABLE 20.15

PERCENT OF ALL PATHOLOGICAL CONDITIONS

	No. of Specimens	Gills			Internal Organs			Total Pathologies
		Symbionts	Other Pathologies	Total	Symbionts	Other Pathologies	Total	
Shrimp	214	124	145	269	111	75	186	455
Stomatopods	26	42	42	84	19	4	23	107
Crabs	129	50	336	386	22	32	54	440
Bivalves	55	58	5	63	376	91	467	530
Squid	29	10	17	27	121	7	128	155
Total	453	284	545	829	649	209	858	

pages preceding the tables. Clarification of certain terms used follows. "In gill chambers" refers only to the location of the dorvillid polychaete frequently found living in the gill chamber of the spider crab, *Anasimus latus*. The adult polychaete is too large to go between gill filaments but may wander between the separate gills. "Between gill filaments" generally indicated the location of a non-parasitic symbiont. Under symbionts, the "algae" found only on the gills of *Anasimus latus*, may be an unknown protozoan or alga. "Degenerate parasite" refers to a parasite that has been attacked by the host's leucocytes. Identification was made at an early stage of defense by the host when the parasite could still be identified as such in the lesion. "Ectocommensal" indicates an unknown apparently non-parasitic symbiont as compared to known non-parasitic symbionts such as the coelenterates found among some crab gills. "*Amusium* HP bacteria" refers to a specific bacterial disease of the hepatopancreas (HP) of the paper shell scallop, *Amusium papyraceus*. "Small ciliate", "stalked ciliate" and "other ciliate" indicate the three types of ciliates observed in sections of shrimp gills and are discussed under shrimp, below. "Helminths" indicates parasitic worms that could not be further classified as trematodes, cestodes, etc., when not enough of the parasite was present in the sections or it was a very young larval stage, difficult to identify. "*Amusium* halo cell" indicates an unknown disease in the paper shell scallop which may be caused by a protozoan and is discussed in detail below. "Unknown" refers to a symbiont, usually parasitic, which was not present in the sectioned tissue in sufficient amount to identify it. Under pathological conditions other than symbionts "other bacteria" refers to bacteria not tested with the Gram stain. "Cyst-unknown" indicates a lesion which was the result of the defensive reaction of the host against a parasite, bacteria, virus or perhaps mech-

anical damage. If the reaction by the host had progressed to the extent of destroying the invading organism, one could not distinguish between the possible etiologies. "Leucocytic infiltration", either general or specific indicates a reaction by the host to the invading organism.

When a pathological condition was recorded in an internal organ the condition may have been in the outer or inner connective tissue, around blood vessels, nerves or ducts in the organ as well as in the parenchyma of the organ itself. Locations of conditions in the gills were listed rather than combined, as the locations were considered more important. If a pathological condition was found in the gill filaments the affected area was localized compared to its presence in the branchial sinus which may have become blocked and therefore, affected the entire distal portion of the gill. Locations in the gill were also differentiated between symbionts attached to or actually in the gill and those merely caught between the gill filaments but living freely. Since gill symbionts and other pathological conditions are generally different from those in the internal organs, they were treated separately in this report.

Stomatopods were included with shrimp in most of the tables in this report and in Appendix S.

Shrimp

Shrimp were the most common animals collected (47%). They were caught at every station and during every month collections were made (Table 20.1). *Penaeus aztecus*, the brown shrimp, was collected most frequently (89 animals). It was found at every station and caught at least once every month. *Trachypenaeus similis*, the rough-back shrimp was the next most common (44 animals) and found at all stations and collection periods with the exception of two months. *Sicyonia dorsalis*, the rock shrimp,

was only found at Station 2 and *Penaeus setiferus*, the white shrimp, only at Station 1. *Solenocera vioscai*, the broken-back shrimp, was only collected during three periods and only at Stations 2 and 3. *Sicyonia stimpsoni*, a rock shrimp, was collected and used once, thinking at first it was *S. dorsalis* which it closely resembles.

Gills

Shrimp had the highest percent of gill symbionts, most of which were ciliates (Table 20.3). Three kinds of ciliates were found. A small ciliate, which was believed to be an apostome ciliate of the genus *Synophyra*, was the most common.

This ciliate has a complicated life cycle (Chatton and Lwoff, 1935) and has been known to infect some of the decapods used in this study (Johnson and Bradbury, 1976). Briefly, the life cycle of this apostome is as follows. The free-swimming stage enters a decapod's gill and grows into a relatively large organism. During this growth, the gill tissue around the ciliate becomes swollen, fills with excess cells and contains areas of necrosis and atrophy. Then the ciliate divides into many daughter cells. These are released into the surrounding water, through a break in the atrophied gill tissue, as the free-swimming stage. The stages of infection by this ciliate that have been identified in the shrimp used in this study were when the ciliate had enlarged within the damaged gill and the early stages of division into daughter cells. When the ciliate is in the free-swimming stage the only way to positively identify it is to cause infection by a laboratory test. It is impossible to identify when in early stages of infection or if only the edges of a lesion are seen in the sectioned tissue because other pathological conditions or even mechanical damage could possibly cause the same reac-

tions in the gill (Ernst and Neff, 1978).

This small ciliate was found among the gills of all shrimp studied and was the most common symbiont with a positively identified stage of *Synophrya* sps. the next most common. It was found in all shrimp except *S. stimpsoni* (only six animals collected). Lesions which possibly could be caused by this organism were found in all shrimp and were the most common pathological condition (excess cellularity and atrophy).

Unknown cysts were the next most common lesion in shrimp gills, and some of these may also have been caused by *Synophyra* sps. The small ciliate, which may be the freely swimming stage of *Synophyra*, was most common in the spring months while the late infection stage, where the organism could be identified as *Synophyra* sps., was most common in the summer. The unidentified lesions of excess cellularity and atrophy, most of which were probably due to *Synophyra* sps., were also most common in the summer.

The other two ciliates found among shrimp gills were a stalked species of the order Peritricha, and an unknown ciliate which resembled that seen infecting a stomatopod in 1976. The stalked ciliate was common in *S. dorsalis* (45%) and was seen in the gills of one *P. setiferus*. It attached to the thin cuticle of the gill filaments but did not appear to cause any damage other than a very slight thickening of the cuticle. The unknown ciliate was found only among the gills of one *P. setiferus*.

Nematodes were found in the branchial sinuses of *P. setiferus* and *S. dorsalis* and between and in the gill filaments of *S. dorsalis*. Trematode larvae were also found in the gills of shrimp (*P. setiferus* and *P. aztecus*).

Other parasitic symbionts were rare and included labryinthylids, a suctorian and *Nematopsis* sps. Those symbionts that apparently were non-parasitic were also rare, and included a copepod, a coelenterate, larval

crabs and unknowns. The larval crabs and possibly all the others may have simply been swept into the gill chamber by the movement of the water by chance, and do not normally inhabit shrimp gills.

S. dorsalis had the highest percentage (216%) of total gill symbionts and *P. aztecus* the lowest (85%). However, *P. aztecus* had the largest variety of gill symbionts (six). The greatest percentage of all symbionts was found at Station 2 in the summer and the least at Station 3 in the winter.

The two major pathological conditions other than symbionts (excess cellularity and atrophy, and cysts from unknown causes) have been discussed in relation to the parasitic ciliate, *Synophyra* sps. Other pathological conditions (Table 20.4) included swollen filaments which occurred in every specimen of *S. dorsalis* and *S. stimpsoni*. One specimen each of *P. aztecus* and *P. setiferus* also had this abnormality. This may have been due to some pathological condition, particularly in the penaeid shrimp. Since it occurred in every specimen of the genus *Sicyonia*, although only a portion of the filaments in each gill were affected, it would appear more likely that this reflected a physiological condition rather than a pathological one, and was manifest by the action of the fixative on the gill tissues.

Normally, the mucous glands in the shrimp gills stained with Alcian Blue, indicative of a sulphated acid mucopolysaccharide. In a few *P. aztecus* and *T. similis*, however, these glands stained only with PAS, suggesting loss of the sulfur and acid moieties. This may have been due to a metabolic disorder caused by chemical poisoning of the enzyme systems involved.

The few cases of hyperplasia found in the gills had unknown etiologies. The remaining types of conditions, *i.e.* thickened cuticles and

swollen areas of branchial sinuses, also had unknown etiologies and could have been caused by mechanical damage as well as disease.

S. dorsalis also had the most pathological conditions other than symbionts (223%) and *S. vioscai* the least (64%). In addition, *S. dorsalis* had the largest variety (seven). The greatest percent of pathological conditions was found at Station 2 in the fall and the least at Station 3 in the spring.

Internal Organs

Nematodes were the most common symbiont in the internal organs of shrimp (58%)(Table 20.5). Eighty-four percent (84%) of the shrimp caught at Station 2 had nematodes and 96% of those caught in the summer had these parasites. Nematodes were found mostly in the stomach (39%) and the hepatopancreas (36%). Cestode larvae were found in 21% of the shrimp and gregarines were in 15%.

S. dorsalis had the highest percent of symbionts (181%), most of which were nematodes. One specimen also contained gregarines in the intestine and eight had degenerate parasites, probably all nematodes. *P. aztecus* also averaged more than one symbiont per shrimp (147%), including nematodes (87%), gregarines (28%) and cestode larvae (21%). Degenerate parasites, trematode larvae and an unknown symbiont were also found. *S. stimpsoni* also averaged more than one symbiont per specimen (117%) even though only six specimens were studied. The symbionts were flatworms and gregarines in the intestines and nematodes in the hepatopancreas, stomach and gonad. *P. setiferus, T. similis* and *S. vioscai* all averaged less than one symbiont per specimen. They had the same symbionts mentioned above plus a sporozoan found in the gonad of one *S. vioscai*.

Pathological conditions other than parasites in shrimp internal organs were generally derived from infections by parasites (Table 20.6). Cysts of unknown origin were the most common type of condition observed (24%). These could have been caused by parasites that were successfully attacked by the host or by bacteria, viruses or even injuries. Cysts that contained degenerating parasites and leucocytic infiltration of the tissues around live and degenerating parasites, cysts, and in non-specific areas of the organs, were generally all concerned with the host's defense against foreign protein, probably that of parasites. Most of these pathological conditions were found in the hepatopancreas (48%) and the stomach (28%), both of which had the largest percent of parasites.

P. setiferus had the largest percent of pathologies (175%), most of which were related to the reaction of the host to invaders. Most of the pathological conditions were found in the fall in *P. setiferus*, yet most of the parasites were found in the winter in this species. For *S. dorsalis*, the species with the next highest percent of pathological conditions (145%), the spring season showed the highest concentration of both parasites and pathological conditions related to parasites. In *P. aztecus*, the heaviest concentration of parasites and pathological conditions related to parasitic infection were both in the summer, and both were also consistent in being lowest at Station 2. The remaining shrimp had few pathological conditions and few parasites. Pathological conditions not obviously related to parasitism included atretic eggs, which were found in all shrimp except those in the genus *Sicyonia*, and hyperplasia found in the hepatopancreas of *P. aztecus* and *P. setiferus*, and the stomach of *P. aztecus*.

Stomatopods

The stomatopods used were the mantis shrimp *Squilla chydaea* and *S. empusa*. They were not found during the warm months of the year and usually

were collected at Station 1 (Table 20.1).

Gills

The gills of stomatpods had very few pathological conditions of any sort as compared to the shrimp (Tables 20.3, 20.4). Only one-fourth of the *S. chydaea* and half of the *S. empusa* had small ciliates in the water around their gills. No stages of infection where *Synophyra* sps. could be identified were found, so these small ciliates may have been among the stomatopod gills by chance and not capable of completing their life cycles there. Only one specimen of *S. empusa* had the unknown ciliate among its gill filaments which was seen to infect specimens of *S. chydaea* in the previous year. A suctorian, infecting the gills of one *S. chydaea*, was the only other symbiont observed in the stomatopod gills. Cysts from unknown causes and areas of excess cellularity and atrophy were the only other pathological conditions and may have been caused by mechanical damage as well as from disease.

Internal Organs

No symbionts (Table 20.5) or other pathological conditions (Table 20.6) were found in the internal organs of *S. empusa*. *S. chydaea* only had two trematode larvae and one unknown in the stomach and two cestode larvae in the large nerves by the brain ganglion. One specimen had a bacterial infection in the salivary gland.

Crabs

A total of 129 crabs was used in this study. They were collected every month and at every station (Table 20.1). *Callinectes similis*, the lesser blue crab, was collected most often (52 animals). It was found at every station (Station 3 only in February) and every season except spring. *Portunus spinicarpus*, the spiny crab, was routinely collected at Station 3 and also at Station 2 in April. *Portunus gibbesii* was only

collected during three months and only at Station 1 while *Anasimus latus*, the spider crab, was found only at Station 3 during all periods except winter. Only one specimen of *Myropsis quinquespinosa* was collected. It was taken in April at Station 3. Several other trawling attempts did not produce any usable species.

Gills

Crabs had relatively few symbionts (Table 20.7) but did have, by far, the largest percentage of other types of pathological conditions (Table 20.8) in their gills. The most common symbiont was the parasitic *Synophyra* sps. (12%) and it was found most often at Station 2 in the fall. However, the small ciliate that was believed to be the free-swimming stage in the life cycle of this ciliate was found in only one specimen of *P. gibbesii*. *Synophyra* sps. was not found in *P. spinicarpus* or *M. quinquespinosa*.

The only other parasitic symbionts were a labyrinthylid in the gills of one specimen of *A. latus*, barnacles attached to the gill of *C. similis* and *P. spinicarpus* and an unidentified organism, either an alga or protozoan, attached to the gills of one specimen of *A. latus* in the spring. The barnacles, probably *Octolasmis* sps. or *Lepas* sps. (Walker, 1974), caused only a local thickening of the gill cuticle and slight deformation of the gill filament at their attachment sites. Their main pathological effect would be a decrease in respiratory efficiency by impairing gill movements and reducing the amount of exposed gill. The unknown organism attached to the gills of *A. latus* caused cuticular thickening, swelling of gill filaments and necrotic areas in the gill epithelium associated with a leucocytosis. This form was also seen in these crabs in 1976. The labryinthlid caused hyperplasia and swelling of the host's gill. All other gill symbionts

appeared to be non-parasitic but could have caused loss of respiratory function if they occurred in large numbers. Mechanical damage to the gill filaments could have ensued from their presence if they were large enough, as appeared to be the case in some of the nemerteans.

Some of the pathological conditions which had no obvious etiology may have been caused by *Synophyra* sps. When this organism was visibly present in the crab gill, the gill filament was swollen with excess cells, had necrotic areas, and was atrophied distally. Identical lesions were found where the section of the crab gill did not cut through the center of the lesion where the ciliate was growing. These lesions were most probably caused by *Synophyra* sps. as shown by the fact that crabs with *Synophyra* infections had about 12 times the percent of these lesions as contrasted to the percent of such lesions in *P. spinicarpus* which was not found to be infected with *Synophyra* sps. Other unknown etiologies, however, could possibly have caused the same type of condition. Small and large aggregates of cells in the gill filaments may also have been early stages of infection by this parasite. Cysts, with no obvious etiology, may also have been caused by *Synophyra* or other parasites, bacteria, viruses or injuries. They were found in the filaments (7%), in the branchial sinuses (39%) and some large cysts involved both regions (9%).

Crab gills showed several types of deformities which may have been caused from injury or disease or may have been from genetic origin. Some gill filaments joined into one distally. Occasionally, the branchial sinus was branched and formed two complete distal portions of a gill. All of these deformities were easily observed as crab gills were very symmetrical in form in contrast to other crustacean gills studied which were highly dendritic and more difficult to observe in sectioned material.

Swollen filaments and/or branchial sinuses were common, particularly in *C. similis* (85%). As in the shrimp, this may have been due to injury, disease of may be a reflection of a physiological condition manifested by the fixative.

Internal Organs

Crabs had relatively few internal symbionts (22%)(Table 20.9) and other pathological conditions (32%)(Table 20.10). The symbionts were all parasitic, and again, nematodes were the most common (11%). Most of the parasites occurred in the hepatopancreas (41%). This correlated with the pathological conditions, most of which could have been the result of parasitic infection, as the largest number were also in the hepatopancreas (51%).

The only parasites in *C. similis* were found in the nerves inervating the muscle and in the epimysium or perimysium, none among the muscle fibers. No evidence of any reaction by the host to these parasites was observed. Cysts of unknown origin, leucocytic infiltration around these cysts and one atretic egg were the only other pathologies observed in this crab. In *P. spinicarpus*, all parasites and pathological conditions, except for one atretic egg, were found in the hepatopancreas. Both *P. gibbesii* and *A. latus* had very few parasites and other pathologies in their internal organs.

Molluscs

The paper shell scallop, *Amusium papyraceus*, was the only bivalve collected from Transect II with any consistency (Table 20.1). It was not available in February or October, however, and only one was collected in November. The latter specimen and the three taken at Station 2 in April

were extra species (three other species were collected in sufficient numbers), but only one specimen was found at Station 3 in April when collections were made during daylight hours. One specimen of a scallop, *Pecten gibbus*, was collected as an extra species in March at Station 2. This was a small specimen which measured only 2.2 cm in width and had no pathological conditions of any kind. A rare oyster, *Neopycnodonta cochlear*, was collected in April at Station 3 and used because no other species could be collected. The squid used, *Loligo pealei*, was collected at Station 1 in the summer and at Station 3 in February and April.

Gills

Molluscs had few pathological conditions in their gills (Tables 20.11 and 20.12) as compared to the crustaceans studied. Only one gill symbiont, which appeared to be unknown eggs attached to the gills, was found in 59% of *A. papyraceus*. One labrythylid occurred in one of these scallops and two squid were also infected with this fungus. A sporozoan was found in one squid's gills and two specimens of *A. papyraceus* had *Nematopsis* sps. spores in their gills.

Pathological conditions other than symbionts in molluscan gills included two cysts with unknown etiologies and one instance of hyperplasia in *A. papyraceus*. In the squid, there were two cases of bacterial infection and three of hyperplasia. The hyperplasia occurred in the branchial gland of the squid and appeared to spread to the connective tissue and epithelium of the gill proper. Why hyperplasia would develop in a gland which presumably synthesizes hemocyanin is unknown. The branchial gland has been shown to be the site of hemocyanin synthesis in *Sepia officinalis* and *Octopus vulgaris* (Dilly and Messenger, 1972).

Internal Organs

Molluscs had the largest percentage (288%) of symbionts in internal organs (Table 20.13). Most of these were in *A. papyraceus*, which averaged over four symbionts per specimen (412%). This bivalve also had the greatest variety of symbionts (15), most of which occurred in the gastro-intestinal tract. The most common symbionts in scallops were copepods (63%). A protozoan, believed to be *Pseudoklossia* sps. (Leger and Duboscq, 1915; 1917), was present in 94% of the scallops collected at Station 2. This parasite invaded the nephridial cells of the host where they appeared to undergo degeneration. Certain other parasites also occurred only at Station 3 in *A. papyraceus*. These included nematodes (39%), spores of *Nematopsis* sps. (18%), an unknown bacterial species that infected the epithelium of the hepatopancreas (22%), and an unknown organism, probably a protozoan, which invaded the heart muscle cells and the connective tissue throughout the animal (27%). This organism appeared to have a halo around it due to the fixative and stains used. When in the connective tissue, but not the heart, the host occasionally appeared to react to these cells, causing their degeneration. The oyster, *N. cochlear* only had copepods in the stomach and intestines and no other pathologies.

All of the symbionts in the squid internal organs were parasitic. Eighty-three (83) percent of the squid had cestode larvae, 28% had helminths either too young or insufficient in sample quantity to identify, and 10% had trematodes. Most of these parasites occurred in the animals collected in the summer at Station 1. They were found in the gastro-intestinal tract, including the so-called pancreas.

This organ has never been definitely shown to produce digestive enzymes, as contamination of fluid from the liver is almost impossible to avoid due to the pancreas being a glandular extension of the hepatic

duct (Bidder, 1950; 1966). The morphology of the glandular cells also does not conform to that of a protein secreting cell but rather to a cell involved in ionic regulation with its highly infolded basal membrane and high concentration of mitochondria (Boucaud-Camou, 1972). The organ is covered with a layer of kidney cells, and since the only description that could be found of squid renal organs was of *Sepia officinalis*, which has accessory renal organs as well as a chief renal organ, the "pancreas" of *L. pealei* in this study originally was considered an accessory renal organ due to its morphology and staining characteristics. The function of the squid "pancreas" is still unknown.

Most of the pathological conditions other than symbionts in molluscs (Table 20.4) were cysts of unknown origin (32%). These and other pathologies could have been the effect of the parasites on the host.

The greatest percent (145%) of pathological conditions other than symbionts occurred in scallops collected at Station 3, where these animals had the largest percentage of parasites (584%). The majority of these conditions were also found in the gastrointestinal tract as were the parasites. Sixteen (16) percent of the scallops showed cystic reactions to parasites which was rarely observed among other animals in this study. The only pathologies other than parasites in *L. pealei* were two animals with a cystic reaction to a parasite.

CONCLUSIONS

Shrimp were the most common species of animals collected for this study and consisted of six species. Fewer shrimp were collected per month in the summer and slightly more in the fall as compared to the other seasons. They were found most often at Station 2 and least often at Station 3. Stomatopods were only collected in three months and mostly

at Station 1, never at Station 2. Crabs were the next most common species collected and consisted of five species. They averaged about the same number of specimens every season (16 per month) except during spring when lower numbers were observed, and were found most often at Station 3. Three species of bivalves were collected, but only one, *Amusium papyraceus*, was collected in sufficient numbers (49) to be useful. This species was found most often in the summer, least often in the fall, most often at Station 3 and never at Station 1. The only squid studied was *Loligo pealei*, and it was collected most often in the summer at Station 1.

The total number of all pathological conditions in the gills almost equaled that in all of the internal organs. Shrimp had the largest variety and the highest percent of gill symbionts, most of which were parasitic ciliates. These were the only animals to have metazoan parasites inside their gill tissues (trematode larvae and nematodes). Crabs also had many different kinds of gill symbionts, but most were ectocommensal or did little harm to the gills, such as barnacles, and the total number of crabs with symbionts was low. Crabs had the greatest percentage of pathological conditions other than symbionts, however. Most of these had unknown etiologies and could have been caused by parasites, bacteria, viruses or injuries. The remaining animals had very few symbionts and other pathological conditions in their gills, both in kind and number.

Even though stomatopod gills are the least protected of any of the animals studied, they displayed surprisingly few symbionts or other pathological conditions. Bivalve gills have cilia and a great many mucous glands which help protect them. In squid, the force of the water passing through the mantle may help in preventing symbionts from settling in the gills.

The large majority of pathological conditions in the internal organs

of the invertebrates studied were caused by parasites. They most commonly invaded the gastrointestinal tract. The host frequently reacted against these parasites by mobilizing their defensive cells, the leucocytes, and walling off the parasite by forming layers of connective tissue around the invader. The leucocytes then attempted to destroy the parasite with proteolytic enzymes and quite often were successful. Bivalves had the highest number and largest variety of internal parasites, particularly the paper shell scallop which averaged almost six parasites per specimen in those collected at Station 3. Squid had the next highest percentage of internal parasites but very few reactions against them, while shrimp, which had almost the same percentage of parasites, had over 10 times as many reactions to the invaders.

Generalities can be made about the various groups of animals, such as shrimp or crabs, but there were many large differences between species within each group. For example, all of the shrimp had a higher percentage of symbionts than other pathological conditions in their internal organs except *Penaeus setiferus*, which had over two times as many pathological conditions as symbionts. This species had 35 times as many of these pathological conditions in its internal organs as *Trachypenaeus similis*. The species with the lowest percentage of all types of pathologies in the internal organs, *T. similis*, had a relatively high percentage of all conditions in the gills.

Differences among species also occurred among the crabs. *Anasimus latus* was the only crab with a larger percentage of symbionts in its internal organs than other types of pathological conditions which was similar to conditions found in the majority of the shrimp. This crab was also like the shrimp in that the percentage of symbionts in the gills was approximately the same as the average percentage in shrimp but

was over three times the amount found in other crabs.

In general, bivalves were found to have the largest percent of all pathological conditions due to the very high number of internal parasites in *A. papyraceus*. Shrimp had relatively high percentages of pathologies in all categories. Crabs had a high total percentage of pathologies due to the large number of pathological conditions other than symbionts in their gills. Stomatopods were the healthiest of all the animals.

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CHAPTER TWENTY-ONE

REPRODUCTIVE CYCLE, HISTOLOGICAL-HISTOPATHOLOGICAL SURVEY OF GONADAL TISSUE AND KARYOTYPE ANALYSIS OF SELECTED SPECIES OF MACROEPIFAUNA AND DEMERSAL FISHES

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ABSTRACT

During the 1977 effort in the histological-histopathological survey of gonadal tissue o f macroepifauna and demersal fishes of the South Texas Outer Continental Shelf (STOCS), tissues were collected during nine sampling efforts. Twenty-four (24) species and 878 specimens were collected. This included additional species and specimens that were necessary to maintain continuity for the reproductive cycle study and to assure proper controls.

The purpose of this portion of the histopathological effort was three-fold: first, to establish the normal seasonal (physiological) changes in the histology of the male and female gonads; second, to examine the gonads for pathological conditions; and third, to develop methodology for karyological analysis and establish karyotypes for marine organisms. Seasonal changes (reproductive cycle) in the histology of the gonads were only partially established, since the survey was conducted during five samplings in 1976 and nine samplings in 1977. During this period several months were not sampled at all due to collecting protocol, thus leaving gaps in the data. Also, during some samplings only one sex of some species was collected. Gonadal tissues were examined for pathological conditions and/or parasites. A number of pathological conditions were found in these tissues, but the incidence of pathology in the gonads was only 16.9%. Chromosomal counts and karyotypes were established for some invertebrates and fishes.

INTRODUCTION

The histological-histopathological characterization study of the macro-epifauna and demersal fishes of the STOCS was initiated in the summer of 1976 and continued through 1977. Physiological conditions and pathological changes and/or occurrences were monitored and catalogued. This study consisted of the survey of: 1) vertebrate and invertebrate gonads; 2) karyotype analyses of vertebrate and invertebrate species.

This report deals with the survey of histopathological conditions of gonadal tissue, partial reproductive cycles based on 1976 and 1977 data, and karyotype analysis of selected vertebrate and invertebrate species. The analyses of the gonad and gonadal tissues of vertebrates and invertebrates aided in the understanding of the normal seasonal physiological changes associated with the reproductive cycle. The survey also recorded any pathological conditions already occurring in the tissues.

If the histopathological conditions of gonads and gonadal tissues are to be monitored, it is important to first establish the normal reproductive cycle changes occurring in gonadal tissues. In contrast to other tissues, which are not seasonally dependent, the gonads are constantly changing according to the breeding season and environmental factors such as photoperiod, temperature and/or food supply (Burns, 1976, Fuller, *et al.*, 1976, Hoar, 1969; Larson, 1972; Schwassmann, 1971). Since gonadal tissues undergo a complete temporal change due to external and internal factors (Andrew and Hickman, 1974, Bloom and Fawcett, 1975; Hoar, 1969; Sadlier, 1973), it is important to know what changes normally occur before attempting to assign a pathological condition to such changes. Each species has its own inherent reproductive cycle that puts it at a different phase at any given period (Barr, 1963a, b, c; Burns, 1976; Larson, 1972; Liley, 1969; Fuller *et al.*,

1976; Macer, 1974; Schwassmann, 1971) making it difficult to generalize about tissue condition. An additional problem arises in the fact that individuals of the same species may be at different phases in the reproductive cycle. Because the gonadal tissues are of two types, testicular and ovarian, the problem of establishing normal conditions is further compounded. This requires the collection of additional individuals per species to ensure equal (or close to equal) distribution of male and female specimens. Partial reproductive cycles are reported herein for those species that were collected during the majority of the cruises. The other species provided back-up data since it is difficult to predict which species will be available during any given collecting effort.

The pathologies of the ovary and testes as recorded were primarily limited to certain major conditions. Parasites were normally easy to identify and their effects on the tissue and/or organ readily seen. Without an established histological reproductive pattern, it was difficult to know if conditions such as interstitial cells, amorphous masses, leucocytic infiltration, and fibroblast infiltrations were part of the normal cycle or pathological.

Development of methodologies for karyological analysis and the determination of karyotypes of related species were also done as part of the study. The methodologies for karyological analysis have been reported in the 1976 Final Report to the Bureau of Land Management (Ramirez, 1978). The karyotypes and chromosome numbers of several species are reported here to provide a basis for future monitoring for chromosomal aberrations.

MATERIALS AND METHODS

Sampling

Samples for histopathological analysis were taken during three seasonal

and six monthly cruises. Collections were made at Stations 1, 2 and 3, Transect II, with a 35-foot (10.7 m) standard otter trawl set to sample epifauna and near surface infauna. Additionally, at Southern Bank, demersal fish were collected with a hook and line. Whenever possible, ten individuals of each species were collected to insure equal distribution of male and female specimens.

A total of 878 specimens was collected during the study period. This was in excess of the 675 specimens required by the contract. Since all species were not evenly distributed spatially or temporally, additional species were collected to insure sampling continuity from one cruise to another. This provided an overlap in the species that were available during different cruises. Since a goal of this study was to provide a catalogue of seasonal changes as well as pathological conditions, continuity was essential. Tables 21.1 and 21.2 show the same species were not present in every trawl. By increasing the number of species sampled, some continuity was maintained.

In this study, not only was gonadal histology investigated, but seasonal changes in male and female tissues were also evaluated. The need for ten specimens per species was important in attempting to obtain equal numbers of males and females since secondary sexual characteristics are not always evident. It was also important to collect, whenever possible, the same species every cruise.

Shipboard Processing

Specimens selected for sampling were processed on board ship to avoid any post-mortem histological changes (Galigher and Kozloff, 1971; Gurr, 1962; Guyer, 1953; Lillie, 1977; Pearse, 1975). This became critical for samples from Station 3, Transect II, because these specimens were from

TABLE 21.1

VERTEBRATES COLLECTED DURING 1976 AND 1977 ALONG TRANSECT II AND SOUTHERN BANK

	1976						1977											
	Jun	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wenchman																		
Pristipomoides aquilonaris	10	15		10	10	5			6	8		12	10	10		9	9	7
Longspined porgy																		
Stenotomus caprinus	5	7		7	12	7		14	10	5		6	5	5		10	10	8
Sand seatrout																		
Cynoscion arenarius	6	3		10	1	5		7	5	10		5	4				8	5
Atlantic croaker																		
Micropogon undulatus	5			10	2	4		2								12	15	11
Gulf butterfish																		
Peprilus burti		5		10						1								
Rock sea bass																		
Centropristis philadelphica		7		5	6	5		7				6						
Red snapper																		
Lutjanus campechanus		6			2					4		1	5	5	3	3	5	5
Rough scad																		
Trachurus lathami					10													
Dwarf goat fish																		
Upeneus parvus						5												
Black ear bass																		
Serranus atrobranchus								3										
Pinfish																		
Lagodon rhomboides									5									
Vermilion snapper																		
Rhomboplites aurorubens	7	6		10	5	6				5		5	6	6	10	10	1	10
Spot croaker																		
Leiostomus xanthurus										5						6		5
Scaled sardine																		
Harengula pensacolae														5				
Atlantic bumper																		
Chloroscombrus chrysurus														5				

TABLE 21.2

INVERTEBRATES COLLECTED DURING 1976 AND 1977 ALONG TRANSECT II

	1976						1977											
	Jun	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Paper scallop *Amusium papyraceus*				4	6	10		5	7			7	16	14				12
Blue crab *Callinectes similis*	4	10		3	5			5				2	5	19		13	9	17
Portunid crab *Portunus gibbesii*										6								2
Portunid crab *Portunus spinicarpus*				6	7	10				12		16		5		9	9	10
White shrimp *Penaeus setiferus*						8		6	7	7						8	10	10
Rock shrimp *Sicyonia dorsalis*				6	10	16			5			8						
Broken back shrimp *Solenocera vioscai*									5	10		9		10		10	5	9
Brown shrimp *Penaeus aztecus*	6	8		18	18	5		4	7	5		10	20	19		11	8	16
Rough back shrimp *Trachypenaeus similis*						10		10	11	5						9	9	7
Squid *Loligo pealei*	5	8		14	15	8		20	12			8	7	4			4	
Squid *Loliguncula brevis*										8			5	10		11	1	
Spider crab *Anasimus latus*																	5	

deeper waters than at Stations 1 and 2 and tended to undergo rapid histological changes due to pressure differences. Whenever possible, the animals were kept alive in a holding tank until processed.

Gonads were removed from the animals as soon as possible and fixed *in toto*. Fish gonad size ranged from 2 to 10 mm in diameter and from 10 to 50 mm in length. Fish gonads were fixed *in toto* due to their texture. They tended to roll back upon themselves when sectioned due to the highly elastic tunica (Hoar, 1969; Nelsen, 1953) resulting in severely distorted tissues. Since most fish gonads were less than 10 mm in diameter the fixatives could penetrate into the tissues rapidly. More importantly, *in toto* fixation prevented tissue distortion. It enabled the study of germinal development for possible sequential maturation of germinal cells. By preserving the entire gonad and maintaining orientation, material was obtained from the distal, medial and proximal areas and any variation in germ cell maturation analyzed.

Invertebrate gonadal tissues did not present the same problems as fish gonadal tissue. Invertebrates were dissected on board, whenever possible, gonads removed, sectioned and fixed. In several cases (shrimp and crabs), it was necessary to fix the thorax of the animal *in toto*. In these cases, the animal was decapitated, the abdomen removed, the exoskeleton peeled off and the thorax placed in the fixative.

Fixatives used were Bouin's (picric-acetic-formalin), Dietrich's (acetic-alcohol-formalin) and buffered formalin (Conn *et al.*, 1965; Galigher and Kozloff, 1971; Gurr, 1962; Guyer, 1953; Lillie, 1977; Pearse, 1975). These three fixatives were chosen and used because of the versatility allowed in staining reactions and their fixing capabilities.

Laboratory Processing

Tissues were processed according to standard procedures for a given fixative. Tissues were trimmed, or further trimmed, prior to laboratory processing. Fixatives were washed from the tissues, and the tissues were dehydrated and embedded. Tissues were sectioned at 5 µm. Some tissues were sectioned at 10 µm due to their texture or nature. Slides of each specimen were stained in Heidenhain's iron-hematoxylin/eosin (Galigher and Kozloff, 1971) and either the Feulgen nuclear reaction (Guyer, 1953) or Harris Hematoxylin-eosin (Galigher and Kozloff, 1971; Gurr, 1962). For study of the normal reproductive cycle in each species, a total of six slides were prepared. Sections were prepared from three areas of each ovary and testes to ascertain if differential and/or sequential development was occurring in any of the specimens.

Karyotype Analysis

Methodologies for karyotype analysis were modified from existing protocol to fit the nature of marine organisms (Ramirez *et al.*, 1978). Chromosome counts for seven species of fish and four species of invertebrates were made by either preparing karyotypes or photographs of chromosomal squashes.

RESULTS AND DISCUSSION

The reproductive cycles of fish and invertebrates can be established fairly well by histologically and behaviorally tracing the pattern of gamete formation. Field studies of reproductive cycles of fish are based on the gonadosomatic ratio (gonad weight/body weight)(Barr, 1963a, b, c; Baerends, 1971; Burns, 1965; Fuller *et al.*, 1976; Larson, 1972; Liley, 1969).

Studies have shown the gonads at different stages of development, but have made little or no attempt to trace the process histologically (Barr, 1963a, b, c; Leake, 1975; Sadlier, 1973).

Ideally, this would be easy if all animals sampled were in synchrony. The invertebrates appear to be more synchronous than the fish, which show a greater variability from station to station, and occasionally within specimens at a given station. Due to this variability by station, month and species, it is necessary to collect a greater number of specimens per species per station to provide a representative statistical base. One to two additional years of sampling would be necessary to provide the data necessary to establish conclusively the reproductive cycle for each species.

From the 1976 and 1977 sampling, a tentative reproductive cycle has been developed for *Pristipomoides aquilonaris* (wenchman), *Stenotomus caprinus* (longspined porgy), *Cynoscion arenarius* (sand seatrout), *Rhomboplites aurorubens* (vermilion snapper), *Penaeus aztecus* (brown shrimp), *Callinectes similis* (blue crab), and *Loligo pealei* (squid). Too much variation was noted even for organisms collected during every sampling effort to predict any of these cycles with total confidence.

The observed variation showed that animals collected were in early, intermediate, and mature stages of development. Furthermore, it was not known how fast animals observed in a given stage of development were developing. Correlations of the stage of development with temperature and light period have not been attempted. The developmental data available in the literature were insufficient to make any assumptions about the reproductive cycle behavior (Baerends, 1971; Bieniarz and Epler, 1976; Burns, 1976; Fuller *et al.*, 1976; Larson, 1972; Liley, 1969; Schwassmann, 1971).

Ovarian Histology

Fish

The teleost ovary is unique among vertebrates. The ovaries are hollow and lined with germinal epithelium that gives rise to the ovigerous folds. The oocytes develop from the edge of these folds. In contrast with other fish and vertebrates, the developing oocytes are not surrounded by large amounts of connective tissue stroma, follicular material, or vascular stroma but develop within a single cell layer follicle (Figure 21.1A).

The gross anatomies of the ovaries of the fish species reported here were much the same. The paired ovaries were completely enclosed in peritoneal folds to form a cystovarian type of ovary. The walls of the ovary consisted of layers of connective tissue and smooth muscle to form a capsule.

During development, the oocyte increases in size through the time yolk is deposited. The follicular cells change from squamous-like epithelial cells to cuboidal-like cells (granulosa) that contribute to the deposition of yolk, secrete hormones (Barr, 1963a, b; Hoar, 1969; Leake, 1975) and form the zona radiata (chorion)(Figure 21.1B). Ripe ova are released into the cavity of the ovary that is continuous with a simple ciliated oviduct. The release of ova leaves the ovigerous folds empty and distended with young oocytes and an occasional unshed ovum.

The pattern of ovulation varied among the species of fish examined. Some species produced large amounts of cellular debris, others disrupted the ovigerous folds, while some left large numbers of unshed ova that were eventually resorbed.

The atretic-resorbing oocytes and cellular debris (amorphous mass) was earlier classified (Ramirez *et al.*, 1977) as a pathological condition. With the additional 1977 data it appeared that these conditions were part

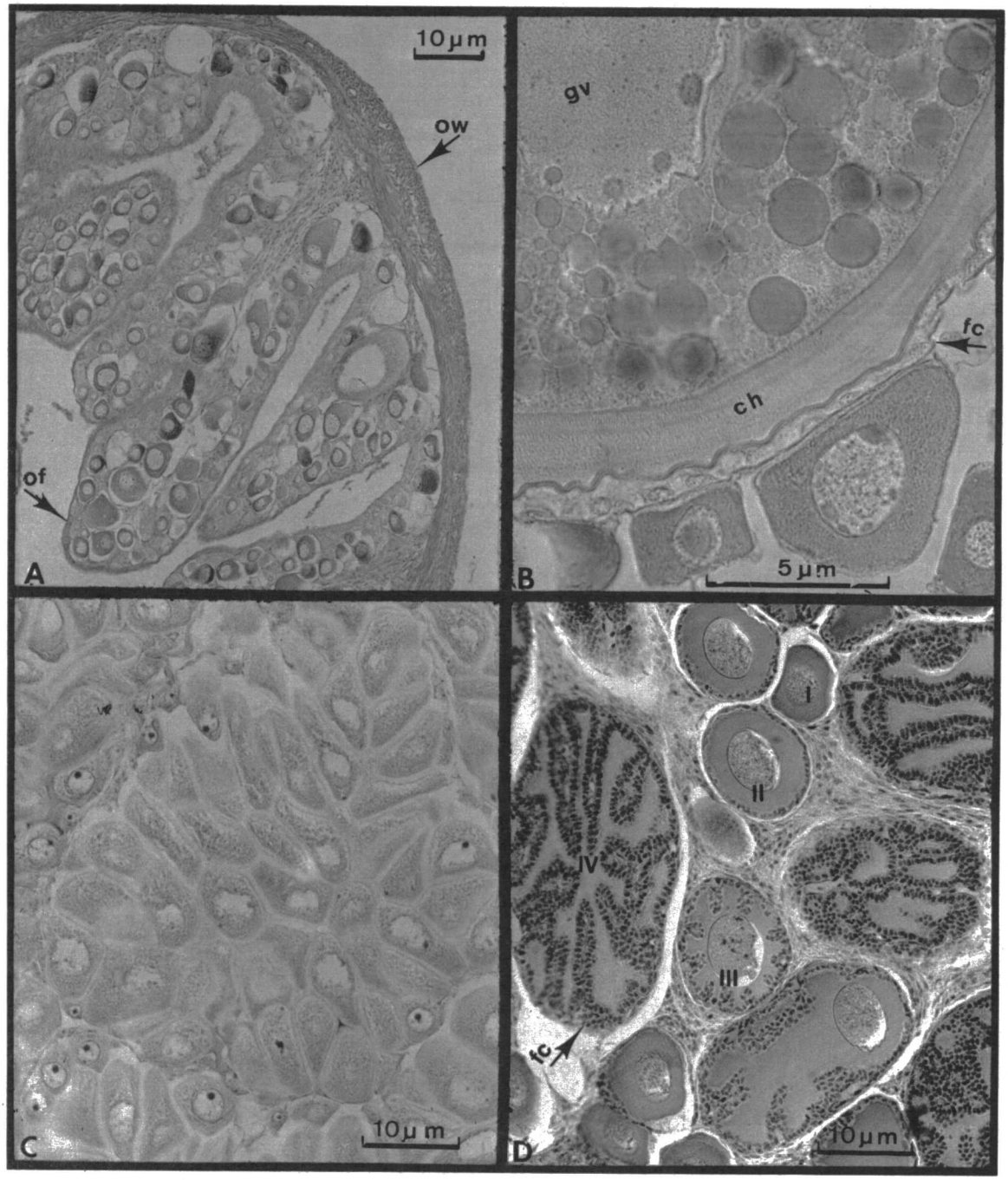


Figure 21.1

A. Longspined porgy (*Stenotomus caprinus*). General teleost ovarian organization showing ovary wall (ow) and ovigerous folds (of) extending into hollow ovary. 135X Feulgen.

B. Wenchman (*Pristipomoides aquilonaris*). Large mature oocyte with large germinal vesicle (gv), well developed chorion (ch) and single layer of follicle cells (fc). 540X Mallory's.

C. Scallop (*Amusium papyraceus*). Ovarian lobes filled with maturing oocytes. 135X H & E

D. Squid (*Loligo pealei*). Ovary showing four different stages of oocyte development (I-IV). Large oocyte (stage IV) with infolded follicle cell layer (fc). 135X H & E

of the normal cycle. The atretic-resorbing oocyte has been shown to occur in the fish that have been hypophysectomized or hormone treated (Barr, 1963a, b) and can be considered abnormal, yet residual gametes have been shown to undergo hyalinization and resorption (Macer, 1974). In examining the species used in this survey, certain species regularly demonstrated hyalinization, resorption, amorphous masses, and/or cellular debris that appeared to be part of the regular reproductive cycle. These conditions were not included nor counted as pathologies.

The stages of development of fish oocytes were based on oocyte size and whether vitellogenesis was occurring. References have been made for staging of oogenesis in the literature (Barr, 1963a, b; Macer, 1974) but only for selected species. For this study the oocyte stages were limited to general stages that could be applied to the majority of species studied (Table 21.3).

Invertebrates

The histology of invertebrate ovaries is not as uniform or as easy to describe as that of the vertebrate ovary. Most invertebrate ovaries, such as in the shrimps and crabs, are multilobulated masses of germinal tissues that may be separated from other organs and tissues or may extend and branch among other organs or be closely associated with other organs. In contrast, the squid ovary is unpaired and supported medianly by mesentery to the dorsal wall.

In the species sampled (Table 21.2), the majority had the general multilobed paired type of ovaries that increase in size with an increase in the number of oocytes. The ovary of the squid was enclosed in peritoneal-like membrane while the scallop's ovary was in the highly reduced "foot".

TABLE 21.3

MATURATION STAGES OF FISH OOGENESIS
ON THE SOUTH TEXAS OUTER CONTINENTAL SHELF

STAGE	HISTOLOGICAL APPEARANCE
Immature	Small uniform oocytes no larger than 10 μm in diameter; Cytoplasm without vacuoles & stains densely
Previtellogenesis:	
Quiescent	Similar to Immature Stage but obviously post spent and recovering; Germinal vesicle with one or two large nucleoli
Small Oocytes	Oocytes developing; Size of oocytes 15-100 μm; Follicle cell squamous like; Cytoplasm stains light; Germinal vesicle large with increased number of nucleoli
Large Oocytes	Increase in oocyte size; Range 100-200 μm; Follicle cells changing to cuboidal-like
Vitellogenesis:	
Primary Yolk	Oocytes larger than 150 μm; cytoplasmic vacuoles (primary yolk) begin to appear; Follicle cells cuboidal; Zona radiata begins to form
Secondary Yolk	Oocytes larger than 150 μm; Primary yolk droplets present plus densely staining yolk granules; Well formed zona radiata; Well formed follicle cell layer.
Mature	All stages of oocytes present; Majority of oocytes in 300 μm plus size with primary and secondary yolk present; Tightly packed oocytes.
Ripe	Similar to mature; Some indication of oocyte release from follicle and ovigerous folds.
Spent	Ovigerous folds empty and distented; residual mature oocyte present.

The oocytes of the invertebrates, with the exception of the squid, are not as complex as that of the fish. Invertebrate oocytes differ in maximum possible size. Most invertebrate oocytes, rather than being surrounded by follicle cells, develop within a lobe or large follicle. Development is either synchronous (Figure 21.1C) or sequential.

The developing oocytes of the squid are clustered and each oocyte is surrounded by a follicular cell syncytium (Figure 21.1D). The stages of oogenesis can be recognized by the structure of the follicle (Ramirez and Guajardo, 1977; Selman and Arnold, 1977).

Table 21.4 describes the histological appearance and description of the developing oocyte in the squid. The follicle cell layer surrounding the squid oocyte showed definite cyto-differentiation stages. These changes have been shown to be involved in vitellogenesis and secretory functions (Ramirez and Guajardo, 1977; Selman and Arnold, 1977).

Testicular Histology

Fish

The testicular gross morphologies of the fish species sampled were similar. The paired testes, with a very short sperm duct, were located posteriorly dorso-ventrally in the peritoneal cavity. The size varied with stage of development. Histologically, the testes consisted of a series of ill-defined lobes of thin connective tissue and elastic fibers lined with resting spermatogonia in the quiescent stage (Table 21.5; Figure 21.2A). Fish spermatogenesis was cystic rather than with true seminiferous tubules, as found in other vertebrates. During spermatogenesis the resting spermatogonia began to divide and form clusters of cells in separate cysts. Further cell division resulted in an increase in the size of the cysts. All of the cells within a given cyst were at the same

TABLE 21.4

MATURATION STAGES OF SQUID OOGENESIS
ON THE SOUTH TEXAS OUTER CONTINENTAL SHELF

STAGE*	HISTOLOGICAL APPEARANCE
Immature	Majority of oocytes less than 50 μm in diameter surrounded by few squamous follicle cells
I	Growing oocyte; Large germinal vesicle with several nucleoli; Oocyte surrounded by several squamous follicle cells; Oocyte and follicle 50-100 μm
II	Oocyte range 100-200 μm in diameter; Active proliferation of follicle cells and change from squamous to cuboidal shape
III	Follicle cells continue to proliferate and folds of follicle cells penetrate the growing oocyte. Majority (approx. 80%) of follicular volume is follicle cells. No yolk deposits are yet evident; Oocyte range 200-400 μm.
IV	Vitellogenesis is evident; Oocyte increases in size pushing the follicular layer to the periphery. The follicular cells have formed a snycytium; Oocyte size 400-800 μm.
V	Vitellogenesis continues; Chorion is formed; Follicular syncytium is pushed out; Cellular syncytium is sloughed off.
Mature	Oocyte size 800 μm-1.5 mm; Chorion formation complete-Oocyte ready to be shed.

*Adapted from Sellman & Arnold, 1977

TABLE 21.5

STAGES OF SPERMATOGENESIS OF TELEOST FISH FROM THE SOUTH TEXAS OUTER CONTINENTAL SHELF

STAGE	HISTOLOGICAL APPEARANCE
Immature	Lobules closed, lined with large, non-dividing resting spermatogonia; No spermatogenesis seen
Quiescent	Recovering from spent condition, some residual spermatozoa in sinus of lobules; Lobules lined by resting spermatogonia; Some dividing spermatogonia cysts present
Early Development	Increase in dividing spermatogonia cysts
Mid Development	Primary spermatocyte cysts predominant; Dividing spermatogonia and secondary spermatocyte cysts present
Late Development	Cysts at all stages of spermatogenesis present; Spermatid cysts predominant
Mature	Large number of cysts with mature spermatids, many cysts have ruptured releasing the spermatids into the sinuses that are formed by the ruptured cysts; Some cysts in various stages of spermatogenesis
Ripe	Similar to Mature with greater number of cysts ruptured; Increase in number of spermatids in sinuses
Spawned	Lobules with open sinuses; Residual spermatozoa seen in sinuses; Resting spermatogonia predominant stage

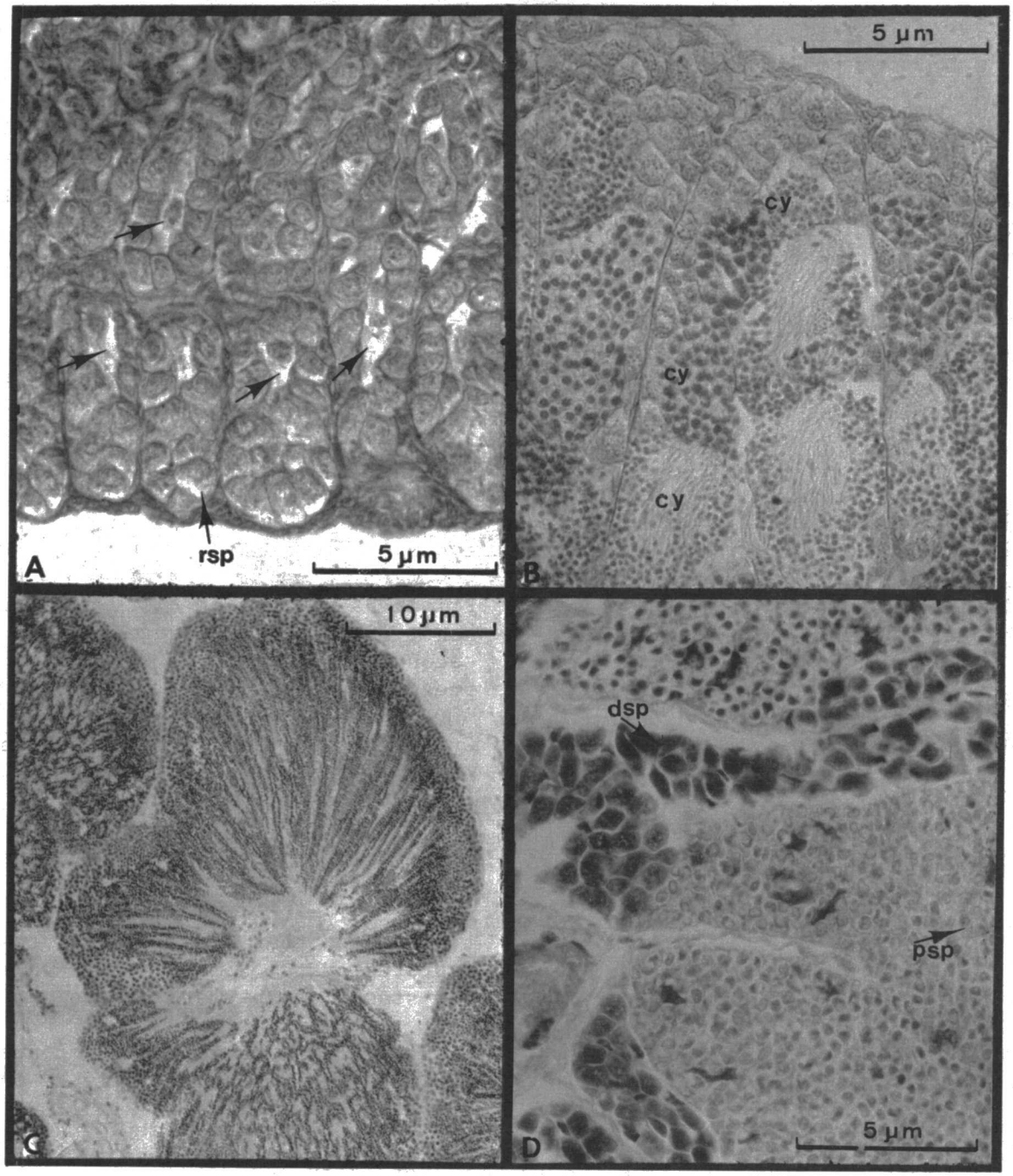


Figure 21.2

A. Longspined porgy (*Stenotomus caprinus*). Testis at quiescent stage; (rsp) resting spermatogonia; empty sinuses (arrows). 540X Mallory's.

B. Longspined porgy (*Stenotomus caprinus*). Maturing testis with several cysts (cy) at different stages of spermatogenesis. 540X Mallory's.

C. Scallop (*Amusium papyraceus*). Large sperm cluster (cyst) with different stages of spermatogenesis. 220X Feulgen.

D. Brown shrimp (*Penaeus aztecus*). Testis showing dividing spermatogonia (dsp) and primary spermatocytes (psp). 540X H&E

stage of spermatogenesis and in synchrony (Figure 21.2B).

The stages of spermatogenesis and sexual maturity were established on the basis of the type and number of the different cysts of spermatogenesis seen (Table 21.5). The stages were determined to fit the majority of the fish species studied.

Invertebrates

The process of spermatogenesis in the invertebrates varied from that of the fish. The process ranged from a synchronous (scallops) to sequential (shrimps and crabs) to a modified seminiferous tubule type (squid) or spermatogenesis (Figures 21.2C, 21.2D, 21.3A).

In the scallop, spermatogenesis proceeded in clusters (modified cysts) in which several stages developed centripetally with every cluster in synchrony. In the arthropods, development was sequential. Depending on the area of the testes studied, different stages of spermatogenesis were seen. At different periods of maturity, predominance of certain stages of spermatogenesis was noted.

The squid's testes resemble, in structure and spermatogenesis, the mammalian seminiferous tubule type of development. Within the tubule every stage of spermatogenesis is seen sequentially, with the resting spermatogonia on the periphery and different stages toward the center where the mature spermatoza are collected (Figure 21.3A).

The spermatogenesis stage designation used for the fish (Table 21.5) was also used for the invertebrates, although the histological description differed. Predominant spermatogenic stages were used to establish the stage in spermatogonial development in the different invertebrates.

Reproductive Cycle

A total of fifteen species of fish and twelve species of invertebrates

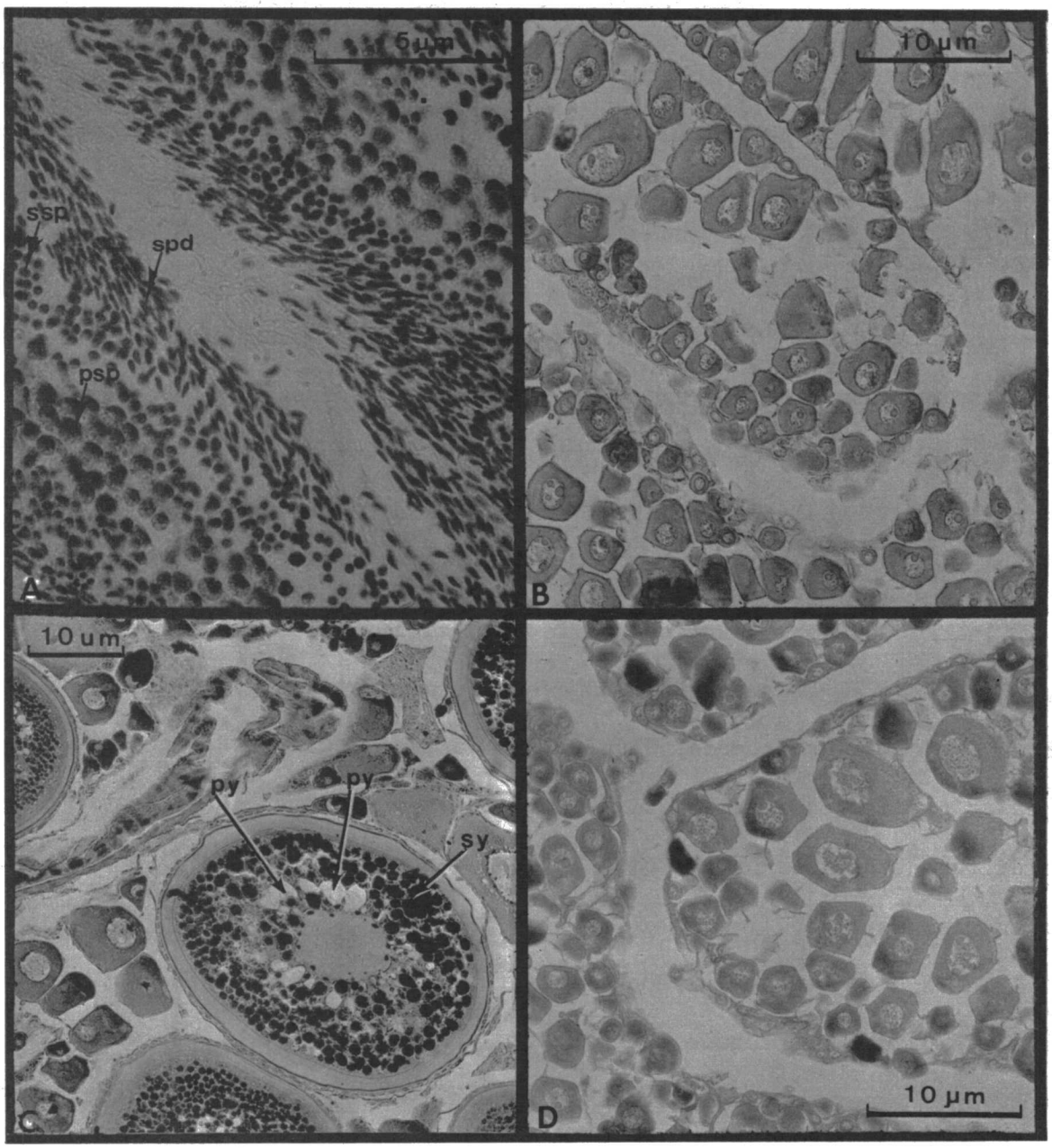


Figure 21.3

A. Squid (*Loligo pealei*). Longitudinal section of seminiferous tubule with different stages of spermatogenesis; (psp) primary spermatocytes; (ssp) secondary spermatocytes; (spd) spermatids. 540X Feulgen.

B. Wenchman (*Pristipomoides aquilonaris*). Ovigerous folds with small previtellogenic oocytes. 220X Mallory's.

C. Wenchman (*Pristipomoides aquilonaris*). Large vitellogenic oocytes with primary (py) and secondary (sy) yolk. 135X H&E.

D. Wenchman (*Pristipomoides aquilonaris*). Ovigerous folds in a distended stage, 220X Mallory's.

were collected along Transect II for the reproductive cycle study (Tables 21.1 and 21.2). The wenchman (*P. aquilonaris*) was the most abundant and largest group with 54 males and 51 females. Some of the other species of fish such as the longspined porgy (*S. caprinus*) and vermilion snapper (*R. aurorubens*) also had good distribution of male and female individuals and were collected during most sampling periods. Among the invertebrates, the brown shrimp (*P. aztecus*) was the most consistently collected species, followed by the squid (*L. pealei*), paper scallop (*Amusium papyraceus*) and blue crab (*C. similis*).

The reproductive cycle for these species have been partly established histologically. Several major gaps occur in the data as a result of little or no overlap in the samples collected. This lack of an overlap was due to collecting protocol and temporal and spatial distribution of the animals (the animals were either all of one sex, or not available in the collection, or no sampling was done during an important period of the reproductive cycle). The cycles established reflect this in giving an incomplete or contradicting picture. This may be due to overlapping cycles occurring, but in the partial data available, all stages of reproduction appear. When these data are integrated with other components of this study (*i.e.* zooplankton, identification and numbers of eggs, and larval forms), perhaps a complete picture can be developed.

Fish

The fish for which sufficient data have been collected to show some pattern are the wenchman, longspined porgy and vermilion snapper (Table 21.1). The wenchman was collected from Station 3, Transect II during all five sampling periods of 1976 and eight of the nine sampling periods of 1977. Histologically, the female started oogenesis in the period between

December and March. The wenchman was not collected during this time, but in March and April when it was collected, oogenesis had started and the oocytes were in the previtellogenic stages (Figure 21.3B). The oocytes were seen in various stages of growth with a size range of 15-200 μm in diameter (Table 21.6). In July and August, when collected again, the ovaries were observed to have large oocytes, ranging between 150 and 300 μm in diameter, and with primary and secondary yolk granules (Figure 21.3C).

No samples were collected during September. In October the majority of the wenchman sampled were in the immature or quiescent stage (Figure 21.3D). They had either spawned, although no evidence for this was available, or they were immature developing animals. A few were in developing stages suggesteing they were either late developers or residuals.

The wenchman was collected primarily from Station 3. In June, July and August, the wenchman was also collected from Station 2. The ovaries of these animals were in the previtellogenic stage while the Station 3 specimens had mature oocytes (Figure 21.3C). These animals were either moving inshore, or out to sea as they matured. Comparison of larvae, juvenile and adult swim patterns were not done. Therefore, it was difficult to support these observations.

The male wenchman differed from the other species of fish in the process of spermatogenesis. While in most fish the cysts progress to maturity with the majority of the cysts being at a given stage, the wenchman appeared to fluctuate with the testes having cysts at all stages of spermatogenesis (Table 21.7). A trend could be seen where some stages might have been predominant, yet all stages were still seen (Figure 21.4A).

One hundred and one (101) specimens of the longspined porgy were collected during 1976 and 1977. This species was collected during every collecting period (Table 21.1), but due to the sampling protocol no samples

TABLE 21.6

REPRODUCTIVE CYCLE OF FEMALE WENCHMEN (*Pristipomoides aquilonaris*), COLLECTED DURING 1976 AND 1977 FROM STATION 3, TRANSECT II. EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS

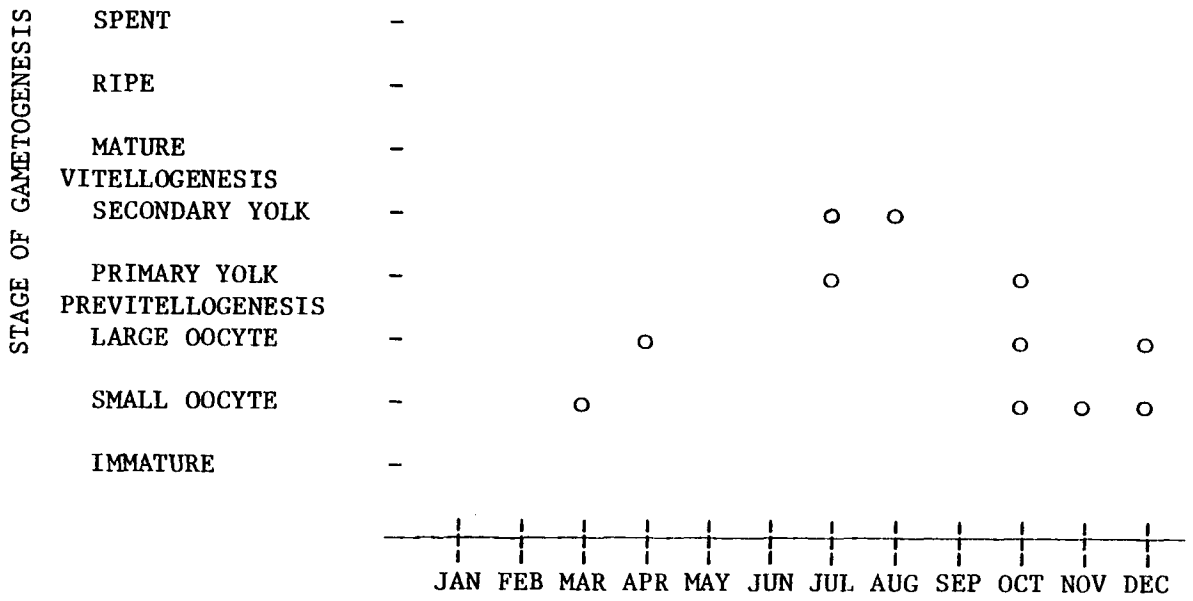
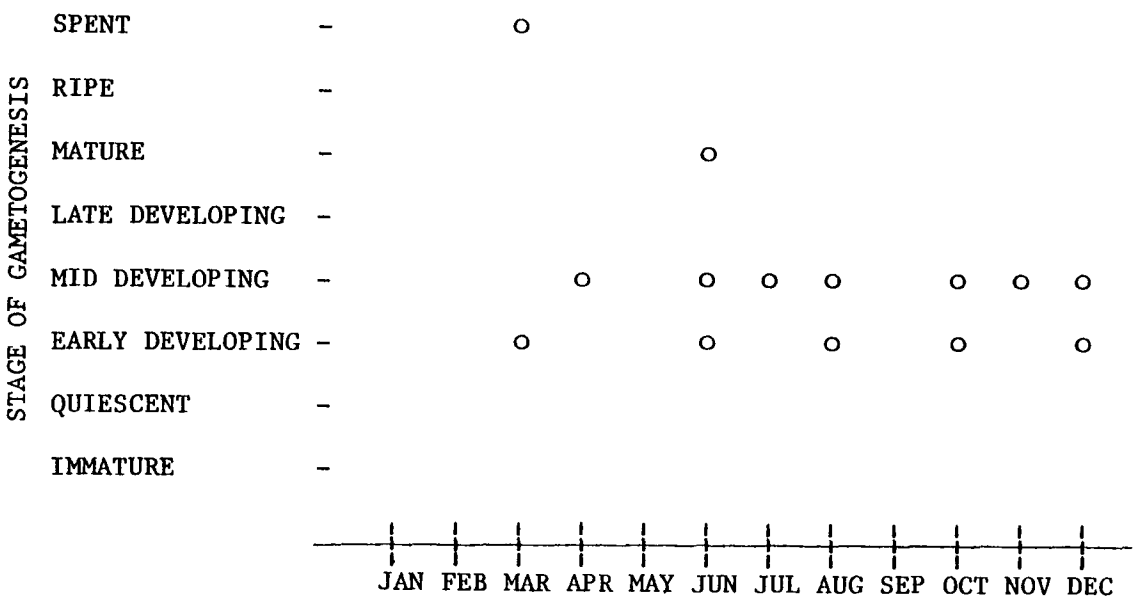


TABLE 21.7

REPRODUCTIVE CYCLE OF MALE WENCHMEN (*Pristipomoides aquilonaris*), COLLECTED DURING 1976 AND 1977 FROM STATION 3, TRANSECT II. EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS



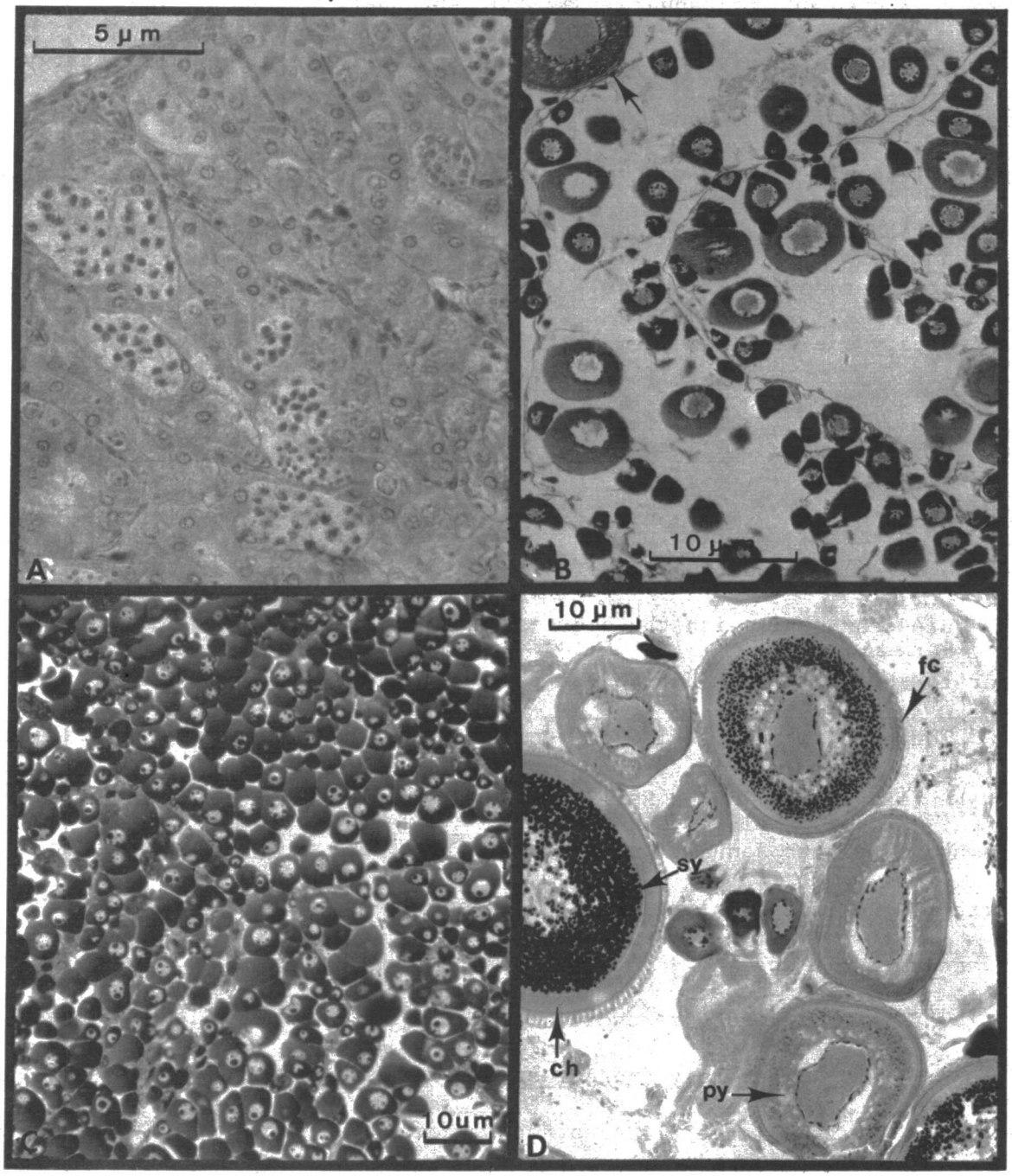


Figure 21.4

A. Wenchman (*Pristipomoides aquilonaris*). Testis with cysts at various stages of spermatogenesis. 540X H&E.

B. Longspined porgy (*Stenotomus caprinus*). Ovary with oocytes at different previtellogenic stages; oocyte with primary yolk (arrow) present. 220X H&E.

C. Longspined porgy (*Stenotomus caprinus*). Ovigerous folds with large number of previtellogenic oocytes. 100X H&E.

D. Longspined porgy (*Stenotomus caprinus*). Mature oocytes with chorion (ch), well developed follicle cell layer (fc), and primary (py) and secondary (sy) yolk. 135X H&E.

were collected during January, May and September.

The immature-quiescent stage in oogenesis for the longspined porgy was observed first in June (Table 21.8; Figure 21.4B). Growth of the previtellogenic oocytes was seen during October and November (Figure 21.4C). In December, oocytes were seen in the vitellogenic stages with some near the mature stage (Figure 21.4D). No samples were collected in January. In February one fish was seen in the mature-ripe stage and seven others contained maturing oocytes (vitellogenesis; primary and secondary yolk granules). During March, only one female was analyzed, and in April only two. The latter were in the vitellogenic stage with primary and secondary yolk. No collections were made in May, but in June the ovaries were at the quiescent stage with the oocytes at a small previtellogenic stage similar to the stage seen during the previous June (Figure 21.4B).

The pattern of oogenic development showed that oogenesis progressed to maturity in the cooler period of the year and the wenchman most likely spawned in either January or May when collections were not made. The March and April collecting efforts did not yield enough females to give an accurate picture.

The male reproductive cycle paralleled the female cycle very closely (Table 21.9). June, July and August samples showed the fish to be at the quiescent stage (Figure 21.2A) of spermatogenesis. The majority of cells seen were resting spermatogonia with some testes definitely being post-spent, since residual spermatozoa were seen in the sinuses of the lobules. The testes were seen in various stages of development during October, November and December (Figures 21.5A, 21.5B). In February, the majority of the developing cysts were filled with mature spermatids. Some cysts had ruptured and had released the mature spermatids into the sinuses that were formed by the ruptured cysts (Figure 21.5C). As with the female, few

TABLE 21.8

REPRODUCTIVE CYCLE OF FEMALE LONGSPINED PORGY (*Stenotomus caprinus*), COLLECTED DURING 1976 AND 1977 FROM STATION 3, TRANSECT II. EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS

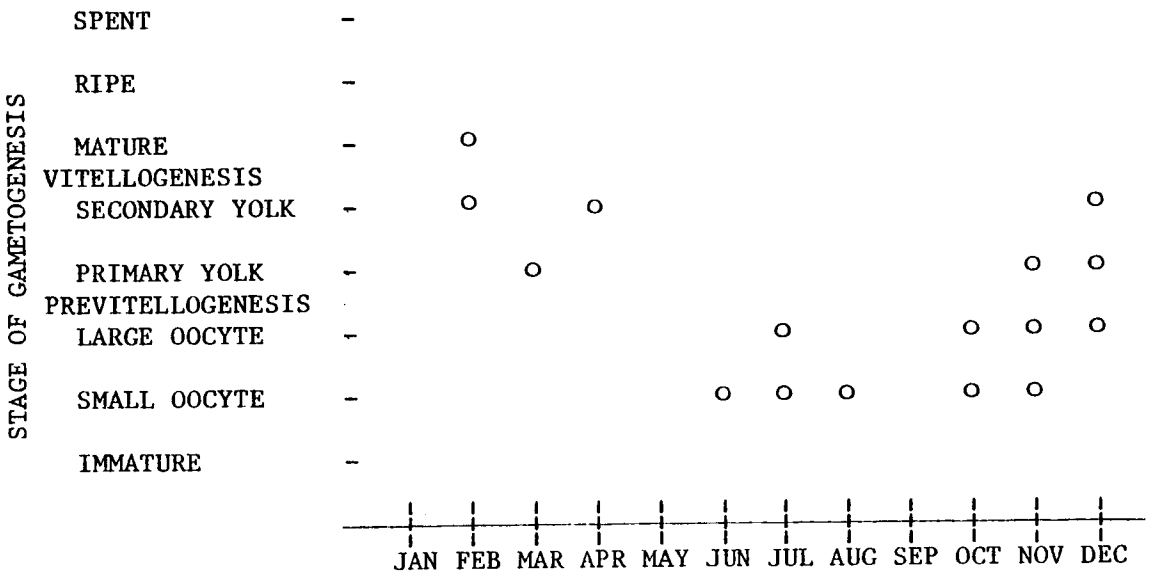
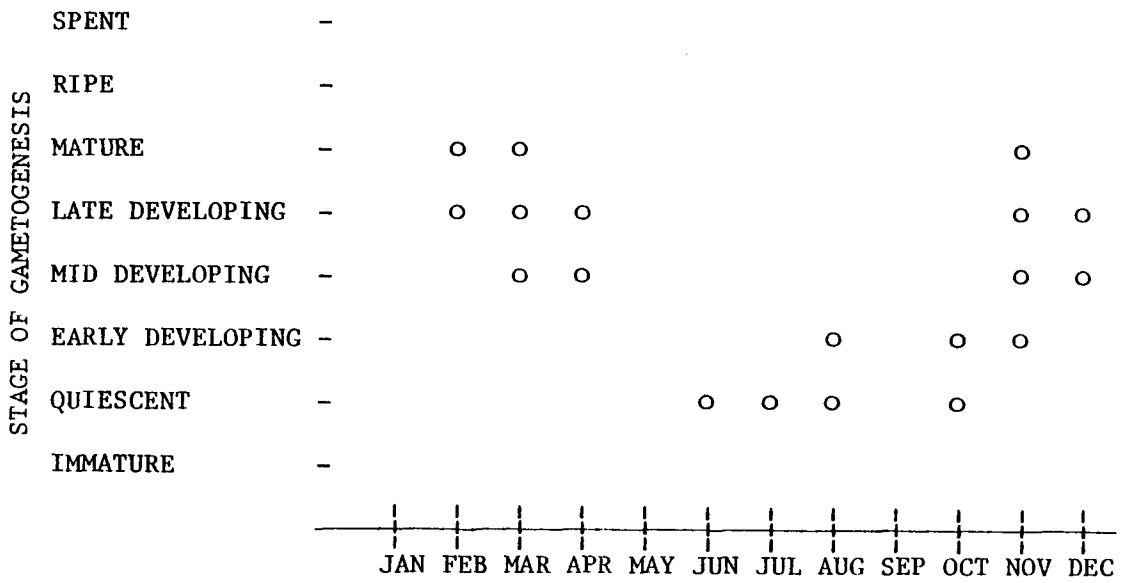


TABLE 21.9

REPRODUCTIVE CYCLE OF MALE LONGSPINED PORGY (*Stenotomus caprinus*), COLLECTED DURING 1976 AND 1977 FROM STATION 3, TRANSECT II. EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OF PROPORTIONS



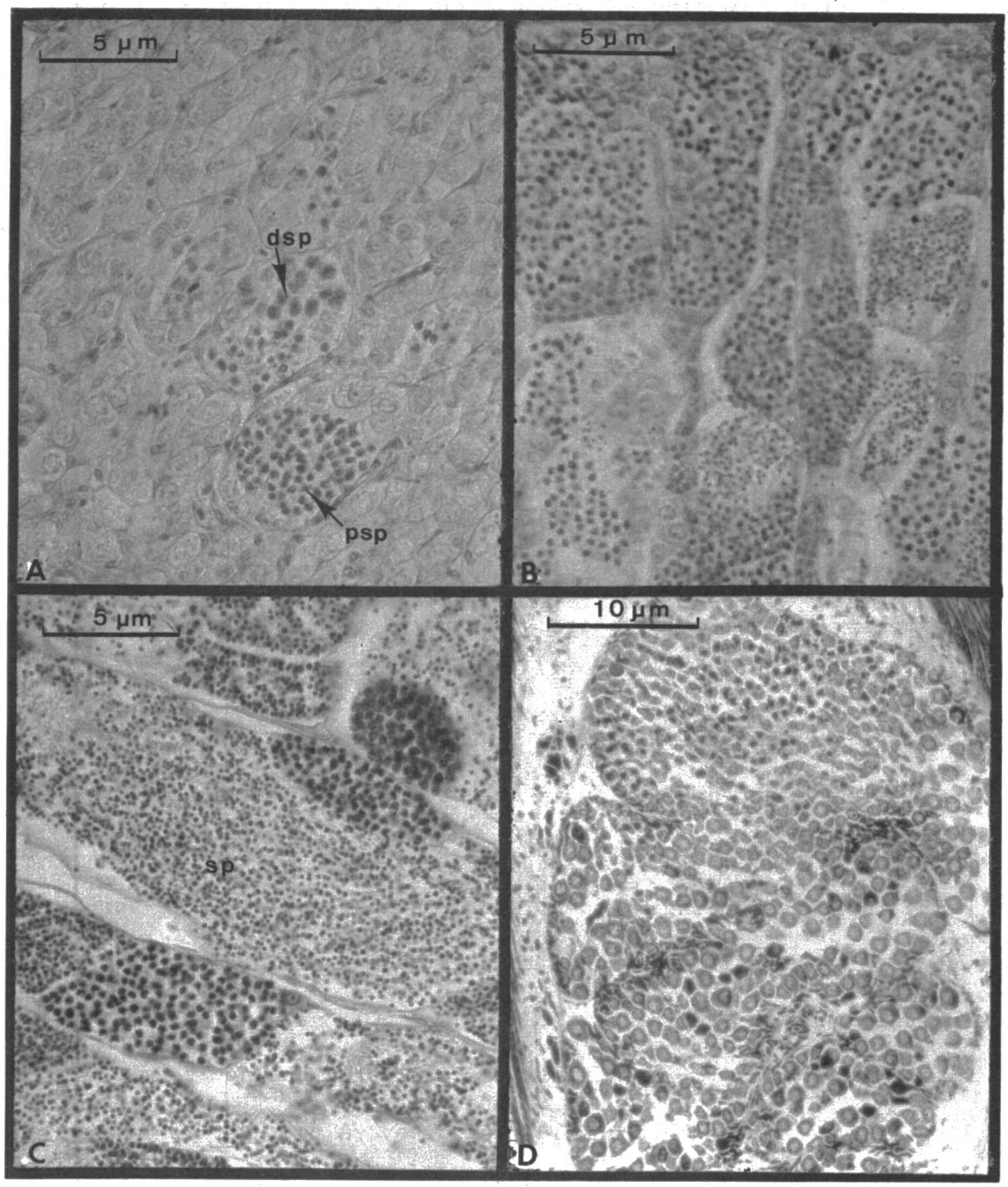


Figure 21.5

A. Longspined porgy (*Stenotomus caprinus*). Testis in early development stage with dividing spermatogonia (dsp) and primary spermatocyte (psp) cysts. 410X Feulgen.

B. Longspined porgy (*Stenotomus caprinus*). Testis in mid development stage with cysts in various stages of spermatogenesis. 410X H&E.

C. Longspined porgy (*Stenotomus caprinus*). Testis in late development to mature stage with many cysts having ruptured and forming spermatozoa (sp) filled sinuses. 410X H&E.

D. Brown shrimp (*Penaeus aztecus*). Immature-quiescent ovary with majority of oocytes very small and no yolk. 220X H&E.

males were collected during March and April making it difficult to analyze the process of spermatogenesis completely. Spawning could have occurred any time between January and May as the testes were in a post spawned, quiescent stage in June. During March and April, some of the males were at the ripe stage, while others were at various stages of maturity. These animals were either late developers or animals with residual development. If this is the case, the longspined porgy would have spawned during January and/or February, coinciding with the data available for the female.

Sufficient data were available for the vermilion snapper to make a partial analysis of the reproductive cycle (Tables 21.10 and 21.11). These fish were collected by hook and line at the Southern Bank Station, therefore, sampling was partially biased by type of fish taking the bait. Both males and females showed a similar pattern. Tables 21.10 and 21.11 showed a dual cycle emerging. Gametogenesis was initiated in April for both males and females and reached maturity in August for the females and from August to October for the males. What appeared to be a new cycle of gametogenesis was being initiated during October. No data was available for January through April making it impossible to develop any definite pattern or interpretation of this data.

The sand seatrout (*C. arenarius*) was collected during 12 of the 14 sampling periods of the 1976 and 1977 studies. A total of 28 females and 28 males was collected. Sampling ranged from one to ten specimens per effort and for three of these efforts only females were collected. Tables 21.12 and 21.13 show the erratic pattern developed from the observations of the male and female sand seatrout gonads.

The other fishes sampled were collected either a limited number of times or in insufficient numbers. A greater problem was the unequal distribution of males and females collected. Many times either all males or

TABLE 21.10

REPRODUCTIVE CYCLE OF FEMALE VERMILION SNAPPER (*Rhomboplites aurorubens*), COLLECTED DURING 1976 AND 1977 FROM SOUTHERN BANK. EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PORPORTIONS

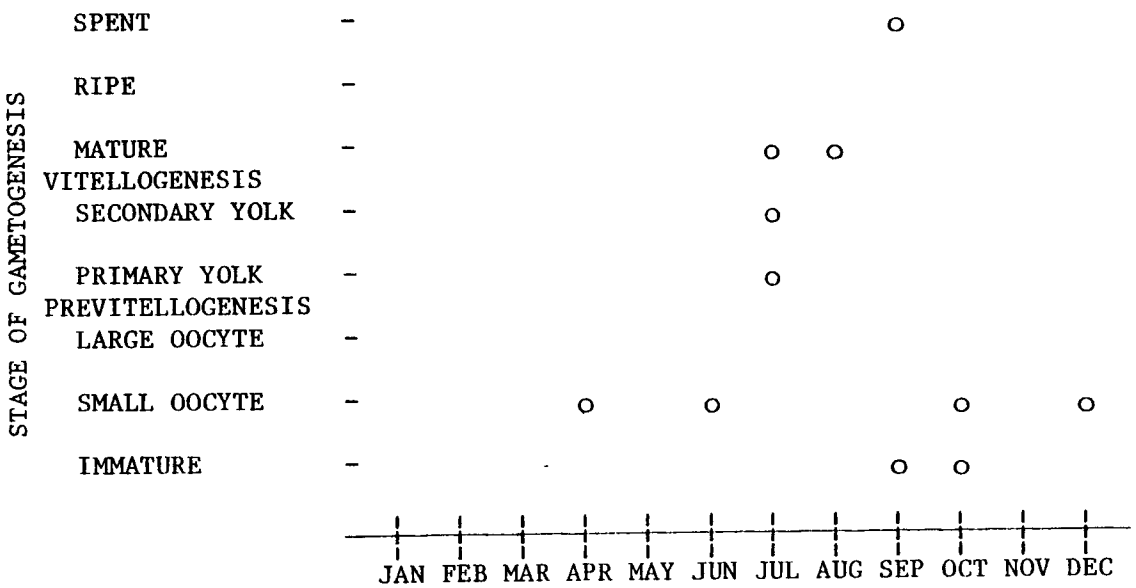


TABLE 21.11

REPRODUCTIVE CYCLE OF MALE VERMILION SNAPPER (*Rhomboplites aurorubens*), COLLECTED DURING 1976 AND 1977 FROM SOUTHERN BANK. EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS

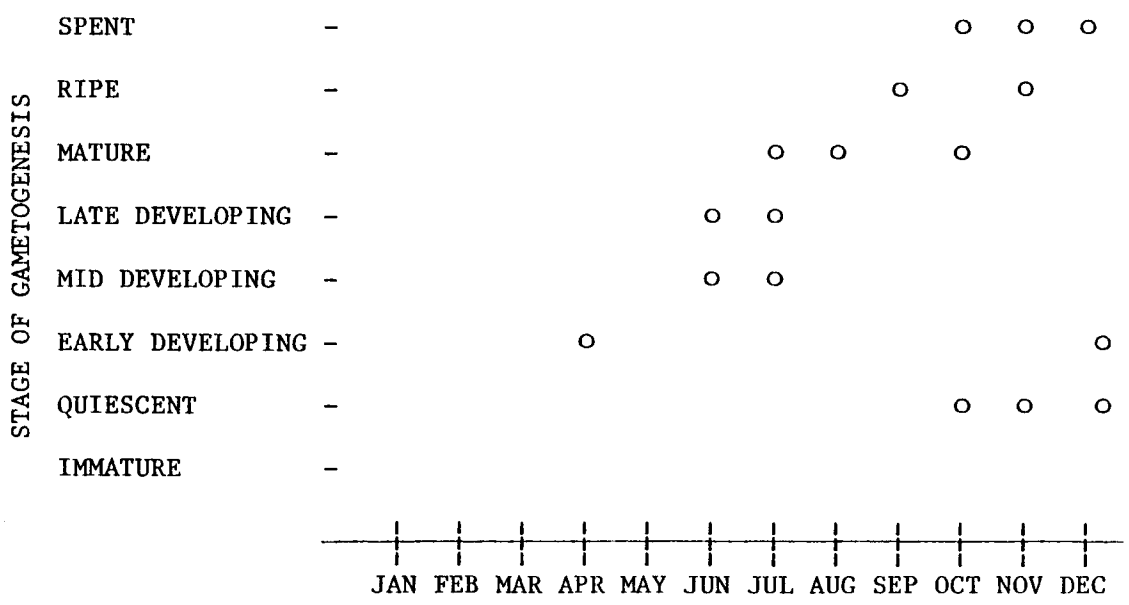


TABLE 21.12

REPRODUCTIVE CYCLE OF FEMALE SAND SEATROUT (*Cynoscion arenarius*), COLLECTED DURING 1976 AND 1977 FROM STATIONS 1, 2 AND 3, TRANSECT II EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS

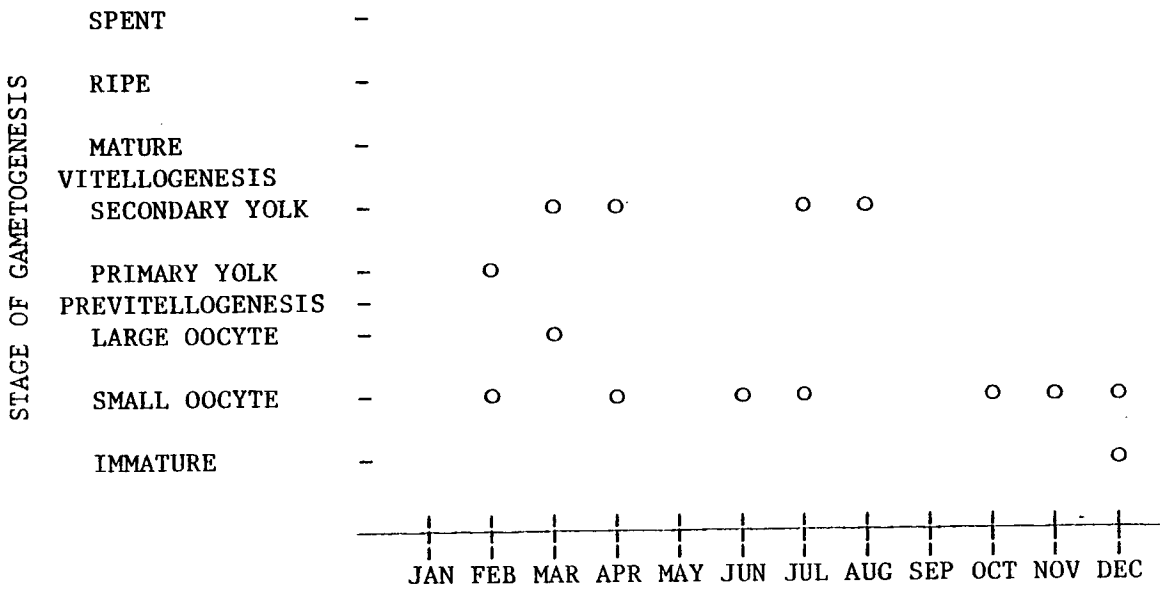
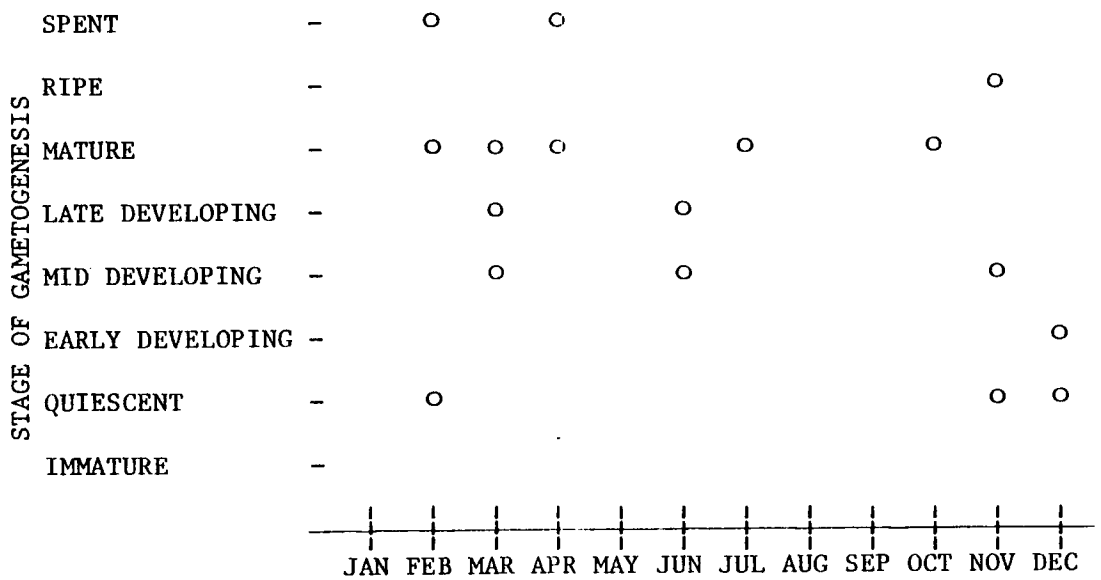


TABLE 21.13

REPRODUCTIVE CYCLE OF MALE SAND SEATROUT (*Cynoscion arenarius*), COLLECTED DURING 1976 AND 1977 FROM STATIONS 1, 2 AND 3, TRANSECT II EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS



all females were collected. Analysis of these species would have been fruitless and inconclusive.

Invertebrates

Table 21.2 shows the temporal distribution of the invertebrates in the collecting effort. The brown shrimp (*P. aztecus*) was collected every sampling effort and showed the greatest number of individuals collected. Out of 14 sampling periods the squid (*L. pealei*) and blue crab (*C. similis*) were collected 11 times and the scallop (*A. papyraceus*) and portunid crab (*Portunus spinicarpus*), nine times each.

In a histological examination of the brown shrimp it was observed that the processes of oogenesis and spermatogenesis were synchronous (Tables 21.14 and 21.15). The immature-quiescent stage in gametogenesis was seen during June and July (Figures 21.5D and 21.6A). In August, development was seen progressing to mature and ripe stages in the October-December period (Figures 21.6D, 21.6C). The February-March collections were small in the number of specimens collected. Since a great fluctuation in gametogenesis was seen, the data for this period were inconclusive.

Histologically, the squid presented a very dispersed picture. In both the male and female, gonads had all stages of development of gametes (Tables 21.16 and 21.17). The female gonads showed all stages of oogenesis in most of the sampled periods with an increase in mature oocytes in June. The male, as described in the Testicular Histology Section of this report, had a seminiferous tube-like type of spermatogenesis (Figures 21.3A and 21.6D). Therefore, all stages of gamete formation were present in the tubule, and did not give a definite clue to the stages of reproduction.

Since the paper scallop is a hermaphroditic organism, equal number of male and female gonads were sampled every sampling period. The reproductive cycle for the paper scallop appeared to end sometime during April and

TABLE 21.14

REPRODUCTIVE CYCLE OF FEMALE BROWN SHRIMP (*Penaeus aztecus*), COLLECTED DURING 1976 AND 1977 FROM STATION 2, TRANSECT II. EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS

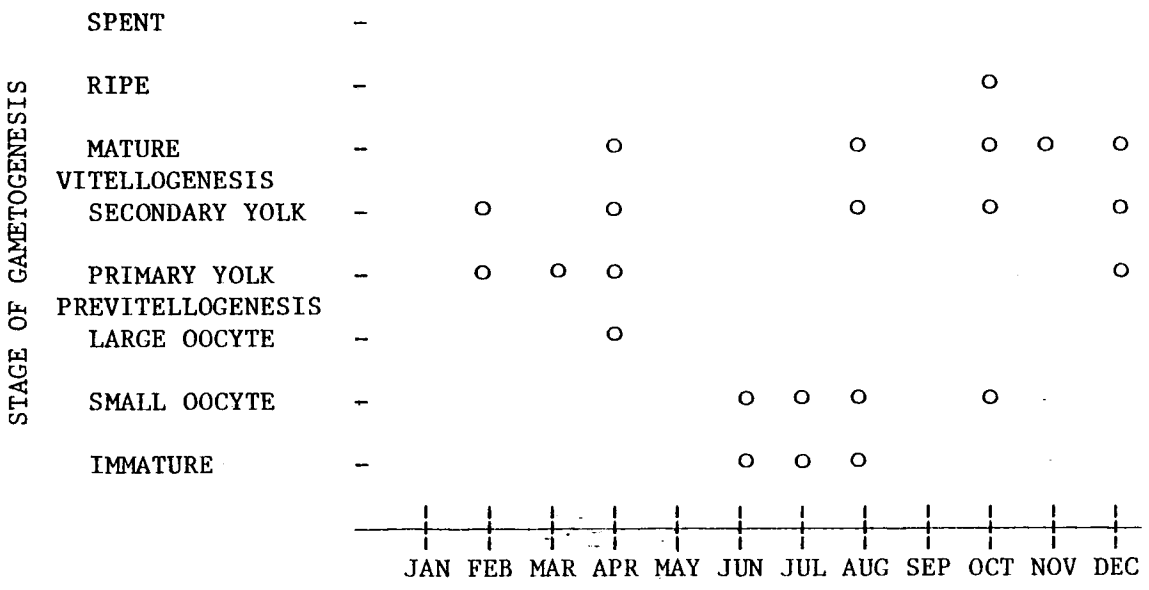
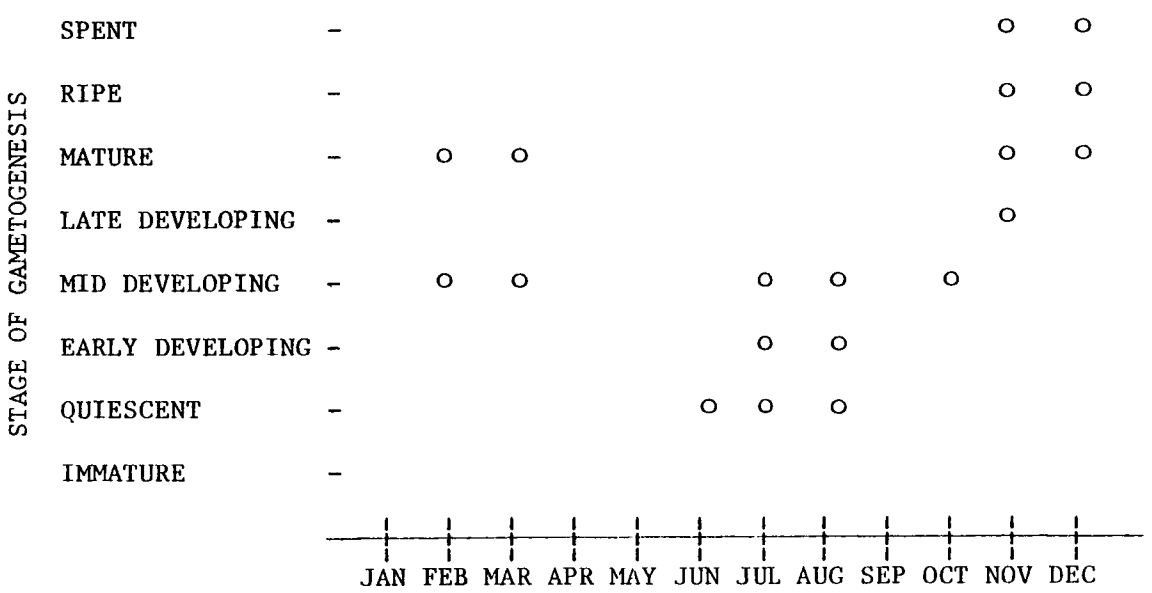


TABLE 21.15

REPRODUCTIVE CYCLE OF MALE BROWN SHRIMP (*Penaeus aztecus*), COLLECTED DURING 1976 AND 1977 FROM STATION 2, TRANSECT II. EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS



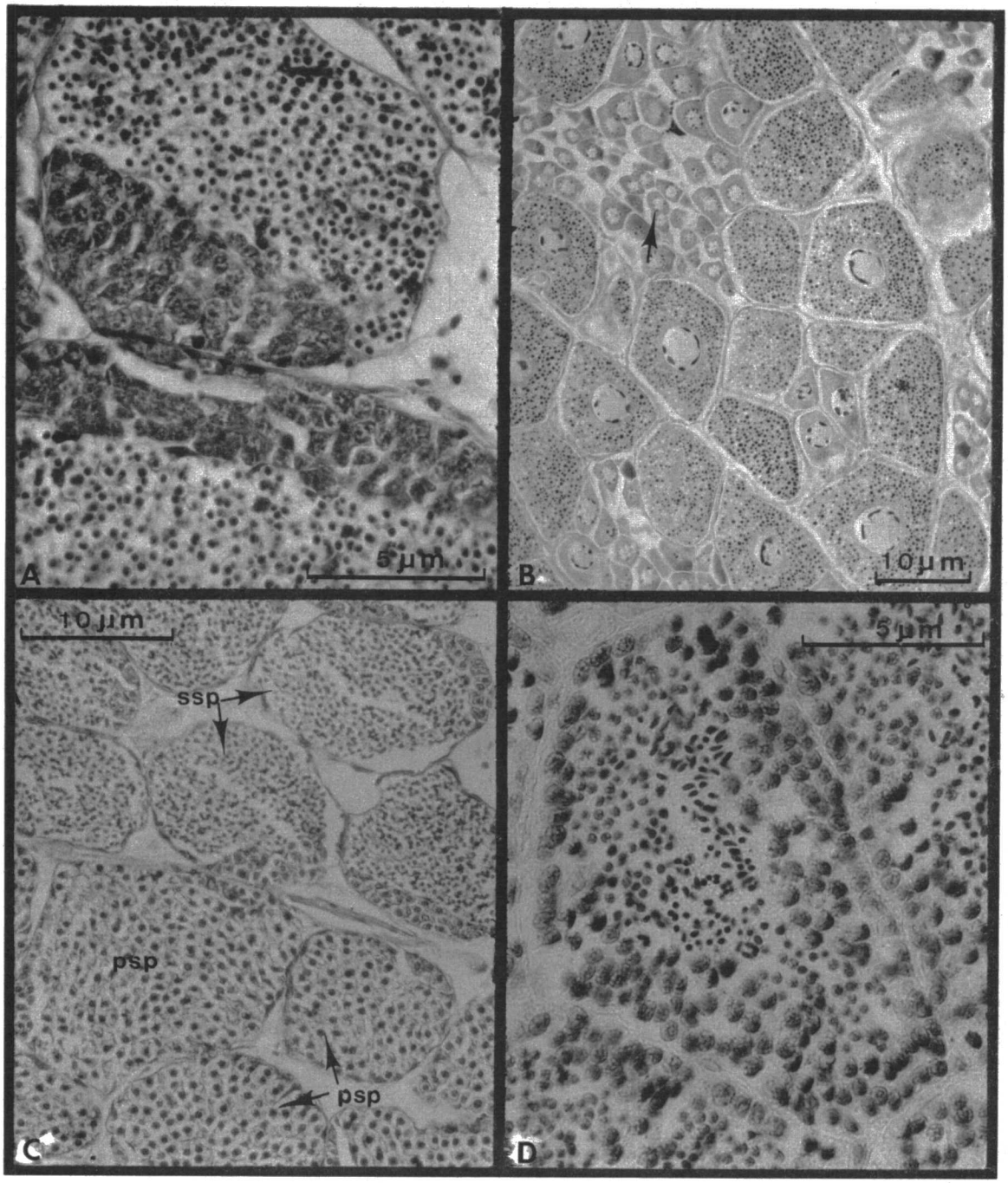


Figure 21.6

A. Brown shrimp (*Penaeus aztecus*). Testis at quiescent stage. 540X H&E.

B. Brown shrimp (*Penaeus aztecus*). Ovary with large maturing oocytes with yolk granules. Cluster of previtellogenis oocytes (arrow) present. 135X H&E.

C. Brown shrimp (*Penaeus aztecus*). Testis' lobes filled with primary spermatocytes (psp) and secondary spermatocytes (ssp). 220X H&E.

D. Squid (*Loligo pealei*). Cross section of testis showing the seminiferous tubule arrangement with different stages of spermatogenesis. 540X Feulgen.

TABLE 21.16

REPRODUCTIVE CYCLE OF FEMALE SQUID (*Loligo pealei*),
COLLECTED DURING 1976 AND 1977 FROM STATIONS 1, 2 AND 3, TRANSECT II.
EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED
AND DOES NOT INDICATE NUMBERS OR PROPORTIONS

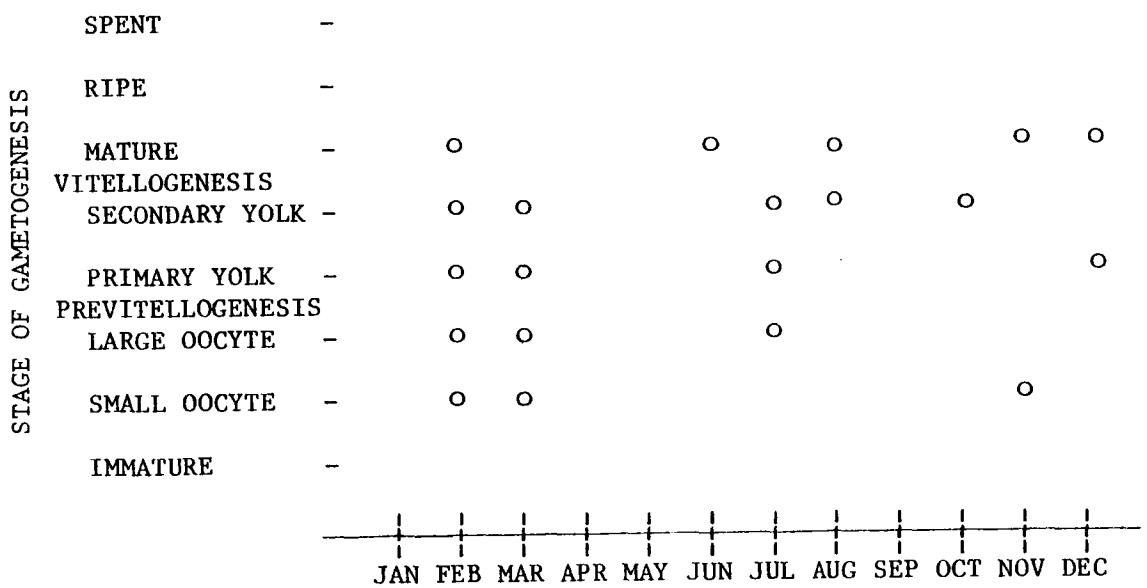
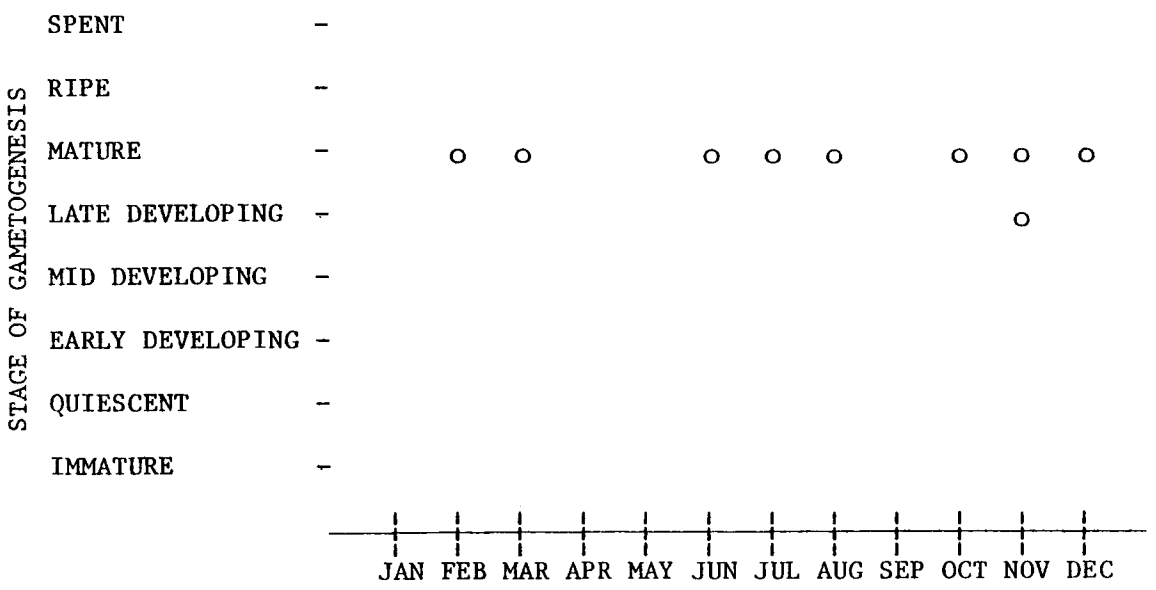


TABLE 21.17

REPRODUCTIVE CYCLE OF MALE SQUID (*Loligo pealei*)
COLLECTED DURING 1976 AND 1977 FROM STATIONS 1, 2 AND 3, TRANSECT II.
EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED
AND DOES NOT INDICATE NUMBERS OR PROPORTIONS



May (none collected) since they were spent in June. Spent animals were collected through October. At the same time, animals in earlier stages of gametogenesis were also collected. Mature oocytes (Figure 21.1C) and large amounts of spermatid clusters were seen from December through April (Figure 21.2C).

The blue crab presented a better pattern in gamete formation even though it was collected only during the June through December period (Tables 21.18 and 21.19). In June, when first sampled, the ovaries had very small previtellogenic oocytes. In December, all stages of oogenesis were found among the sampled animals. The male gonads also showed early stages of spermatogenesis in June and the developing to mature stages increased through December. In a related species to the blue crab (*Callinected sapidus*) reports indicated that peak spawning was seen during the March-April period and females with sponge (egg mass) were seen in greater numbers during July (More, 1969).

Other invertebrate species examined during this study showed some emerging patterns, but not enough samples were collected to develop a complete reproductive cycle. The general pattern of histological observations reported with some degree of confidence, coincided partly with published reports, although not enough data was generated to establish a direct correlation.

Pathology

A variety of pathological conditions was observed (Tables 21.20 and 21.21) in the 878 samples analyzed. From these analyses, 149 specimens (16.9%) displayed some pathological conditions. Invertebrates accounted for 88 infected specimens (10%) while vertebrates accounted for 61 infected specimens (6.9%).

Only generalized statements can be made from the existing data, since

TABLE 21.18

REPRODUCTIVE CYCLE OF FEMALE BLUE CRAB (*Callinectes similis*), COLLECTED DURING 1976 AND 1977 FROM STATIONS 1, 2 AND 3, TRANSECT II EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS

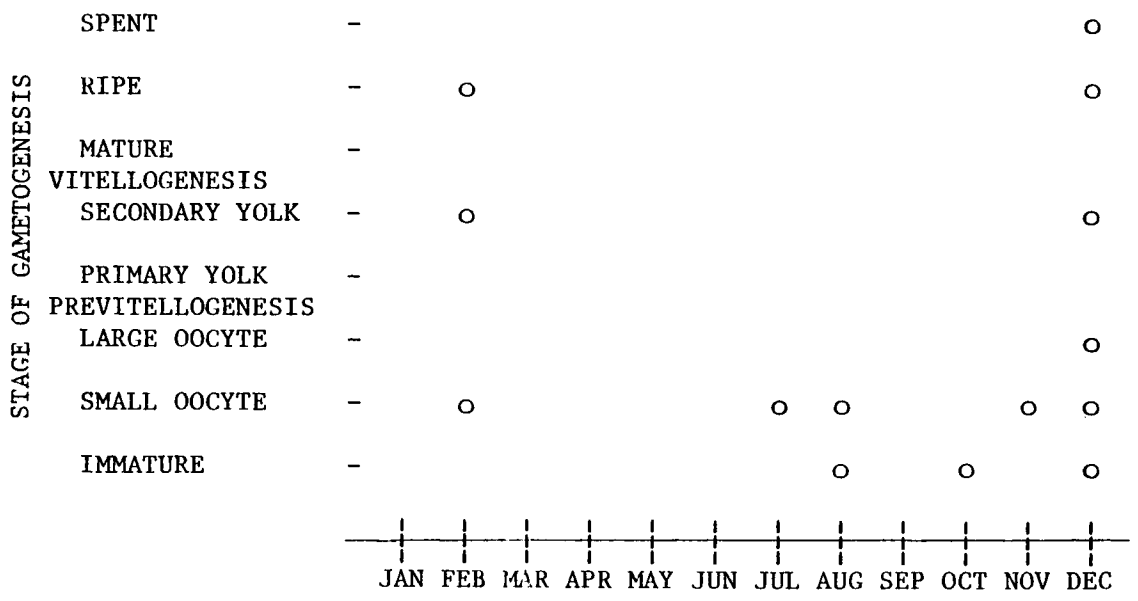


TABLE 21.19

REPRODUCTIVE CYCLE OF MALE BLUE CRAB (*Callinectes similis*), COLLECTED DURING 1976 AND 1977 FROM STATIONS 1, 2 AND 3, TRANSECT II. EACH POINT INDICATES THE PREDOMINANT STAGE IN GAMETOGENESIS OBSERVED AND DOES NOT INDICATE NUMBERS OR PROPORTIONS

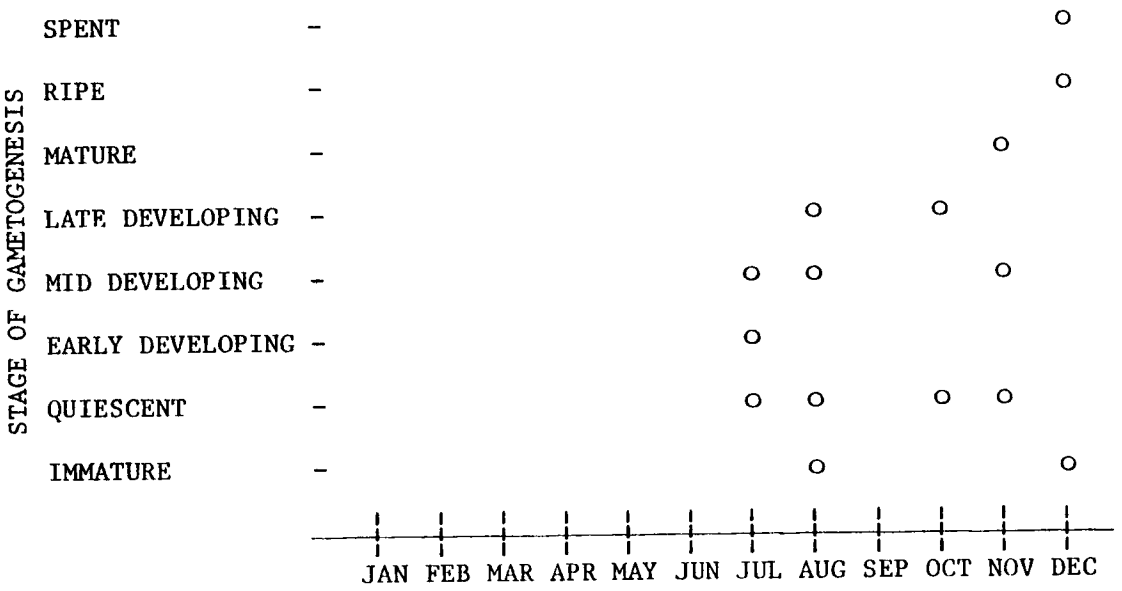


TABLE 21.20

SURVEY OF GONADAL PATHOLOGICAL INCIDENCE FOR VERTEBRATES COLLECTED DURING 1977 ALONG TRANSECT II AND SOUTHERN BANK

Specimen	Parasites	Neoplasm & Hyperplasia	Cysts	Degenerated Gonad	Other[1]
Wenchman					
Pristipomoides aquilonaris		2	8		12
Longspined porgy					
Stenotomus caprinus	4	1			4
Sand seatrout					
Cynoscion arenarius	2		1	1	5
Atlantic croaker					
Micropogon undulatus	2				3
Gulf butterfish					
Peprilus burti					
Rock sea bass					
Centropristis philadelphica			1		1
Red snapper					
Lutjanus campechanus			4		2
Threafin					
Polydactylus octonemus					
Black ear bass					
Serranus atrobranchus					
Pinfish					
Lagodon rhomboides					1
Vermilion snapper					
Rhomboplites aurorubens	8			5	3
Spot croaker					
Leiostomus xanthurus			1		
Scaled sardine					
Harengula pensacolae			1		
Atlantic bumper					
Chloroscombrus chrysurus	1			2	

[1] Fibroblast infiltration, leucocyte infiltration, vascularization, unknown diseases or causes, or other abnormalities.

TABLE 21.21

SURVEY OF GONADAL PATHOLOGICAL INCIDENCE FOR INVERTEBRATES COLLECTED DURING 1977 ALONG TRANSECT II

Specimen	Parasites	Neoplasm & Hyperplasia	Cysts	Degenerated Gonad	Other[1]
Paper scallop *Amusium papyraceus*	4	6	6	1	8
Blue crab *Callinectes similis*		4		7	8
Portunid crab *Portunus gibbesii*					
Portunid crab *Portunus spinicarpus*	1			3	6
White shrimp *Penaeus setiferus*	3			4	3
Rock shrimp *Sicyonia dorsalis*	6				
Broken back shrimp *Solenocera vioscai*	2			1	2
Brown shrimp *Penaeus aztecus*	19			1	1
Rough back shrimp *Trachypenaeus similis*	1				
Squid *Loligo pealei*					7
Squid *Loliguncula brevis*					5
Spider crab *Anasimus latus*	1				

[1] Fibroblast infiltration, leucocyte infiltration, vascularization, unknown diseases or causes, or other abnormalities.

too few specimens were collected to state a definite effect or trend. In another study, involving 290,000 fishes (151 species), it was reported that the data were not sufficient to clarify the relationship between initiation of the disease and the disease prevalence distributional pattern (Mearns and Sherwood, 1977).

A common pathology observed was the presence of helminths (Figures 21.7A, 21.7B). In some cases, the helminths had penetrated the gonad (Figure 21.7B), while in other cases, they were associated with the gonad on the periphery (Figure 21.25) or in the connective tissue or mesentery supporting the gonad. In another study, the helminths were considered to be an environmental indicator (Overstreet and Howse, 1977). Mearns and Sherwood (1977) stated that as collecting moved away from the center of the pollution point, the presence of parasites increased.

Sporozoan and protozoan (Figures 21.7C, 21.7D) infections were found through entire collecting samples in both vertebrates and invertebrates. Heavy infections by these organisms resulted in complete destruction of gonadal area (Figure 21.7D).

Table 21.22 shows that the highest incidence of parasites in the vertebrates was during the coldest part of the year (Quarter I). Invertebrates had an increase of parasitism during the warmer months (Quarter I and II). Correlation with temperature data was not done; therefore, only generalizations can be made as to the relative importance of temperature with respect to the incidence of parasitism.

Neoplastic growths were seen associated either with the gonadal wall or supportive connective tissue (Figures 21.8A, 21.8B, 21.8D). Some mature oocytes appeared to have neoplastic growths in the ooplasma (Figure 21.8B).

Neoplasia studies of aquatic specimens have just started to develop enough of a data bank to ascertain any relationship regarding the specimens

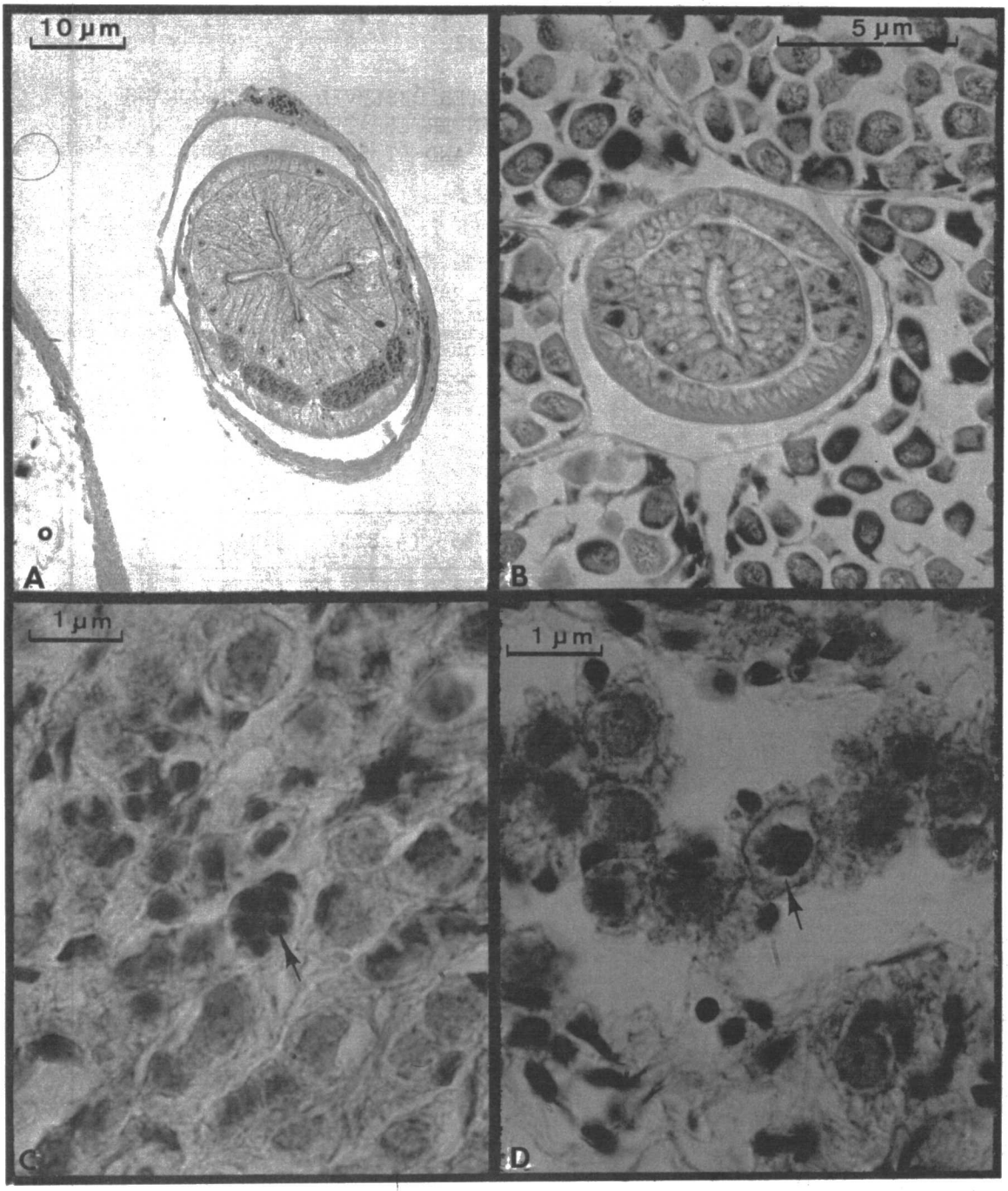


Figure 21.7

A. Longspined porgy (*Stenotomus caprinus*). Helminth parasite adjacent of ovary (o). 135 X H&E.

B. Rock shrimp (*Sicyonia dorsalis*). Helminth parasite embedded in ovary. 540X H&E.

C. Vermilion snapper (*Rhomboplites aurorubens*). Sporozoan parasite (arrow) in degenerated testis. 1320X H&E.

D. Vermilion snapper (*Rhomboplites aurorubens*). Protozoan parasite (arrow) in degenerated testis. 1320X H&E.

TABLE 21.22

1977 QUARTERLY[1] ANALYSIS OF PARASITES OBSERVED IN THE GONADS OF VERTEBRATES AND INVERTEBRATES COLLECTED ALONG TRANSECT II AND AT SOUTHERN BANK

VERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	7	41.0%
II	2	12.0%
III	4	24.0%
IV	4	24.0%
TOTAL	17/353 (4.8%)	

INVERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	6	15.0%
II	10	26.0%
III	15	39.0%
IV	7	18.0%
TOTAL	38/525 (7.2%)	

[1]Quarters = January-March, I; April-June, II; July-September, III; October-December, IV

[2] % of Total Incidence = $\frac{\text{Incidence per Quarter}}{\text{Incidence of Pathology for year}}$

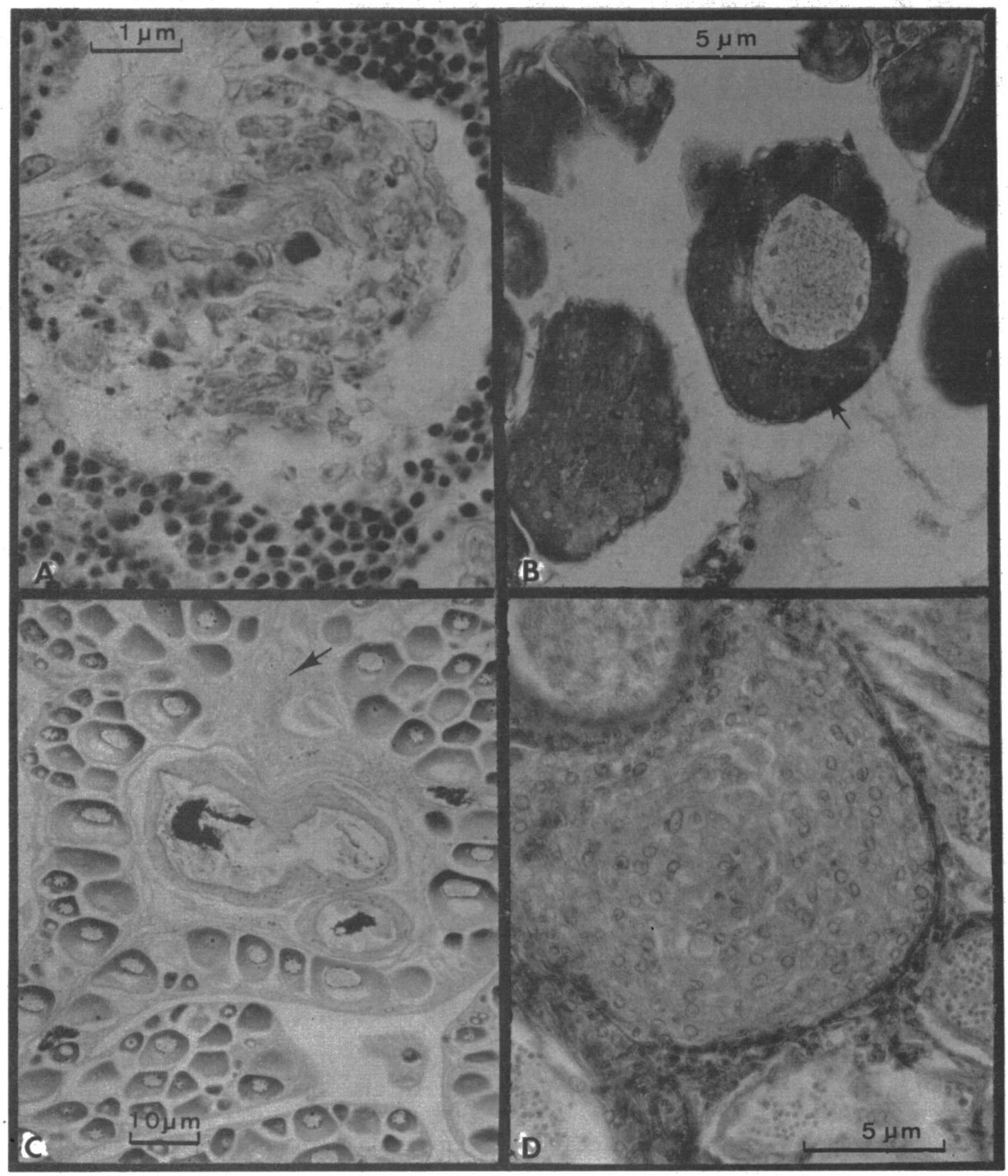


Figure 21.8

A. Blue crab (*Callinectes similis*). Neoplastic growth in testis. 1320X H&E.

B. Wenchman (*Pristipomoides aquilonaris*). Maturing oocyte with neoplastic inclusions (arrow). 540X Mallory's.

C. Red snapper (*Lutjanus campechanus*). Cystic reaction to degenerating parasite and fibroblast infiltration (arrow). 100X H&E.

D. Wenchman (*Pristipomoides aquilonaris*). Neoplastic cyst seen in testis. 410X H&E.

and their environments (Harshburger, 1977). Before the etiology of a particular neoplasma can be established, the following have to be considered:

1. Identification and classification of neoplasma common to a particular organ, a particular species and/or a particular habitat;

2. Analysis of water, food, sediments and the environment and identification of one or more carcinogens or possible carcinogens;

3. Simulation of the exposure under controlled laboratory experiments and inducement of the same neoplasma in the same organ, the same species and by the same route of exposure.

Not enough data have been collected to definitely establish that a neoplasia has occurred and not a hyperplasia, since an early state of neoplasia resembles hyperplasia (Stewart, 1977).

Hyperplasia has been defined as the increase in the number of individual tissue elements, excluding tumor formation, whereby the bulk of the organ is increased (Stewart, 1977). Very few incidences of hyperplasia and neoplasia were seen during this sampling period. Hyperplasia was seen in 10 out of 525 (1.9%) invertebrates while only three out of 353 (0.08%) vertebrates (Table 21.23). The incidence of hyperplasia was more prevalent during the cooler months.

Various types of cysts were observed in the specimens collected. Some of the cysts were clearly reactions to invasion by parasites (Figure 21.8C), but most were of unknown origin (Figure 21.8D). Vertebrates seem to have had a higher incidence of cysts during warmer months (Quarters II, III) while the incidence of cysts in invertebrates was observed to be the highest during the cooler months (Quarter IV) of the year (Table 21.24). Vertebrates had the highest incidence of cysts (4.5%). The invertebrates had a much lower incidence (1.1%).

TABLE 21.23

1977 QUARTERLY[1] ANALYSIS OF NEOPLASTIC AND HYPERPLASIA OBSERVED IN THE GONADS OF VERTEBRATES AND INVERTEBRATES COLLECTED ALONG TRANSECT II AND AT SOUTHERN BANK

VERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	1	33.0%
II		
III		
IV	2	67.0%
TOTAL	3/353 (.8%)	

INVERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	2	20.0%
II		
III	1	10.0%
IV	7	70.0%
TOTAL	10/525 (1.9%)	

[1]Quarter = January-March, I; April-June, II; July-September, III; October-December, IV

[2]% of Total Incidence = $\frac{\text{Incidence per Quarter}}{\text{Incidence of Pathology for Year}}$

TABLE 21.24

1977 QUARTERLY[1] ANALYSTS OF CYSTS OBSERVED IN THE GONADS OF VERTEBRATES AND INVERTEBRATES COLLECTED ALONG TRANSECT II AND AT SOUTHERN BANK

VERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	1	6.0%
II	7	44.0%
III	7	44.0%
IV	1	6.0%
TOTAL	16/353 (4.5%)	

INVERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	1	17.0%
II	1	17.0%
III	1	17.0%
IV	3	50.0%
TOTAL	6/525 (1.1%)	

[1]Quarter= January-March, I; April-June, II; July-September, III; October-December IV

[2]% of Total Incidence = $\frac{\text{Incidence per Quarter}}{\text{Incidence of Pathology for Year}}$

Failure of gonads to develop, whether male or female, often appeared to be associated with nematode parasitism. A few gonads were found completely destroyed by bacterial invasion while the causative agent(s) of other degenerated gonads could not be identified (Figure 21.9A). Invertebrate and vertebrate incidence of degenerated gonads was 3.0% and 2.3% respectively (Table 21.25).

Fibroblast infiltration, vesiculation, leucocytic infiltration and other conditions were combined under one heading (Table 21.26). Due to this combination, the largest occurrence of pathologies was seen in this category. These conditions were usually associated with other conditions such as parasitism, neoplastic growth or hyperplasia. Fibroblast infiltration and vesiculation were also seen in post spent animals which could have been part of the "normal" reproductive cycle (Figure 21.9B). Until an adequate data base is available, such conditions cannot be definitely categorized.

Tables 21.27 - 21.29 summarize the incidence of histopathologies and parasites of the invertebrate and vertebrate gonads. The wenchman (70 specimens, 16 infected) had the highest incidence of pathological conditions among the vertebrates (22.9%) and the longspined porgy (71 specimens, 8 infected) had the lowest incidence (11.3%). Of the invertebrates, the scallop (53 specimens, 18 infected) had the highest incidence of pathologies (40%) while the rough back shrimp (51 specimens, 1 infected) had the lowest incidence (1.9%).

A generalized prediction can be made as to which period of the year the highest incidence of pathologies occur (Table 21.27). The vertebrates are more subject to infection during the cooler months (Quarters I and IV). Invertebrates also showed a high percent of infection during Quarter IV.

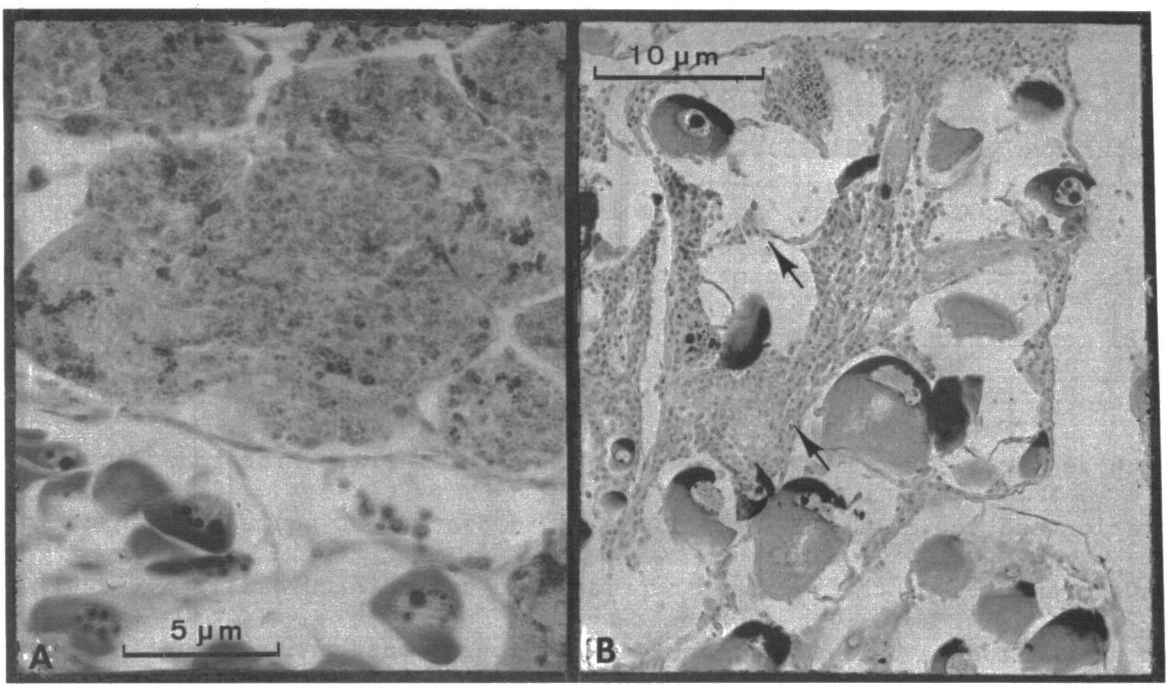


Figure 21.9

A. White shrimp (*Penaeus setiferus*). Degenerating ovary due to unknown cause. 410X H&E.

B. Vermilion snapper (*Rhomboplites aurorubens*). Fibroblast infiltration (arrow) into ovigerous folds of spent ovary. 220X H&E.

TABLE 21.25

1977 QUARTERLY[1] ANALYSIS OF DEGENERATED GONAD IN THE GONADS OF VERTEBRATES AND INVERTEBRATES COLLECTED ALONG TRANSECT II AND AT SOUTHERN BANK

VERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	5	63.0%
II		
III	2	25.0%
IV	1	13.0%
TOTAL	8/353 (2.3%)	

INVERTEBRATES

Quarter	Incidence	% of T. I.[2]
I		
II		
III	4	25.0%
IV	12	75.0%
TOTAL	16/525 (3.0%)	

[1]Quarter= January-March, I; April-June, II; July-September, IV; October-December, IV

[2]% of Total Incidence = $\frac{\text{Incidence per Quarter}}{\text{Incidence of Pathology for year}}$

TABLE 21.26

1977 QUARTERLY[1] ANALYSIS OF OTHER PATHOLOGIES IN THE GONADS OF VERTEBRATES AND INVERTEBRATES COLLECTED ALONG TRANSECT II AND AT SOUTHERN BANK

VERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	8	25.0%
II	6	19.0%
III	5	17.0%
IV	13	41.0%
TOTAL	32/353 (9.1%)	

INVERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	12	30.0%
II	6	15.0%
III	3	8.0%
IV	19	48.0%
TOTAL	40/525 (7.6%)	

[1]Quarter= January-March, I; April-June, II; July-September, III; October-December, IV

[2]% of Total Incidence = $\frac{\text{Incidence per Quarter}}{\text{Incidence of Pathology for year}}$

TABLE 21.27

1977 QUARTERLY[1] ANALYSIS OF TOTAL PATHOLOGICAL INCIDENCE OBSERVED IN THE GONADS OF VERTEBRATES AND INVERTEBRATES COLLECTED ALONG TRANSECT II AND AT SOUTHERN BANK

VERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	21	28.0%
II	16	21.0%
III	18	24.0%
IV	21	28.0%
TOTAL	76/353 (21.5%)	

INVERTEBRATES

Quarter	Incidence	% of T. I.[2]
I	21	19.0%
II	17	15.0%
III	24	22.0%
IV	48	44.0%
TOTAL	110/525 (20.9%)	

[1]Quarter= January-April, I; March-June, II; July-September, III; October-December IV

[2]% of Total Incidence = $\frac{\text{Incidence per Quarter}}{\text{Incidence of Pathology for year}}$

TABLE 21.28

HISTOPATHOLOGY OF FISH GONADAL TISSUE COLLECTED DURING 1977
ALONG TRANSECT II AND AT SOUTHERN BANK

Specimen	Analyzed	Infected	Incidence of Infection
Wenchman			
Pristipomoides aquilonaris	70	16	22.9%
Longspined porgy			
Stenotomus caprinus	71	8	11.3%
Sand seatrout			
Cynoscion arenarius	43	8	18.6%
Atlantic croaker			
Micropogon undulatus	37	4	10.8%
Gulf butterfish			
Peprilus burti	1	0	0%
Rock sea bass			
Centropristis philadelphica	12	2	16.7%
Red snapper			
Lutjanus campechanus	28	6	21.4%
Threadfin			
Polydactylus octonemus	5	0	0%
Black ear bass			
Serranus atrobranchus	3	0	0%
Pinfish			
Lagodon rhomboides	5	1	20.0%
Vermilion snapper			
Rhomboplites aurorubens	52	11	21.2%
Spot croaker			
Leiostomus xanthurus	16	1	6.3%
Scaled sardine			
Harengula pensacolae	5	1	20.0%
Atlantic bumper			
Chloroscombrus chrysurus	5	3	60.0%
TOTAL	353	61	17.3%

TABLE 21.29

HISTOPATHOLOGY OF INVERTEBRATE GONADAL TISSUE COLLECTED DURING 1977 ALONG TRANSECT II

Specimen	Analyzed	Infected	Incidence of Infection
Paper scallop *Amusium papyraceus*	53	18	33.9%
Blue crab *Callinectes similis*	50	11	22.0%
Portunid crab *Portunus gibbesii*	8	0	0%
Portunid crab *Portunus spinicarpus*	58	10	17.2%
White shrimp *Penaeus setiferus*	46	10	21.7%
Rock shrimp *Sicyonia dorsalis*	13	6	46.2%
Broken back shrimp *Solenocera vioscai*	56	5	8.9%
Brown shrimp *Penaeus aztecus*	100	21	21.0%
Rough back shrimp *Trachypenaeus similis*	51	1	1.9%
Squid *Loligo pealei*	53	4	7.5%
Squid *Loliguncula brevis*	32	3	9.4%
Spider crab *Anasimus latus*	5	1	20.0%
TOTAL	525	88	16.8%

Further analyses are needed before a complete correlation can be established.

Karyotype

The majority of chromosomal analyses have been done on freshwater fish (Denton, 1973; Wharton *et al.*, 1977) and only a limited number of marine species have had their chromosome number established (Lee and Loh, 1975; Nicholson and Byrne, 1973; Regan *et al.*, 1968; Wharton *et al.*, 1977). Similarly with marine invertebrates, a limited number of species have been karyologically analyzed (Ahmed and Sparks, 1967, 1970; Menzel, 1968; Menzel and Menzel, 1965).

Seven marine fish and four marine invertebrates (Table 21.30) were used in the initial chromosomal analysis effort. Several problems had to be solved before chromosomes could be counted. Some of the animals sampled did not produce analyzable material. This was due to several factors such as (1) wrong colchicine dosage, (2) wrong treatment time, (3) improper hypotonic treatment, (4) improper spreading techniques, and (5) use of tissue with high mitotic activity. These factors will vary from species to species, from tissue to tissue and with size and/or age of animal. The factors for species listed in Table 21.30 were established fairly well. Chromosome counts were made and analyzable karyotypes are presently being developed for these species.

The basic protocol for chromosomal analysis used was a modification of the bone marrow and tissue techniques developed by Ford *et al.*, (1956). Modifications of this technique have been applied to other tissues. Gill epithelium, liver, kidney, spleen and scale epithelium have been used successfully for freshwater fish (Denton and Howell, 1969; McPhail *et al.*, 1966). Gill epithelium has provided the best results in the marine fish.

Of the seven species of fish analyzed, the silver perch, *Bairdiella*

TABLE 21.30

LIST OF SPECIES UTILIZED IN THE CHROMOSOMAL ANALYSIS EFFORT WITH CHROMOSOME NUMBERS

Species	Chromosome Number
Fish:	
Sand seatrout - *Cynoscion arenarius*	48
Vermilion snapper- *Rhomboplites aurorubens*	--
Barred grunt- *Conodon nobilis*	--
Silver perch- *Bairdiella chrysura*	48
Bigeye snapper- *Priacanthus arenatus*	38-44
Atlantic bumper- *Chloroscombrus chrysurus*	44
Dwarf sea perch- *Diplectrum bivittatum*	45
Invertebrates:	
Blue crab- *Callinectes sapidus*	24
Squid- *Loliguncula brevis*	22-24
Brown shrimp- *Penaeus aztecus*	22
Paper scallop- *Amusium papyraceus*	10-12

chrysura, sand seatrout, *C. arenarius*, and Atlantic bumper, *Chloroscombrus chrysurus* were completely evaluated including counting and karyotyping. These species have 48, 48 and 44 chromosomes, respectively, with the majority of chromosomes being telocentric (Figures 21.10A, 21.10B, 21.10C). Tentative chromosome counts were made on the other species, but not enough replication was done to establish the exact number. These species fell within a range of 44 to 54 chromosomes.

Invertebrate chromosome counts reported in the literature have been made on either oocytes or blastula cells. For this study, adult tissue was used. Different tissues were tried. Glandular tissue and gill epithelium proved effective in obtaining countable chromosomal spreads. The squid, *L. brevis*, had 22 to 24 chromosomes, the paper scallop 10 to 12 chromosomes and the blue crab 24 chromosomes (Figure 21.10D). The major problem with these organisms was the size of the chromosomes. The squid and scallop chromosomes range from 0.25 μm to 4 μm in size, making the identification of the chromosomes difficult. Replicates of these species are being done to confirm initial counts and to obtain analyzable chromosomes.

CONCLUSIONS

From the partially established reproductive cycles of selected invertebrates and fishes the following conclusions can be made. The fishes showed a great variability from station to station and occasionally within specimens at a given station. Invertebrates showed a greater degree of synchrony, with sequential development in some. Due to this variability, any future studies should analyze a larger number of specimens per species per station to provide a more representative statistical base. To establish complete reproductive cycles for the species used in this study at least two more years of sampling would be necessary.

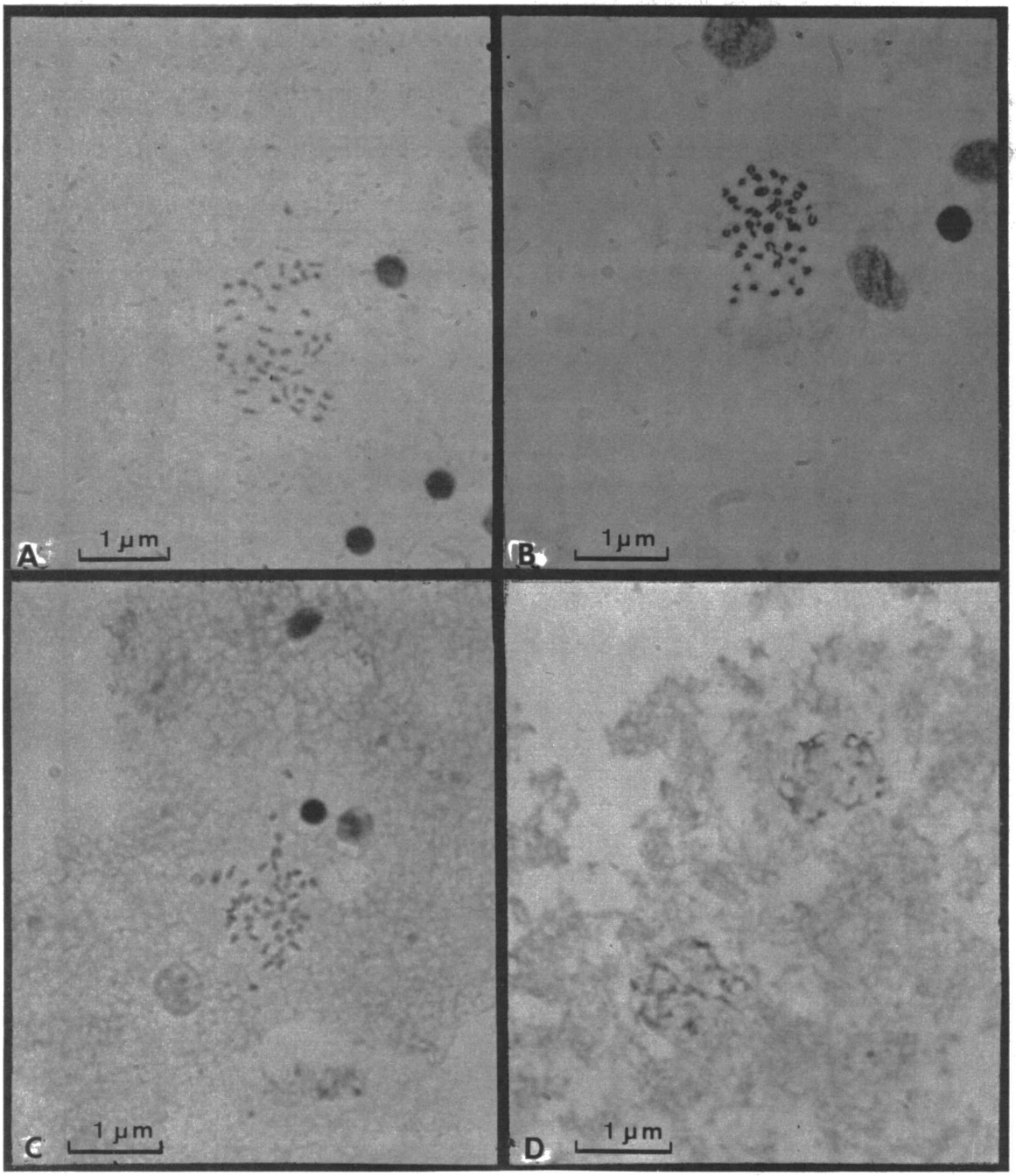


Figure 21.10

A. Silver perch (*Bairdiella chrysura*). Chromosome spread from gill epithelium showing 48 chromosomes. 1320X Giemsa Stain.

B. Sand seatrout (*Cynoscion arenarius*). Chromosome apread from gill epithelium showing 48 chromosomes. 1320X Giemsa Stain.

C. Atlantic bumper (*Chloroscombrus chrysurus*). Chromosome spread from gill epithelium showing 44 chromosomes. 1320X Giemsa Stain.

D. Blue crab (*Callinectes sapidus*). Chromosome squash from the digestive gland showing 24 poorly defined chromosomes. 1320X Giemsa Stain.

Pathological conditions observed in the fish and invertebrate gonads included parasitism, hyperplastic growth, cysts, vascularization, degenerated condition, fibroblast infiltration and other abnormal conditions. One hundred and forty-nine (149) of the 878 animals analyzed had a type of pathological and/or parasitic condition.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.