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by

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
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INVESTIGATIONS INTO THE SEASONAL DEEP CHLOROPHYLL MAXIMUM IN THE WESTERN NORTH ATLANTIC, AND ITS POSSIBLE SIGNIFICANCE TO REGIONAL FOOD CHAIN RELATIONSHIPS

by

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A.B., Yale University

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PHILOSOPHY

at the

WOODS HOLE OCEANOGRAPHIC INSTITUTION

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ABSTRACT

In many marine environments accumulations of chlorophyll have been reported to occur at or below depths to which 1% of ambient light penetrates. The phenomenon has been called the Deep Chlorophyll Maximum (DCM). On occasion zooplankton have been observed to be suggestively associated with a DCM. In order to determine, to what extent and under what circumstances, the DCM represents a significant food resource, data were obtained from vertically stratified net tows (both 0.333 μm and 0.067 μm mesh) and water bottle casts taken on eight cruises in the western North Atlantic between November 1973 and August 1976. Parameters measured included: zooplankton biomass, zooplankton functional group abundance, phytoplankton species abundance, chlorophyll concentration, ATP concentration, particulate nitrogen concentration, ^{14}C fixation, biological macro-nutrients (NO_3, NO_2, NH_3, PO_4, $Si(OH)_4$), oxygen concentration, temperature, and salinity. Parameters were measured as concommitantly as possible. Sampling was conducted in the Sargasso Sea, in Gulf Stream cold core rings, and in the Slope Water. Results obtained bear upon three major ecological problems: (a) the evolution of the biological community in a Gulf Stream cold core ring; (b) the sense in which the Gulf Stream represents an ecological discontinuity; and (c) the significance of the DCM as a locus for trophic activity.

Zooplankton biomass in the upper 800 m of four Gulf Stream cold core rings significantly exceeded that in the Northern Sargasso Sea. The center of its vertical distribution was uniquely deep. Such a distribution may result in reduced ecological efficiency and increase the

flux of organic matter to the deep sea. The phytoplankton assemblage of a cold core ring was significantly different from that of both the Slope Water and the Northern Sargasso Sea many months after ring formation. Certain species appeared to capitalize on some aspect of the ring environment and were especially numerous in ring samples.

Due to the composition, distribution, and variability of its characteristic phytoplankton the Slope Water represented a herbivore habitat very different from that in either the Northern Sargasso Sea or a six-month-old cold core ring. Under highly stratified conditions the preceding contrast was maximal. No common species was found only on one or the other side of the Gulf Stream, yet the species could be sorted into groups that had maximal abundances either in the Slope Water or the Northern Sargasso Sea. These groups appeared to differ in their responsiveness to nutrient concentration variation.

The DCM in diverse environments appeared to be an essentially identical phenomenon. The DCM accumulated phytoplankton cells (and possibly other organic particulates) sinking from above. Phytoplankton growth occurred at DCM depths despite low light levels. Various microbial processes appeared to be enhanced at DCM depths. As a consequence the DCM signalled a depth zone which, under stratified conditions, was a significant food resource especially since mixed-layer food was scarce.

Concentrations of zooplankton biomass at the DCM and the vertical distributions of zooplankton functional groups indicated the DCM in the western North Atlantic was a locus of particularly intense trophic

activity. The depth interval of the DCM had more total biomass and more microplankton biomass than above and below. Further, at DCM depths, the abundance of particular zooplankton functional groups appeared to reflect the size of the dominant phytoplankton. Not only presumed herbivores but a purely carnivorous group, the chaetognaths, on some occasions aggregated at DCM depths.

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PREFACE

The thesis that follows represents the juxtaposition of four discrete papers. Chapter One, "Variability in zooplankton biomass distribution in the Northern Sargasso Sea: the contribution of Gulf Stream cold core rings", will appear in Fisheries Bulletin (W.H.O.I. Contribution Number 3939) co-authored by P. H. Wiebe, L. Haury, and S. Boyd. Chapter Two, "Phytohydrography and herbivore habitat contrasts in the western North Atlantic" has been submitted to Deep-Sea Research (W.H.O.I. Contribution Number 4018) co-authored by E. Hulburt and P. H. Wiebe. The second author, E. Hulburt, made all the species identifications reported therein. Chapter Three, there entitled "Seasonal deep chlorophyll maxima in the western North Atlantic. Predictability and potential as a food resource" and Chapter Four, there entitled "Seasonal stratification and the vertical distributions of zooplankton biomass and functional groups in the western North Atlantic", will in more abbreviated form, be submitted to Marine Biology as a two-part paper. Although there will be no co-authors, I would be remiss if I did not observe that some of the co-authors of the first two papers were equally invaluable both in performing the research reported and in writing the latter manuscripts. Had they so desired, co-authorship would have been completely appropriate.

ACKNOWLEDGEMENTS

First and foremost I would like to thank my advisor, Peter H. Wiebe, for his continual support and unflagging, downright stubborn, enthusiasm. Special thanks are also due Steven Boyd, whose comradeship and assistance have been invaluable both at sea and on shore.

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None of the shipboard work described would have been possible without the patient cooperation of the Woods Hole Oceanographic Institution ships' crew, particularly J. Cotter and H. Rougas of the R/V KNORR. College student volunteers, M. Haygood, S. Lawrence, K. Wood, M. A. Wickes, M. Stroman, and others too numerous to individually mention, devotedly and enthusiastically assisted data collection and analysis. Manuscript preparation has been rendered comparatively painless due to the tolerance, good humor, and astonishing alacrity of our secretary, J. Peterson, and J. Zwinakis, D. Meinart, M. Mello, and F. Dunlap of the W.H.O.I. graphics department.

Spiritual and aesthetic sustenance have been bestowed upon me by E. Hulburt and J. Cox, both of whom, I maintain, are virtual Boddhistavas. My Middle Street family, my parents, and L. Haygood have endured months of bizarre egocentricity and meglomania. Lab-neighbors R. Howarth, C. Taylor, R. Cuhel (who also lavished nutritional attentional upon me),

and F. Carey have patiently endured repeated interruptions and progressively more distracted, often near-rhetorical, questions. Throughout A. Carey has ensured haute cuisine. Last I thank A. Jahn for showing me it could be done and W. Kinney for his carefully rationed inspiration. The thesis to follow, I dedicate to the memory of the purest scholar I shall ever know, Jeffrey H. Miller.

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GENERAL INTRODUCTION

In many oceanic environments, whenever near-surface stratification has been reasonably persistent, well-defined maxima in chlorophyll concentration occur at or just beneath the base of the euphotic zone - traditionally defined as extending from the surface to that depth to which 1% of the ambient light penetrates (Riley *et al.*, 1949; Steele, 1964; Yentsch, 1965; Anderson, 1969, 1972; Saijo, 1973; Takahashi *et al.*, 1974; Eppley *et al.*, 1973; and others). This phenomenon has been called the Deep Chlorophyll Maximum - DCM (Venrick *et al.*, 1973). Reports of a DCM in the western North Atlantic were among the earliest in the literature (Riley *et al.*, 1949). However, the Pacific Ocean has become the focus of investigation into the DCM with recent publications by Gunderson *et al.* (1976), Kiefer *et al.* (1976), and Jamart *et al.* (1977). The latter two papers attempt to model development of a DCM and, largely on theoretical grounds, evaluate some of the alternative explanations for DCM formation that have been proposed.

The present study was designed to investigate the DCM in a systematic manner with nearly synoptic assessment of the various physical, biological, and chemical factors that have been individually correlated with DCM formation. The western North Atlantic, due to the character of the Gulf Stream, appeared to be uniquely suited to such an effort. The Gulf Stream constitutes one of the sharpest hydrographic (Worthington, 1976) and ecological (Grice and Hart, 1962; Hulburt, 1963, 1964, 1966) discontinuities anywhere in the open ocean. Therefore it is possible to conveniently sample a DCM in distinct but contiguous pelagic environments.

Further, the Gulf Stream periodically forms accentuated meanders that can separate from the Gulf Stream and become closed rings (Fuglister, 1972). Southerly directed meanders, enclosing a core of cold and relatively fresh Slope Water, are called cold core rings. Northerly directed meanders, enclosing a core of warm and relatively saline Sargasso Sea water, are called warm core rings. If they do not coalesce with the Gulf Stream (Richardson, 1976), rings eventually become indistinguishable from the surrounding waters. Wiebe *et al.* (1976a) have termed such rings "large-scale interaction sites for open ocean plankton communities". Because all the biological and physico-chemical attributes of rings do not decay in phase (Wiebe *et al.* 1976a), by observing a DCM in a ring and in the surrounding waters it appeared possible to separate the effects of some of the factors held to be critical to DCM formation and maintenance.

The purpose of this study has been to find out if the DCM in the western North Atlantic is a locus of trophic interaction. Three interrelated questions are posed. First, what are the properties of the DCM and how do they appear to change through time, i.e., when and under what circumstances does it represent a food resource? Second, what animal distributions appear to have been shaped by the DCM and is there an identifiable assemblage of animals particularly associated with the DCM? Third, what might be the relationship between those animals (if there is any) and the DCM? Answering these questions requires detailed information about the vertical distributions of phytoplankton and zooplankton in the Slope Water and in the Northern Sargasso Sea. None was available for either region. Accordingly, Chapters One and Two establish the context in which answers to the above three questions can be framed. Chapters Three and Four specifically address those questions.

CHAPTER ONE. VARIABILITY IN ZOOPLANKTON BIOMASS DISTRIBUTION IN THE NORTHERN SARGASSO SEA: THE CONTRIBUTION OF GULF STREAM COLD CORE RINGS

INTRODUCTION

A number of papers have characterized the zooplankton biomass of the Northern Sargasso Sea (Grice and Hart, 1962; Menzel and Ryther, 1961; Deevey, 1971; Deevey and Brooks, 1971; Bé, 1971; and others). Because of the variety of methods employed in both sampling and processing, the results of these studies are not readily comparable. In general, previous authors have portrayed the Sargasso Sea as a remarkably homogeneous faunal province. The scale and frequency of regional variability resulting from incursions of cold-core rings into the Sargasso Sea have not been generally appreciated. Cold core rings are mesoscale hydrological features 150 to 300 km in diameter and up to several thousand meters in depth. They form when southerly directed Gulf Stream meanders become so accentuated as to separate from the Stream and move south, enclosing a core of cold and relatively fresh Slope Water within a remnant of the Gulf Stream (Fuglister, 1972; Parker, 1971; Richardson, 1976). In the Northern Sargasso Sea, at any one time, there are as many as 10-15 such rings[1]. Estimating the surface area of the

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[1]Lai, D. Y. and P. L. Richardson. Distribution and movement of Gulf Stream rings. Submitted to Journal of Physical Oceanography.

Northern Sargasso Sea as 32.9×10^5 km^2 (Jahn, 1976), cold core rings may cover between 6 and 13% of this surface. (Throughout the ensuing sections, unless otherwise indicated, the terms ring, Slope Water, and Sargasso Sea denote hydrographic not geographic entities.)

An overview of the phytoplankton, zooplankton, and midwater fish populations inhabiting cold core rings has been given by Wiebe *et al.* (1976a). The results of that study indicated that mean zooplankton biomass in the upper 750-800 m of rings between 3 and 10 to 12 months of age was consistently higher than that in the surrounding Sargasso Sea. In these preliminary data the fraction of biomass below 250-300 m in depth was particularly large while the near surface was more similar to the Sargasso Sea. We have now taken vertically stratified hauls in the same ring three months apart. The data from these hauls confirm our initial interpretation.

The objective of this chapter is two-fold. First, to describe the zooplankton biomass distributions characteristic of the Northern Sargasso Sea, of a cold core ring, and to a lesser extent of the Slope Water - the source of ring water. Second, to relate the patterns observed to systematic variations in phytoplankton standing crop, primary productivity, and water temperature, and to explore the significance of ring biomass distribution.

METHODS

Most of the data presented in this chapter were collected on R/V CHAIN cruise 125 (August 1975) and on R/V KNORR cruise 53 (November 1975). The ring sampled (designated Ring-D by the Naval

Oceanographic Office), was formed in February 1975. It was, therefore, about six months old when first sampled and nine months old when sampled again in November. In November the Slope Water was hydrographically complex. It is likely that some of our intended Slope Water tows (MOC 39 and MOC 40) were taken near a warm core ring (Saunders, 1971). The upper 200 m of the water column at that station were warmer and more saline than is typical for the Slope Water. In addition, infra-red satellite photographs clearly show the presence of this warm ring during the period of sampling. Other Slope Water stations may have been influeced by the passage of a warm core ring. In analyzing the data, MOC 39 and MOC 40 are considered separately and designated warm core ring tows (Figure 2). Data corroborating specific points or conclusions have been obtained from R/V ATLANTIS II cruise 71, R/V CHAIN cruise 111 and R/V KNORR cruises 35 and 38 (Table 1).

Collections in Gulf Stream cold core rings, the Northern Sargasso Sea, and Slope Water were made with three types of sampling gear; on the early cruises 1 m diameter ring nets or modified opening/closing 70 cm diameter Bongo nets (McGowan and Brown, 1966), on the two most recent cruises a multiple opening/closing net and environmental sensing system - MOCNESS (Wiebe *et al.*, 1976b) - with a mouth area of 1 m x 1.4 m (effective area is 1 m^2). All nets were constructed from .333 mm Nitex gauze; depth recorders and flow meters were used on all tows.

The 1 m nets were hauled obliquely, ideally to a depth of 800 m. On some cruises a second haul was taken to a depth of 300 m. Bongo nets were towed obliquely within the depth intervals 0-250 m, 250-500 m, and

Table 1

Summary of Slope Water, ring, and Sargasso Sea zooplankton sample stations.

Cruise	Date	Age of ring (months)	Number of samples (stations) Ring	Sargasso Sea	Slope Water	Type of net
ATLANTIS II 71[a]	9/21/72-10/14/72	10-12	8(4)	28(15)	4(2)	1 meter
CHAIN 111[a]	2/7/73-2/18/73	3.5	6(2)	5(2)	2(2)	1 meter and Bongos
KNORR 35[a]	11/23/73-12/3/73	3.0	8(4)	1(1)	5(3)	1 meter and Bongos
KNORR 38[a]	2/12/74-4/3/74	10-12				1 meter
CHAIN 125[b]	8/4/75-8/17/75	6.0	48(1)	32(2)	48(2)	MOCNESS
KNORR 53[c]	11/17/75-12/1/75	9.0	48(1)	40(2)	64(3)	MOCNESS

[a]Positions of stations illustrated in Wiebe *et al.* (1976).

[b]Sargasso Sea: MOC 1,2 (35°37', 68°31'), MOC 3,4 (35°22', 68°17'), MOC 12 (34°11', 71°40'), MOC 13,14,15 (34°10', 71°34'); ring: MOC 5,11 (34°29', 69°56'), MOC 6,7 (34°34', 69°52'), MOC 8 (34°31', 69°49'), MOC 10 (34°33', 69°53'); Slope Water: MOC 16, 17 (38°02', 69°59'), MOC 18,19 (38°05', 70°02'), MOC 20,21 (39°05', 70°12'). All positions north latitude and west longitude.

[c]Sargasso Sea: MOC 23,24,25 (32°44', 71°10'), MOC 26 (32°52', 71°08'), MOC 34 (34°12', 70°30'); ring: MOC 27,28,29 (33°49', 71°54'), MOC 31 (35°50', 71°48'), MOC 32 (33°56', 71°54'), MOC 33 (34°03', 71°56'); warm core ring: MOC 39,40 (40°04', 68°05'); Slope Water: MOC 35,36 (38°56', 67°47'), MOC 37,38 (38°55', 67°46'), MOC 41,42 (39°59', 69°00'). All positions north latitude and west longitude.

500-750 m. With occasional exceptions, the MOCNESS sampled both from 800 m to the surface in 100 m intervals, and from 200 m to the surface in 25 m intervals. Sampling with 1 m and Bongo nets was almost always done at night, while at most MOCNESS station samples were taken both day and night. The types of tows taken on the five cruises are given in Table 1. All samples were preserved in 5-10% formalin buffered to pH 8.0 with sodium tetraborate. In the vicinity of all plankton hauls, hydrographic casts were made yielding nearly concomitant vertical profiles of temperature, salinity, oxygen, chlorophyll, nutrients, primary productivity, and phytoplankton species (see Wiebe *et al.*, 1976a for methods).

Zooplankton biomass was measured by the method of Ahlstrom and Thrailkill (1963) after removal of all organisms greater than 5 cc. Displacement volumes were measured five to nine weeks after a cruise. No attempt has been made in this paper to partition the biomass according to taxa. The species composition of those samples already examined was similar to that reported for the region by Deevey (1971), Deevey and Brooks (1971), and Grice and Hart (1962).

RESULTS

Regional Biomass

The biomass collections obtained in the same ring three months apart on CHAIN 125 and KNORR 53 corroborate differences already noted in 0-800 m zooplankton biomass between the Sargasso Sea, cold core rings, and Slope Water (Figures 1 and 2). On both cruises the Slope Water 0-800 m biomass exceeded that in other two regions (Mann-Whitney U-test, $P < .01$). In August, the contrast

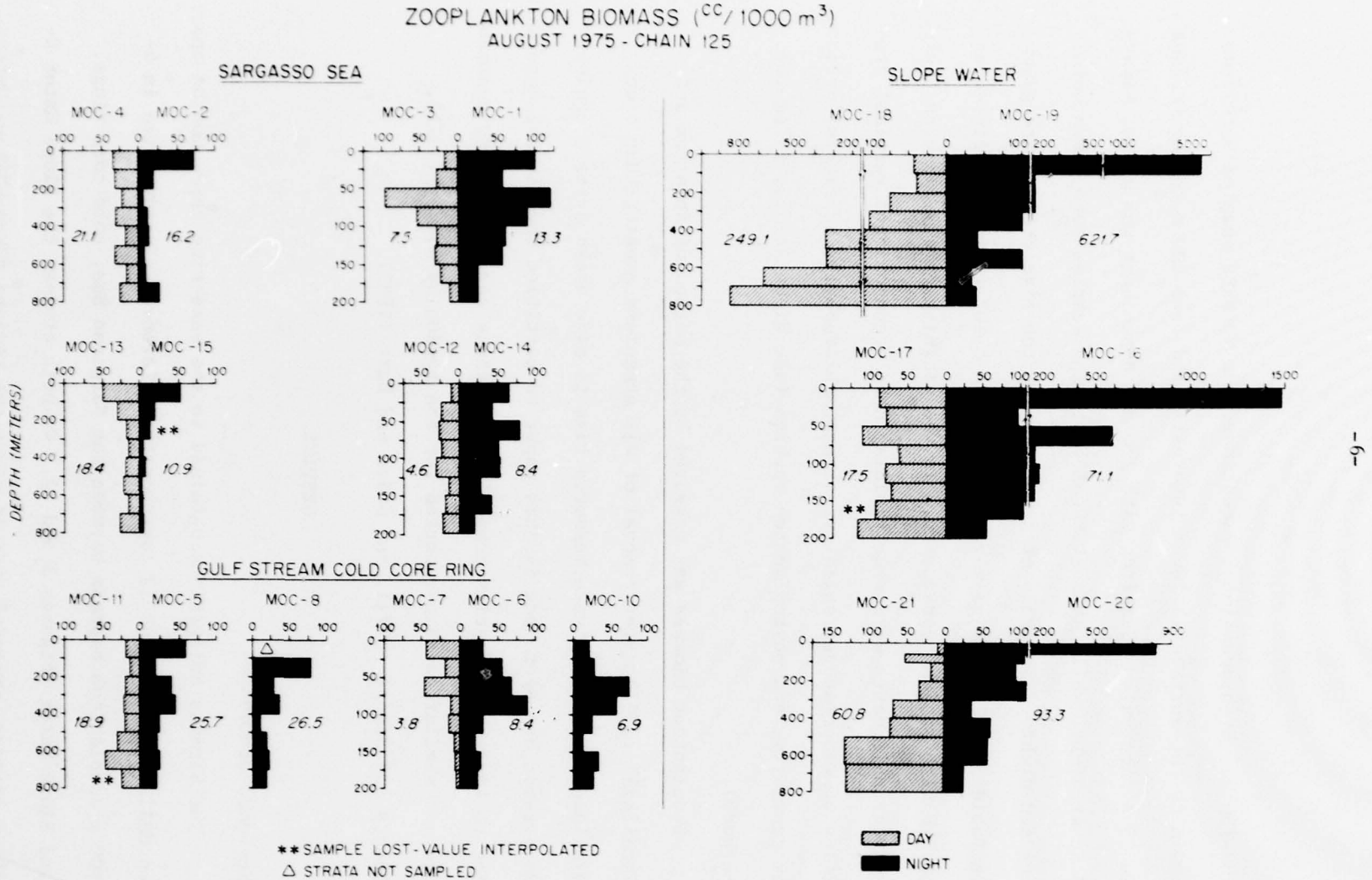


Figure 1. Slope Water, ring and Sargasso Sea zooplankton biomass (cc/1000 m^3). August 1975 - CHAIN 125. Values associated with each profile are cc/m^2 over adjacent profile.

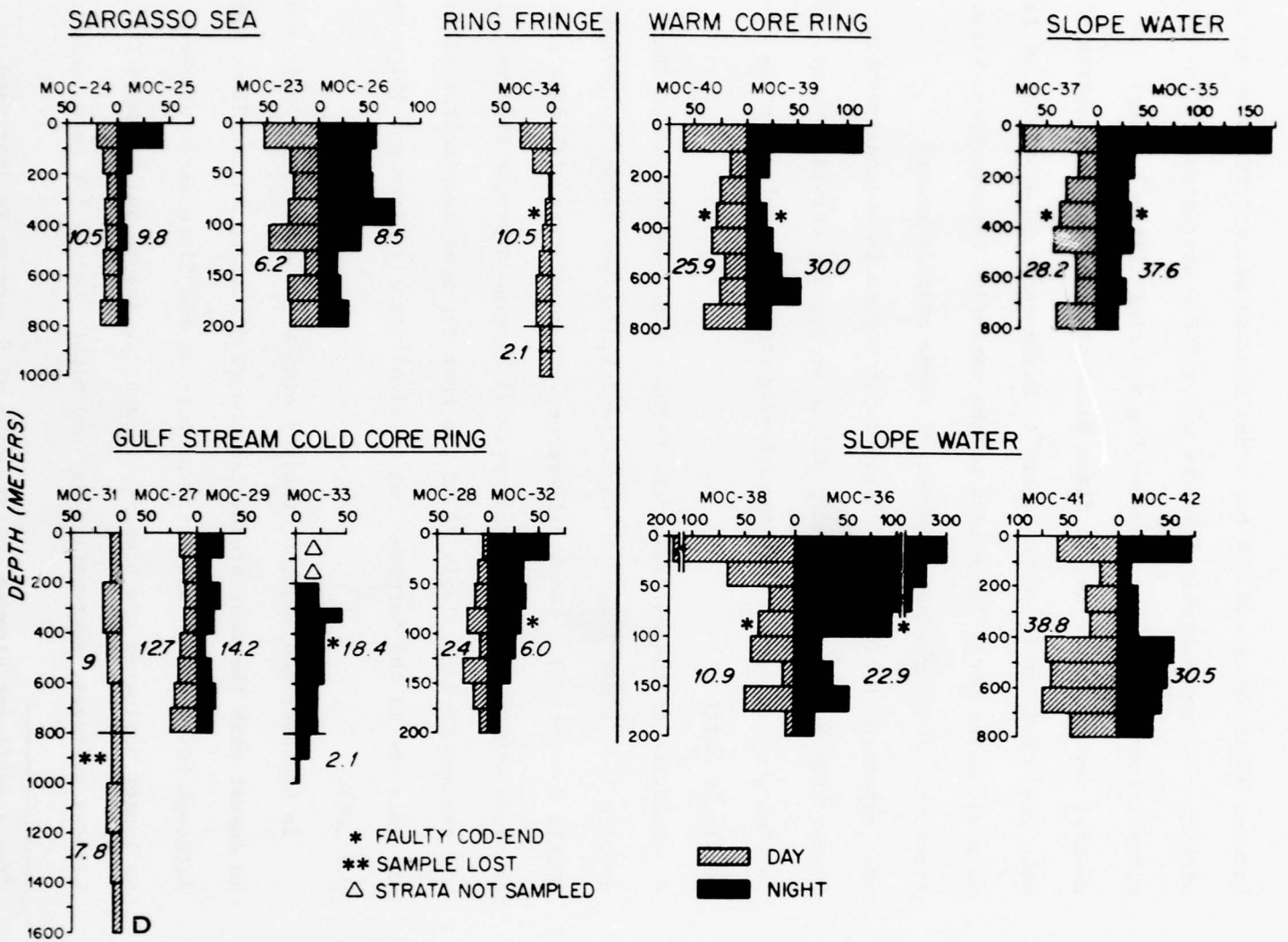


Figure 2. Slope Water, ring and Sargasso Sea zooplankton biomass (cc/1000 m^3). November 1975 - KNORR 53. Values associated with each profile are cc/m^2 over adjacent profile.

between Slope Water and the two other regions was particularly marked with average concentrations in the upper 800 m approximately 10-12 times larger than in the Sargasso Sea and ring (Table 2 - top). At several depths in the August Slope Water stations the zooplankton biomass was dominated by *Salpa aspera*[2]. Differences in abundance of this salp accounted for a large part of the variation between Slope Water stations. The high water content of these animals caused our estimate of biomass by displacement volume to be considerably higher than had we measured dry weight or organic carbon content. It is clear, nonetheless, that the standing stock of zooplankton was exceedingly large.

Relative to the Sargasso Sea, 0-800 m ring biomass was on the average 1.36 times larger in August and 1.33 times larger in November (Table 2 - bottom). These differences are consistent with data from previous cruises; using paired regional biomass averages observed on all cruises to date (Table 3) we see that the mean zooplankton biomass in rings and in the Sargasso Sea is significantly different (Sign test, $p < .05$).

In November zooplankton standing crop was consistently lower than in August with the most pronounced change occurring in the Slope Water. Although *Salpa aspera* was still present at the Slope Water stations it no longer dominated the biomass. Comparing August and November 0-800 m biomass averages, segregating day and night samples for each region, we

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[2]The significant biomass contribution of *S. aspera* is discussed in Wiebe, P. H., L. P. Madin, G. R. Harbison, L. R. Haury and M. L. Philbin. Diel vertical migration by *Salpa aspera*: potential for large-scale particulate organic matter transport to the deep-sea. In manuscript.

Table 2

Comparison of Slope Water, ring, and Sargasso Sea zooplankton biomass (cc/m^2) based on weighted averages of day and night samples. Number of tows used to make average given in parentheses.

Region	Depth interval (m)					
	August (1975)			November (1975)		
	0-800	200-800	0-200	0-800	200-800	0-200
Sargasso Sea	16.6(4)	8.8(4)	8.1(8)	10.2(2)	5.6(2)	6.0(4)
Ring fringe				9.1(1)	4.3(1)	4.8(1)
Cold core ring	22.5(3)	15.6(3)	6.4(6)	13.6(4)	11.4(4)	3.4(5)
Slope Water	256.2(4)	95.6(4)	121.8(6)	33.8(4)	23.03(4)	12.8(6)
Warm core ring				27.9(2)	17.2(2)	10.8(2)

	Ratio ring/Sargasso Sea		
	0-800	200-800	0-200
August	1.36	1.77	.79
November	1.33	2.03	.56

Table 3

Average zooplankton biomass in Slope Water, ring and Sargasso Sea - dry wt (mg/m^3) in column ~ 750 m deep. Number of stations per area and range of biomass values (after colon) given in parentheses. This table is an expanded version of Table 3 in Wiebe *et al.* (1976a). Note that the biomass units in the original table were incorrectly presented as mg/m^2.

Cruise	Slope	Ring	Sargasso Sea	Ring Age (mo.)	Ring ÷ Sargasso	Slope ÷ Sargasso
ATLANTIS II 71	7.43 (1)	2.24 (4:2.06-2.60)	1.68 (4:1.34-2.05)	10-12	1.33	4.42
CHAIN III	4.21 (1)	4.95 (2[a]:2.21-7.68)	2.70 (3[b]:1.99-3.96)	3.5	1.83	1.56
KNORR 35	6.06 (4[c]:3.60-7.74)	3.67 (3[d]:3.15-4.33)	2.47 (1)	3.0	1.49	2.45
KNORR 38[e]	5.74 (4:2.2-9.14)	3.10 (6:2.56-4.98)	2.34 (4:1.76-3.21)	10-12	1.32	2.45
CHAIN 125[e]	9.10 (2[f]:6.85-11.35)	2.26 (3:1.73-2.57)	1.49 (4:0.90-1.97)	6.0	1.52	6.11
KNORR 53[e]	3.43 (4:2.77-4.03)	1.09 (4:0.72-1.35)	.83 (2:0.90-0.86)	0.0	1.31	4.13
				$\bar{X}$ = 1.47	$\bar{X}$ = .73	$\bar{X}$ = 3.52

[a] Each of the two values is integrated for the water column based on three stratified Bongo net tows.

[b] Two values are from oblique meter net tows; one is an integrated value based on three stratified Bongo net tows.

[c] Two values are from oblique meter net tows; one is an integrated value based on three Bongo net tows; one is an oblique Bongo net tow.

[d] One value is an integrated value based on three stratified Bongo net tows; two values based on two stratified Bongo net tows.

[e] cc/m^3 converted to mg/m^3 using equation 4, Table 2 in Wiebe, Boyd and Cox (1975). Note that this conversion affects the regional biomass ratios (see Figure 2) because the relationship between displacement volume and dry weight is not linear.

[f] Salp-rich tows, MOC 39 and MOC 40, excluded.

see that the overall seasonal decline is statistically significant (Sign test, $p < .05$ - computed using cc/m^2 in Figures 1 and 2). Indeed only one November 0-800 m biomass value was as large as the smallest 0-800 m biomass in the same region in August.

Average Vertical Structure

Comparing Ring D biomass partitioned according to depth, the upper 200 m in the ring contained on the average less biomass during both sampling periods than did the Sargasso Sea (Table 2 - top). This was true both day and night during the August and November cruises. In contrast, ring biomass between 200 and 800 m was higher both day and night (Figures 1 and 2). The range of 200-800 m biomass values in the ring and in the Sargasso Sea does not even overlap. The combination of lower average surface biomass and higher average subsurface biomass in the ring is highly significant ($p < .01$, Sign test: computed using sums of 0-200 m and 200-800 m cc's/1000 m^3 derived from Figures 1 and 2). The regional averages of percent 0-800 m biomass present in the upper 200 m in August were 51%, 34%, and 27% in the Sargasso Sea, Slope Water and ring respectively. In November these averages were 45%, 32% and 25% (Table 4). Although very different sampling gear and tow strategies were employed, data from ATLANTIS II 71 corroborate the direction of difference of these observations in that the percentages of 0-800 m biomass found at night in the upper 300 m were 64% and 52% for the Sargasso Sea and ring (Table 5). In addition, the 300-800 m biomass was 1.73 times larger in this latter ring than in the Sargasso Sea immediately surrounding the ring.

Table 4.

Percent of 0-800 m Slope Water, ring, and Sargasso Sea zooplankton biomass in the upper 200 m (800 m tows) only.

D = Day; N = Night.

Region	August (1975)					November (1975)				
	Percentages of individual tows	D	N	N-D	(D+N)/2	Percentages of individual tows	D	N	N-D	(D+N)/2
Sargasso Sea	D_1 = 32% N_1 = 57% D_2 = 41% N_2 = 69%	39%	63%	24%	51%	D_1 = 30% N_1 = 60%	30%	60%	30%	45%
Ring fringe						D_1 = 46%	46%			
Cold core ring	D_1 = 16% N_1 = 32% N_2 = 42%	16%	37%	21%	27%	N_1 = 29% D_1 = 21% D_2 = 19%	20%	29%	9%	25%
Slope Water	*D_1 = 3% *N_1 = 93% D_2 = 7% N_2 = 61%	6%	61%	54%	34%	D_1 = 32% N_1 = 55% D_2 = 13% N_2 = 27%	23%	41%	19%	32%
Warm core ring						D_1 = 30% N_1 = 46%	30%	46%	16%	38%

* On this tow series, MOC 18 and MOC 19m salps were extremely dominant. These tows are excluded from averages.

Table 5

Ring and Sargasso Sea zooplankton biomass - ATLANTIS II 71 (mg/m^2).

Region	0-300 m	0-800 m	$\frac{0\text{-}300}{0\text{-}800}$ X 100	
Ring	954	1648	58%	
	963	2080	46%	52%
	930	1704	55%	
	828	1728	48%	
Sargasso Sea	858	1344	64%	
	798	1072	74%	64%
	765	1640	47%	
	921	1304	71%	

Diel Migration

Complicating these general observations and contributing to sample variability are day/night differences in biomass distributions (Table 4). In all day/night sample pairs the fraction of 0-800 m biomass present in the 0-200 m interval is larger in the night sample (Sign test, $p < .01$). This results from either diel migration or day/night differences in avoidance within the illuminated surface layers.
Avoidance does not appear to be an important factor because at some stations the day 0-800 m biomass exceeds the night 0-800 m biomass. This is true at all Sargasso Sea 0-800 m station pairs and at one Slope Water station (Figures 1 and 2). Furthermore, some species of zooplankton taxa already enumerated, e.g., - euphausiids and pteropods, exhibit strong diel migration patterns in all three areas.

Since we believe diel migration to be the appropriate explanation, the data further suggest that while essentially the same percentage of 0-800 m biomass was migrating into the surface layers of the Sargasso Sea (24-30% during both sample periods), there was a reduced percentage migrating in the ring in November (21% in August versus 9% in November - Table 4). Although a smaller proportion of the biomass may have been migrating in the ring relative to the Sargasso Sea, there was a significantly greater (Mann-Whitney U test, $p < .05$) day/night biomass ratio in the upper 200 m in the ring (Table 6). This apparent contradiction results from the fact, already noted, that the percentage of 0-800 m biomass present in the upper 0-200 m was very much greater in the Sargasso Sea. Day/night ratio of biomass in the upper water column is often used to measure intensity of diel migration; clearly the meaning

Table 6

Day/night differences in Slope, ring, and Sargasso Sea zooplankton biomass in the upper 200 m

Region	Night/Day Ratio	
	August (1975)	November (1975)
Sargasso Sea	1.78*	1.37*
	1.37†	1.86†
	1.84*	
	.99†	
Cold core ring	2.01*	2.48*
	3.10†	1.86†
Slope Water	4.06*	2.10*
	68.33†[a]	2.27†
	14.82†[a]	
		1.70†

*Based on 0-200 m tows

†Based on 0-800 m tows

[a]Ratio affected by extreme salp dominance

of this ratio is highly dependent upon average vertical biomass distribution.

Slope Water day/night sample pairs may be interpreted as documenting diel migration, but the data are extremely variable both within and between cruises (Table 4). There may have been a less well developed migration in the fall.

Shallow Biomass Structure

In the 0-200 m biomass profiles, an intermediate biomass peak occurred between 50 and 100 m depth at nearly every station in August 1975 (Figure 1: MOC 1,3,6,7,10,16,17). At all but one of the Sargasso Sea and ring stations this intermediate peak is the highest observed value in the 0-200 m tows. At Slope Water stations of the same cruise this intermediate peak is the second highest observed value. If we rank each interval in a profile in order of zooplankton abundance, we can test the significance of this observation. For instance, the individual summer tows in the ring and the Sargasso Sea exhibit significant concordance as to which depth intervals have the larger and which the smaller zooplankton biomass (Friedman 2-way analysis of variance on ranks, $p < .005$). Given this result, the best estimate of the differences between intervals is the order of their summed ranks (i.e., 50-75 m > 75-100 m > 100-125 m > 25-50 m > 0-25 m > 150-175 m > 125-150 m > 175-200 m). Applying a procedure for testing differences between individual depth intervals (Nemenyi, 1963), we see that concordance results from the fact that the 50-75 m biomass is significantly greater than the biomass in the intervals 125-150 m, 150-175 m and 175-200 m,

and the 75-100 m biomass is greater than the 175-200 m biomass ($p < .05$). An intermediate peak is not a notable feature of the 0-200 m profiles taken on the fall cruise with the exception of the Sargasso Sea sample pair (Figure 2: MOC 23 and 26).

DISCUSSION

Wiebe *et al.* (1976a) have discussed the formation and decay of an idealized cold core ring. Initially conditions inside a ring core are identical to those in the Slope Water just northward of the Gulf Stream at the time of ring formation. Through time the ring decays; the isotherms deepen, the water becomes more saline, and O_2 minimum deepens, and the constituent flora and fauna either die off or become diluted by populations from the surrounding Sargasso Sea. Because zooplankton populations are generally suited to the environmental conditions they encounter within their normal range, this decay process may be viewed as the gradual imposition of a complex environmental stress upon an entire community. Wiebe *et al.* (1976) have documented some of the intermediate stages in this idealized process. This process can be aborted when a ring is reabsorbed by the Gulf Stream[3] (Fuglister, 1972). All biological and physical properties are not equally conservative so their decay rates would not be the same.

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[3]Richardson, P. L., R. E. Cheney and L. A. Mantini. Tracking a Gulf Stream ring with a free drifting surface buoy. Submitted to Jour. Phys. Oceanogr.

The Regional Contribution of Cold Core Rings

Primary Productivity: It is well known that Slope Water is more productive than the Sargasso Sea. Ryther (1963) estimated that Slope Water is about twice as productive on an annual basis (120 gmC/m^2/yr versus 60 gmC/m^2/yr). Although our own data are scanty, rings on the average are intermediate between Slope Water and the Sargasso Sea (Table 7). A few simplifying assumptions permit budgetary computations to be made regarding the overall effect of rings on the carbon budget of the Northern Sargasso Sea. Let us assume an average ring life of one year and a linear rate of decay of productivity (i.e., that annual ring production is the arithmetic mean of annual Sargasso Sea and Slope Water production). Allowing 6 to 13% as the areal contribution of rings to the Northern Sargasso Sea as explained earlier, and Ryther's estimate of a twofold difference in annual production, the net annual production of the geographic Northern Sargasso Sea is then 3 to 7% higher than if it contained no rings (i.e., 6 x 1.5 = 9, 9 + 94 = 103 and 13 x 1.5 = 20, 20 + 87 = 107). Our assumption of linear decay is an oversimplification. In November 1975, the ring water column, like the Slope Water, began its winter overturn before the surrounding Sargasso Sea. Mixing eroded the seasonal thermocline that had been observed in Ring D in August 1975. The decay we have assumed was reversed, and ring productivity was enhanced (Table 7).

Zooplankton Standing Crop: Similar calculations can be made regarding the relative contribution of rings to the mean zooplankton biomass of the geographic Northern Sargasso Sea. Neglecting one station

Table 7

Summary of Slope Water, ring, and Sargasso Sea primary productivity (mg C/m^2/day), phytoplankton carbon[a] (mg/m^2), and chlorophyll *a* (mg/m^2) measurements.

Region	March (1974)		August (1975)			November (1975)		
	Productivity	Chlorophyll	Productivity	Chlorophyll	Phytoplankton carbon	Productivity	Chlorophyll	Phytoplankton carbon
Sargasso Sea	228.5	46.4	207[b]	13.3	33.4	86.5	12.0	21.0
			100			252.2		
Cold core ring	440.1	73.0	83	17.3	45.0	483.2	10.3	28.2
	333.1		106			155.5		
						186.5		
Slope Water	1025.5	70.4	175	50.5	280.0	1302.2	39.0	287.0
	368.4		270			824.0		
						376.2		
						363.7		

[a]Based on counts of cells larger than 4-5 μm.

[b]The high value in average mgC/m^2/day observed at this station is a consequence of one unusually high surface value.

which had anomalously high values due to extreme salp dominance, the average of Slope Water biomass values is 3.5 times the observed Sargasso Sea biomass (Table 3). Given this ratio and the same linear [i.e., (3.5 + 1) ÷ 2 = 2.25] and areal assumptions made earlier, rings may augment the zooplankton standing crop of the geographic Northern Sargasso Sea by 8 to 16% (i.e., 6 x 2.25 = 14, 14 ÷ 94 = 108 and 13 x 2.25 = 29, 2- + 87 + 116). Our ratio of Slope Water to Sargasso Sea biomass may be compared to that of Grice and Hart (1962), who reported the Slope Water standing crop as three to four times that of the Sargasso Sea. They also excluded extremely salp-rich samples in making this comparison. Our assumption of 2.25 as an annual mean ring/Sargasso biomass ratio (i.e., linear decay) may be an overestimate considering the average biomass ratio obtained on all cruises to date and the average ring age sampled (Table 3). On the other hand some rings do last longer than a year and the lowest ring:Sargasso Sea ratios that we have observed are approximately 1.3 (i.e., greater than 1.0).

We have noted a highly significant decline in 0-800 m biomass from August to November in Slope Water, ring, and Sargasso Sea both in data presented here and in data more recently collected.[4] This observation is consistent with those of Grice and Hart (1962) with respect to the Slope Water. They noted, however, no such decline in the Sargasso Sea. Neither is there a summer-to-fall decline in the Sargasso Sea data of Deevey (1971). The Sargasso Sea and Slope Water data of Fish (1954) exhibit irregular fluctuations in biomass throughout the summer and fall.

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[4]Some of this data presented in Figure 5 of Richardson, P. L., J. Schmitz, and P. H. Wiebe. 1977. Gulf Stream ring experiment. Polymode News 25:3. Unpublished nanuscript.

Moore (1949) presented some Sargasso Sea data indicating a progressive decline of biomass from a spring maximum to a fall minimum. The data of the aforementioned authors substantiate that interseasonal fluctuations in the Sargasso Sea are less marked than in the Slope Water.

Vertical Structure

We have pointed out that, compared to either the Sargasso Sea or Slope Water, an unusually small percentage of 0-800 m biomass is present in the upper 200 m of a ring. We found a relatively large fraction of the 0-800 m zooplankton biomass above 200 m in the Northern Sargasso Sea. The netting employed by Leavitt (1935, 1939) was relatively coarse (1.0 mm) so it is difficult to compare our results with his. Nonetheless, at his two Sargasso Sea stations (2462, 2463) the percentages of 0-800 m biomass present in the upper 200 m were 42% and 49% which corresponds closely to our values (Table 3). Both Leavitt's and our results are virtually identical with those obtained by Menzel and Ryther (1961). From their Table 1 we can calculate the percentages of 0-500 m biomass and 0-1000 m biomass present above 200 m. Averaging the results, we find 44% of the 0-750 m biomass was present during the day above 200 m. Yashnov (1961) presented data for the Sargasso Sea in which 90% of the 0-1000 m plankton was present above 200 m, but he used a relatively fine mesh net (0.180 mm). Unfortunately, Deevey and Brooks (1971) characterized 500 m depth intervals with horizontal tows at the midpoint of each interval to 2000 m, while Grice and Hart (1962) sampled only the upper 0-100 or 200 m.

Several authors suggest that a vertical biomass structure similar to our Slope Water and Sargasso Sea observations is to be expected in

temperate or subtropical oceanic environments relatively free of advective inputs. Vinogradov (1968: figure 47 and stations 3206 and 3829 in Table 18) gave examples of oceanic regions with such a distribution. Zenkevitch and Birstein (1956) agreed that zooplankton biomass in the North Pacific rather steadily decreases from the surface downwards, although the most marked reduction they discuss might be below ourlowest standard sampling depth. The one very deep tow series we obtained in a ring, however, gave no indication of such a reduction (Figure 2, MOC 31).

Zooplankton biomass profiles obtained by Murano *et al.* (1976) in the Northwest Pacific above the Sagami Trough exhibit the expected decrease with depth. Reanalyzed in our manner, the data of Marlowe and Miller (1975) for Station P in the North Pacific support the above generalization; the percentage of their 0-500 m biomass found at night in the upper 200 m was 57%. If one extrapolates their 500 m values as approximately applicable to the 500-800 m interval - a conservative approach for this argument - the resulting percentage becomes 49% (N). This is not unlike our average Slope Water percentage of 51% (N) and quite distinct from the average ring percentage of 33% (N) (Table 4). Station P is very different from Ring D in respect to its vertical biomass distribution.

In Slope Water, the intermediate biomass peak in the upper 200 m approximately coincides with the depth of a nitrite maximum of the type discussed by Vaccaro and Ryther (1960). Our results and those of Marlowe and Miller (1975) appear to differ: they felt that the shallow nitrite peak of Station P was avoided by zooplankton. Since the

levels of nitrite we have observed at the maximum are only slightly lower than those reported by Marlowe and Miller (.2-.5 µg A-N-NO_2/liter versus .64 µg A-N-NO_2/liter), our findings cast doubt on their speculation that nitrite toxicity might have been involved in the maintenance of the biomass minima they observed.

Explanations for Ring Biomass Structure

Given the relatively high zooplankton biomass of the Slope Water, it is clear why cold core rings have a higher average zooplankton biomass than the Sargasso Sea. Further, their higher average primary productivity appears responsible for this difference persisting 10-12 months after ring formation. Our data suggest the decline in ring biomass takes place rather slowly; the oldest rings sampled (10-12 months) had ring/Sargasso biomass ratios only 20% smaller than the same ratios in the newest rings sampled (3.0 and 3.5 months, Table 3). Although physically and chemically intermediate between Slope Water and Sargasso Sea, rings appear to be unique in their vertical distribution of biomass.

We offer two explanations for the small fraction of the 0-800 m biomass found within the upper 200 m of a ring. They are not mutually exclusive and the relative importance of these explanations is species dependent. The simpler argument stresses the importance of a physical factor - temperature. If a Slope Water animal were physiologically restricted to a particular temperature range, its habitat would descend as the ring decayed and isotherms sank. To the extent that the zooplankton population in the Slope Water exhibited this behavior, ring biomass distributions would deepen. This could

apply only to a species which in its home range - the Slope Water - remains beneath the seasonal thermocline (i.e., moderately deep-living and exhibiting limited diel migration). Such a species would most likely have to be either carnivorous or omnivorous. Wiebe and Boyd[5] have documented such a phenomenon for the Slope Water euphausid species, *Nematoscelis megalops*.

A more complex explanation stresses the importance of a biological factor - food resources. The kinds of changes that accompany ring decay must have a substantial effect upon zooplankton-phytoplankton interactions. Using data obtained in August 1975 from five 9-bottle hydrocasts,[6] the number of phytoplankton cells/liter averaged 10,000 in the Slope Water, 2500 in the ring, and 2000 in the Sargasso Sea. Cells smaller than 4-5 μm were not enumerated and could not be included in these computations. Values were integrated from 0-200 m - a conservative procedure tending to reduce Slope Water versus ring or Sargasso Sea differences. The species composition of the ring, while distinct, was more like that of the Sargasso Sea than that of the Slope Water. Again, considering the 0-200 m depth interval, the number of different phytoplankton species an animal would have encountered in a liter of water would on the average have been 6.0 (Slope Water), 9.6 (ring) and 10.4 (Sargasso Sea). Converting the mean cell volume of each species to carbon (Strathmann, 1967) and multiplying by the number of individuals present, yielded values of average phytoplankton carbon of 1400, 200, and 140 ng C/liter.

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[5]Wiebe, P. H. and S. H. Boyd. Limits of *Nematoscelis megalops* in the Northwestern Atlantic in relation to Gulf Stream cold core rings. Part I. Horizontal and vertical distributions. Submitted to J. Mar. Res.

[6]Data in Chapter Two.

Thus, to acquire the same ration of food, a herbivore would have had to filter more than five times more water in the ring than in the Slope Water, and even more in the Sargasso Sea. In addition, the evenness of species' carbon equivalence was .46, .75 and .76. That is, the total carbon/liter was more evenly distributed among different species in the ring and the Sargasso Sea than in the Slope Water. (Evenness equals H/H_{max} (Pielou, 1966) where H is the Shannon-Weaver diversity index computed upon species carbon equivalence rather than abundance and $H_{max} = \text{Log}_e S$ where S = number of species.) This last result implies that a herbivore capable of selecting by carbon content ($\sim$ particle size) would have found it less advantageous to concentrate on a particular species in the Sargasso Sea and the ring than in the Slope Water.

These properties of the phytoplankton population, i.e., species composition, carbon concentration, cell concentration, and cell carbon distribution, have profound effects on a filter-feeding herbivore's harvesting ability. We believe that early in ring evolution herbivorous Slope Water species are deleteriously affected and, therefore, may be replaced by Sargasso Sea forms more quickly than deeper living carnivorous or omnivorous Slope Water species. If we are correct, ring biomass distribution may deepen in part because a ring's 0-200 m biomass declines more rapidly than does its 200-800 m biomass.

Identification of some of the taxa in August 1975 samples, although limited, support the argument that in Ring-D epizooplanktonic herbivores were replaced before epizooplanktonic carnivores or omnivores.[7] The species list of Ring-D thecosomatous pteropods, a largely herbivorous group, was quite similar to that of the surrounding Sargasso Sea.[8]

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[7] Data in Chapter Four.

[8] John Wormuth, unpublished data; cited with permission.

Grice and Hart (1962) found that chaetognaths, a purely carnivorous group, were considerably more abundant in the Sargasso Sea than they were in Slope Water. In six 9-net, fine-mesh tow series (12.5 cm dia. Clarke-Bumpus nets with 67 μm mesh) taken in August, chaetognaths were five to ten times more abundant in the surrounding Sargasso Sea than they were in Ring-D. Other epizooplanktonic carnivores, e.g., *Stylocheiron suhmii* and *S. abbreviatum*, which are routinely found in the Sargasso Sea, were not found in Ring-D August MOCNESS tows.

Organic Flux to Deep-Sea

Rings may contribute a disproportionate fraction of the utilizable organic material available to the Northern Sargasso deep-sea. We feel this is likely both because of their generally higher productivity and because of their unique zooplankton biomass distribution and the factors that have resulted in that distribution. Ring zooplankton biomass below 200 m in that it exceeds Sargasso Sea biomass and ultimately declines to a similar level contributes to this augmentation. Differential seasonal mixing processes could also increase downward particulate flux. For example, in November 1975 we observed that winter mixing had proceeded further in Ring-D than in the surrounding Sargasso Sea water column. Herbivorous ring zooplankton (i.e., Sargasso forms) may have been unable to fully capitalize upon the sudden oportunity afforded by the increased primary production that accompanied the mixing (Table 7). If so, a larger fraction of this enhanced phytoplankton production would sink into the aphotic depths. Physical evidence obtained on two cruises undertaken to study rings during the summer has suggested to us that

the seasonal thermocline may often be less stable in rings than in the Sargasso Sea.

Finally, there is a possibility of enhanced contribution of organic matter into the deep sea due to a lower overall trophic efficiency within the upper 200 m of rings (and Slope Water). If we divide average 0-200 m zooplankton biomass (mgC/m^2 calculated using Equation 4, Table 2, in Wiebe *et al.*, 1975) by 0-200 m phytoplankton carbon (mgC/m^2 from Table 5) - excluding salp-rich MOC 18 and 19, we obtain the following ratios:

	Sargasso Sea	Ring	Slope Water
AUGUST 1975	253	138	84
NOVEMBER 1975	332	131	28

Ratios in the ring are low, as are those in the Slope Water. Lower ratios suggest to us lower overall trophic efficiency within the upper 200 m. Although biased in that many cells are quite small, particularly in the Sargasso Sea, phytoplankton carbon of cells > 5 μm is probably a reasonable estimate of the food available at the time of sampling to many of the herbivorous animals caught by our .333 mm mesh nets. The direction of difference noted above conforms with ideas expressed by Menzel and Ryther (1961) and Heinrich (1962) and others who argued that especially close phytoplankton-zooplankton coupling may characterize oceanic tropical-subtropical waters.

The biomass data presented here illustrate the fact that geographic demarcation of oceanic faunal provinces is not sufficient.

Hydrographic as well as faunal mapping is essential in explaining that portion of station-to-station variability associated with mesoscale hydrographic variability resulting from phenomena like Gulf Stream cold core rings.

SUMMARY

The scale and frequency of physical variability resulting from incursion of Gulf Stream cold core rings into the Northern Sargasso Sea makes this faunal province more heterogeneous than previously recognized. At any one time such rings may cover between 6 and 13% of the surface area of the Northern Sargasso Sea. They are more productive than the surrounding Sargasso Sea and have a zooplankton biomass intermediate between the Sargasso Sea and the Slope Water. Cold-core rings may augment the primary productivity by 3% to 7% and the zooplankton standing crop of the Northern Sargasso Sea by 8% to 16%. Compared to either the surrounding Sargasso Sea or their parent Slope Water, the rings sampled had an unusually large percentage of their 0-800 m biomass at depths greater than 200 m. This distribution can be related to hydrographic and biological changes associated with ring decay. Due to their higher productivity, to differences in vertical biomass structure, and to the possibility that ring food chain efficiency is lower than that of the Sargasso Sea, rings may provide a disproportionately large fraction of the total supply of organic matter to the Northern Sargasso deep sea.

CHAPTER TWO. PHYTOHYDROGRAPHY AND HERBIVORE HABITAT CONTRASTS IN THE WESTERN NORTH ATLANTIC

INTRODUCTION

For many years investigators have studied the phytoplankton of the Northwestern Atlantic Ocean (Riley and Gorgy, 1948; Riley, Stommel and Bumpus, 1949). Hulburt and co-workers (1960, 1963a, 1963b, 1964, 1966, 1967), Marshall (1966, 1968, 1971) and others have documented a strong contrast between phytoplankton species composition in the Slope Water north of the Gulf Stream and in the Northern Sargasso Sea south of the Gulf Stream. A tacit assumption of many of these studies has been that the Sargasso Sea is a relatively monotonous biogeographic province - hydrographically, both uniform and homogeneous.

Only one previous investigator has called explicit attention to Slope Water phytoplankton species assemblages transported across the Gulf Stream (Riley, 1957). Such transport accompanies the incursion of Gulf Stream cold core rings into the Northern Sargasso Sea. Ten to fifteen such rings, each 150-300 km in diameter, cover at any one time 6-13% of the surface area of the Northern Sargasso sea (Chapter One). We have shown that the physical, chemical and biological characteristics of cold core rings may be quite distinct from those of the surrounding Northern Sargasso Sea (Wiebe *et al.*, 1976a; Wiebe, 1976; and Chapter One).

In the sections to follow we analyze phytoplankton species counts in the Northern Sargasso Sea, in the Slope Water, and in Gulf Stream cold core rings, on four oceanographic cruises. Initially, we

investigate seasonal and regional differences in the vertical distributions of a number of population attributes: a number of cells per phytoplankton group per liter; cell carbon per phytoplankton group per liter, number of species per phytoplankton group per liter, diversity and evenness of species abundances, and diversity and evenness of species carbon contents. We analyze the distributions of species carbon contents, as well as species abundances, because we are particularly interested in the phytoplankton community as a food resource for herbivorous zooplankton.

In addition to discussing the above characteristics we examine population structure in phytoplankton communities, interpret patterns of variation in the distributions of species assemblages, and order individual samples and individual species according to these patterns of variation. The principal method of ordination we employ is correspondence analysis. However, a number of other techniques have been employed for this purpose, and we compare some of these - i.e., clustering by percent-similarity (Whittaker and Fairbanks, 1958) and normalized-expected-species-shared (Grassle and Smith, 1976) similarity measures, and discriminant function analysis (Morrison, 1969) - with correspondence analysis using a subset of our data. In this context and in our methods section, some of the advantages and disadvantages of various methods or ordination are discussed. Ordination by correspondence analysis has enabled us to distinguish sample variability associated with specific hydrographic regimes, seasonal change, and depth of sampling.

Physical and chemical observations accompany the phytoplankton species counts. We examine correlation coefficients to see to what

degree species assemblages isolated by correspondence analysis may be related to the concurrent distributions of water temperature, salinity, zooplankton biomass and nutrient concentration.

Our primary objective is to describe and contrast the phytoplankton of these different hydrographic regimes, and to relate these differences to the feeding environments of herbivorous zooplankton.

METHODS

Collection and Counting

The data were obtained from 27 hydrostations taken on four cruises in the western North Atlantic Ocean. The cruises were as follows: KNORR 35 - November 1973 (Fall-One); KNORR 38 - March 1974 (Spring); CHAIN 125 - August 1975 (Summer); and KNORR 53 - November 1975 (Fall-Two). Figure 3 illustrates the positions of the individual hydrostations.

On each hydrocast five-liter Niskin bottles equipped with reversing thermometers nominally sampled at 0 m, 25 m, 50 m, 75 m, 100 m, 125 m, 150 m, 175 m, and 200 m. In addition to phytoplankton species, temperature, salinity, nutrients and oxygen were recorded at all depths. Nutrients (NO_3, NO_2, $Si(OH)_4$, and PO_4) were measured as described in Wiebe *et al.* (1976a). NH_3 was measured but we no longer believe that analysis of NH_3 in frozen samples is a valid procedure. A series of zooplankton samples was obtained near each hydrostation as described in Wiebe *et al.* (1976a) and Chapter One. On each cruise we conducted an expendable bathythermograph (XBT) survey to define the hydrographic characteristics of the areas sampled.

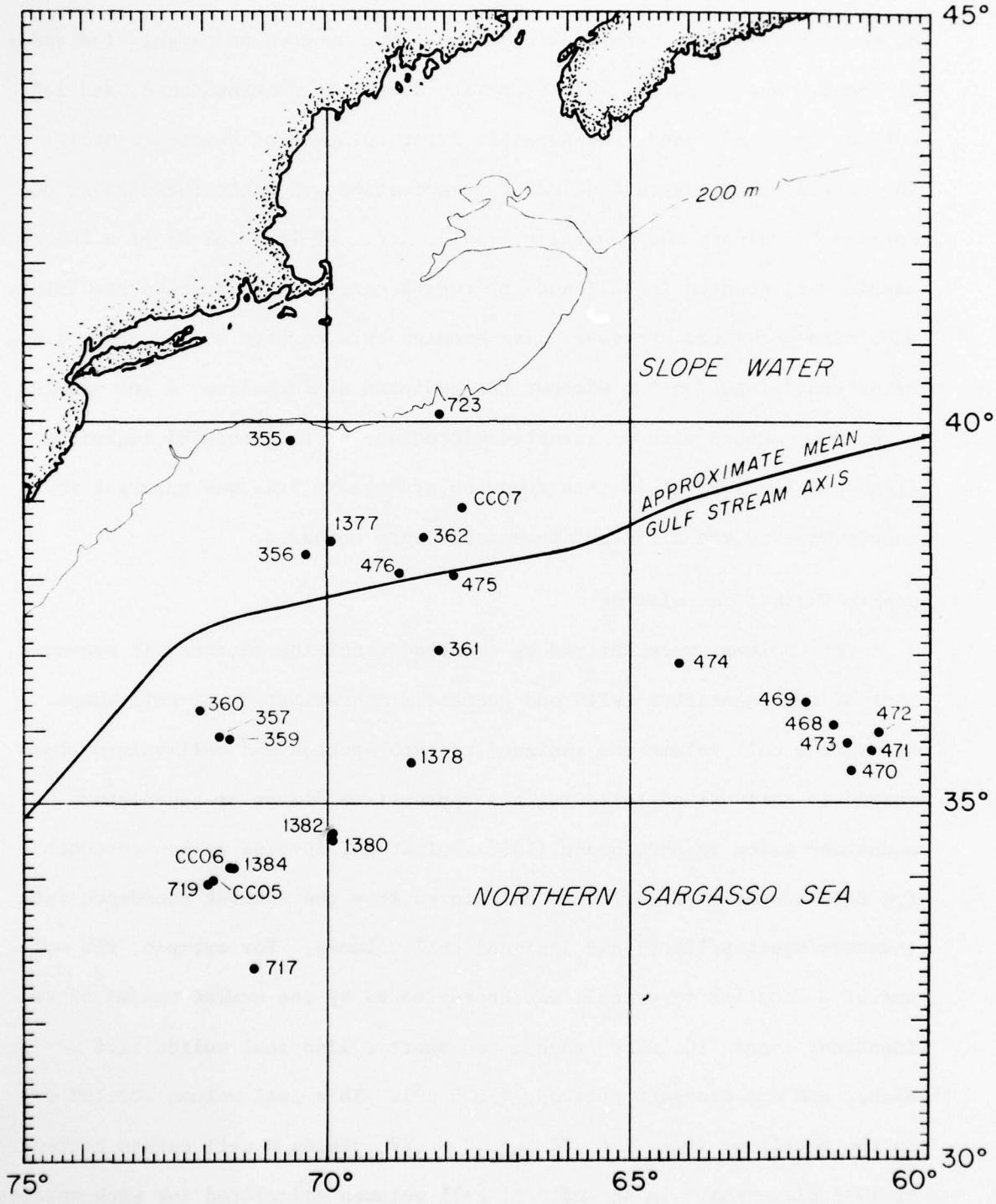


Figure 3. Positions of stations. Hydrostations taken on each cruise are as follows: KNORR 35: 355, 356, 357, 359, 360, 361, 362. KNORR 38: 468, 469, 470, 471, 472, 473, 474, 475, 476. CHAIN 125: 1377, 1378, 1380, 1382, 1384. KNORR 53: CC05, CC06, CC07, 717, 719, 723.

Phytoplankton species were identified and enumerated in 200 ml aliquots withdrawn from each Niskin bottle. One hundred and eighty individual samples were counted, 151 taxonomic categories distinguished, and 135 species names assigned (see Appendix A for full set of sample counts). In general, counts were made after preservation and centrifugation as described by Hulburt and Mackenzie (1971), i.e., at least 33 ml of a 200 ml sample were counted in full and the counts corrected to numbers per liter. When time permitted, however, live samples were counted aboard ship, i.e., after centrifugation but without the addition of formalin. A few samples were also counted with an inverted microscope by the Ütermohl technique (Lund *et al.*, 1958). In this study no systematic bias was apparent when counts made by the different techniques were compared.

Carbon Content Calculation

Cell volumes were derived by a method combining microscopic measurement of representative cells and geometric approximation of cell shape. An average cell volume was assigned to each species and cell volume converted to cell carbon following the appropriate diatom or non-diatom equations given in Strathmann (1967). That is, species carbon contents (pg Carbon/species/liter) were calculated from the species abundance data (numbers/species/liter) and assigned cell volumes. For example, the volume of a *Ceratium teres* cell was approximated by the summed volume of two identical cones (10,421 μ^3 each), two short cylindrical solids (126 μ^3 each), and one elongate cylinder (1005 μ^3). This cell volume (22,199 μ^3) in the equation: $\log_{10} C = .76 \log_{10} V - .29$, yields a cell carbon content of 1031 picograms. In Appendix B, cell volumes calculated for each species are compared to values reported elsewhere. Appendix B is an edited and supplemented reformulation of Table 1 in Travers (1974).

Community Analysis

Our approach to the problem of investigating phytoplankton community structure is a highly conservative one. We follow Fager (1963) in defining a community operationally, as "a group of species which are often found living together". We assume that, in general, the abundance of a species in a habitat reflects the suitability of that habitat for that particular species. We initially consider each individual sample, even those from different depths at the same geographic location, to be independent. We then employ correspondence analysis (CA) to see if our species abundance data set, *in and of itself*, reflects the existence of floral discontinuities, either vertical or horizontal, or of gradients in species composition.

CA is one of a growing class of multivariate analyses which permit an investigator to discern patterns in ecological data. A number of authors have discussed the close mathematical relationship among CA, principal-components (factor) analysis, Hotelling's canonical correlation, and Guttman scaling (Noy-Meir and Austin, 1970; Hill, 1973, 1974; Chardy, Glemarec and Laurec, 1976; Hatheway, 1971; McElroy and Smith, 1975; and Benzecri, 1969, 1973). As Chardy, Glemarec and Laurec (1976) discuss, the major differences in the clustering schema generated by these various methods result largely from fundamental differences in their choice of a) a measure of ecological distance between variables, b) the weights allotted to individual occurrences, and c) the positions of origin of the axes derived.

One interpretation of CA views it as a partitioning of the chi-square statistic describing a contingency table (McElroy and Smith, 1975). In our case, the contingency table is a sample by species

frequency matrix whose values are the individual species counts. Operationally, CA transforms the initial data matrix replacing each species count by its sample probability - i.e., dividing each by the sum of all the values in the table. Benzecri (1973) demonstrates that ecological distance in CA is chi-square distance. Under the hypothesis of independent rows and columns the probability of an individual of a particular species occurring at a particular station is the product of the sums of the appropriate row and column probabilities. Thus there is a symmetrical relationship between row and column classification. Chi-square describes the overall departure from expectation under the above hypothesis. The CA problem is then, to assign sets of scores to both samples and species the value of which reflects the similarity of their contributions to this chi-square. Scaling restrictions on the scores assigned ensure that the position of origin of all axes - i.e., sets of scores - subsequently derived remains the overall center of gravity of the transformed matrix. This strategy gives preference to neither samples nor species and avoids re-centering difficulties.

Hill (1973) presents for hand calculation a simple iterative procedure, reciprocal-averaging, which partitions the chi-square statistic and makes obvious the intrinsic symmetry of CA. A general solution requires calculating the eigenvectors of large matrices. To calculate eigenvectors we have employed computer routines modified by W. Smith, W.H.O.I., from programs written by J. P. Bordet of the Ecole Nationale Superieure des Mines de Paris, Centre d'Informatique Geologique.

We have chosen CA as our method of ordination for several reasons. First, CA may circumvent analytical difficulties introduced by the

possibility that the abundance of a species may be non-linearly related to the physical and chemical factors that constitute an environmental gradient (Van Groenwald, 1976). Second, CA is not insensitive to the contribution of rare species and correctly orders them without standardizing the data input (Hill, 1973). Third, CA is relatively robust and tolerant of variable species richness in different samples (Chardy, Glemarec and Laurec, 1976). Last, as McElroy and Smith (1975) and Hill (1973) stress, CA is fully symmetrical, simultaneously ordering both samples and species along the same axes.

RESULTS

Prior to analyzing the distribution of phytoplankton species and their community structure, we will analyze the specific hydrographic characteristics of the samples and the average environmental properties of the areas from which the samples were obtained.

Physical Sample Ordination

First, we position those samples that will eventually be used in our community structure analysis in volumes whose axes are physical and chemical properties of the samples. Figure 4a-d represents the positions of samples from Fall-One, Spring, Summer, and Fall-Two cruises, respectively, in volumes whose axes are temperature, salinity, and depth. The plane depicted represents a T-S plot. Distance above it is depicted as a solid line and below it as a dashed line. This distance represents sample depth: 0-62.5 m (below) and 62.5-125 m (above). We adopt this atypical graphical method because it parallels the ordination method to

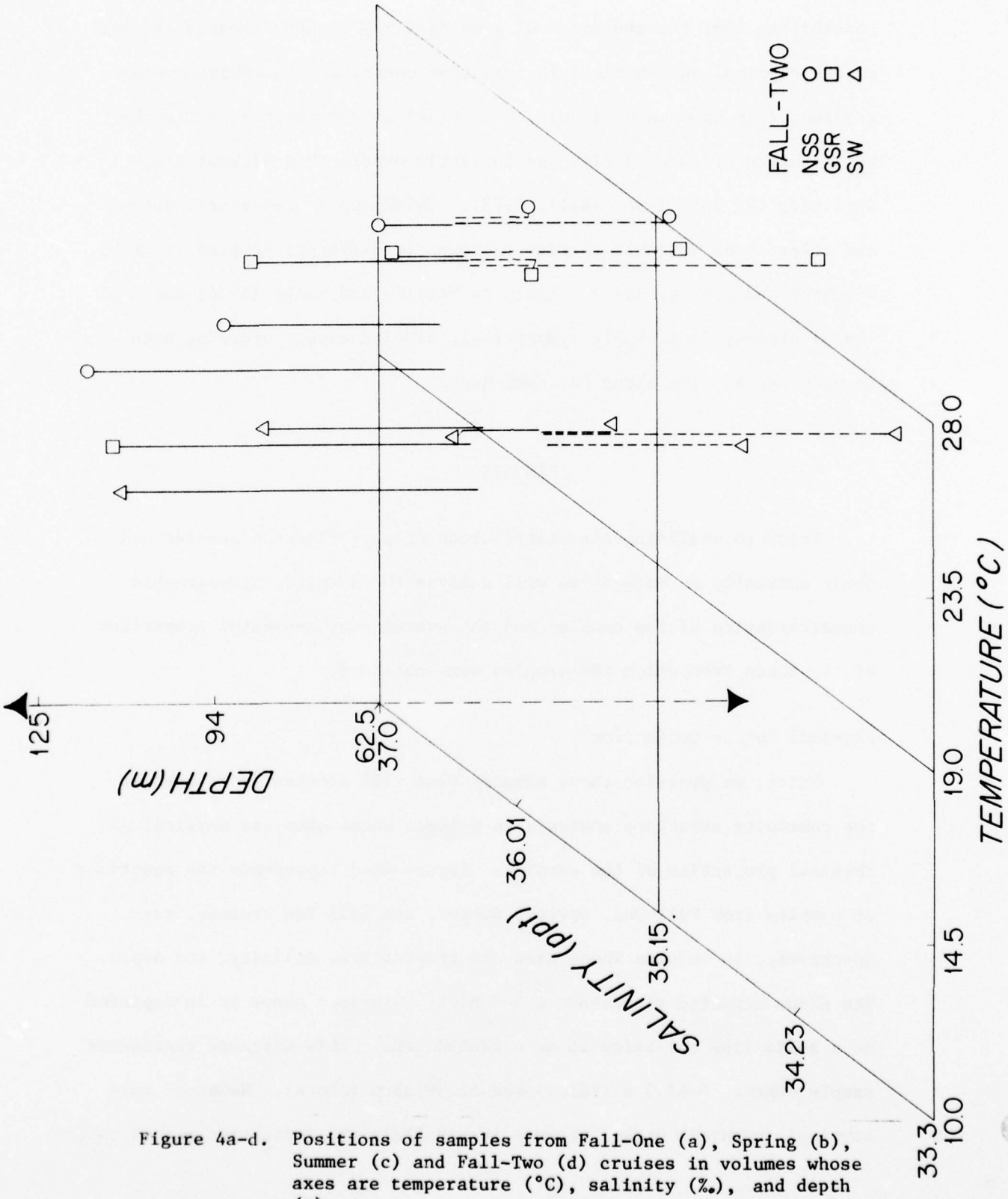


Figure 4a-d. Positions of samples from Fall-One (a), Spring (b), Summer (c) and Fall-Two (d) cruises in volumes whose axes are temperature (°C), salinity (‰), and depth (m).

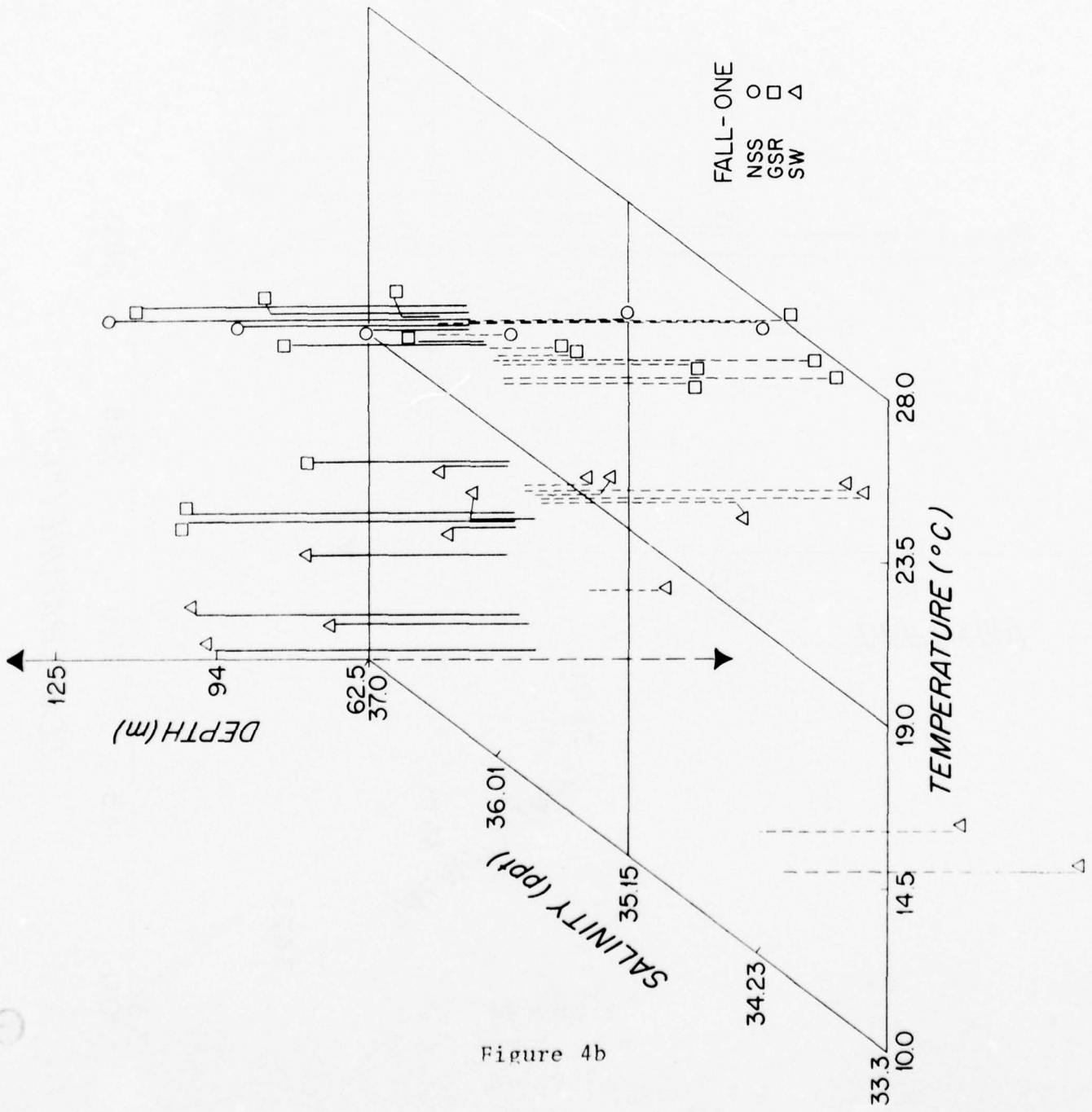

FALL-ONE
NSS ○
GSR □
SW △
DEPTH (m)
125
94
62.5
37.0
SALINITY (ppt)
36.01
35.15
34.23
33.3
TEMPERATURE (°C)
28.0
23.5
19.0
14.5
10.0

Figure 4b

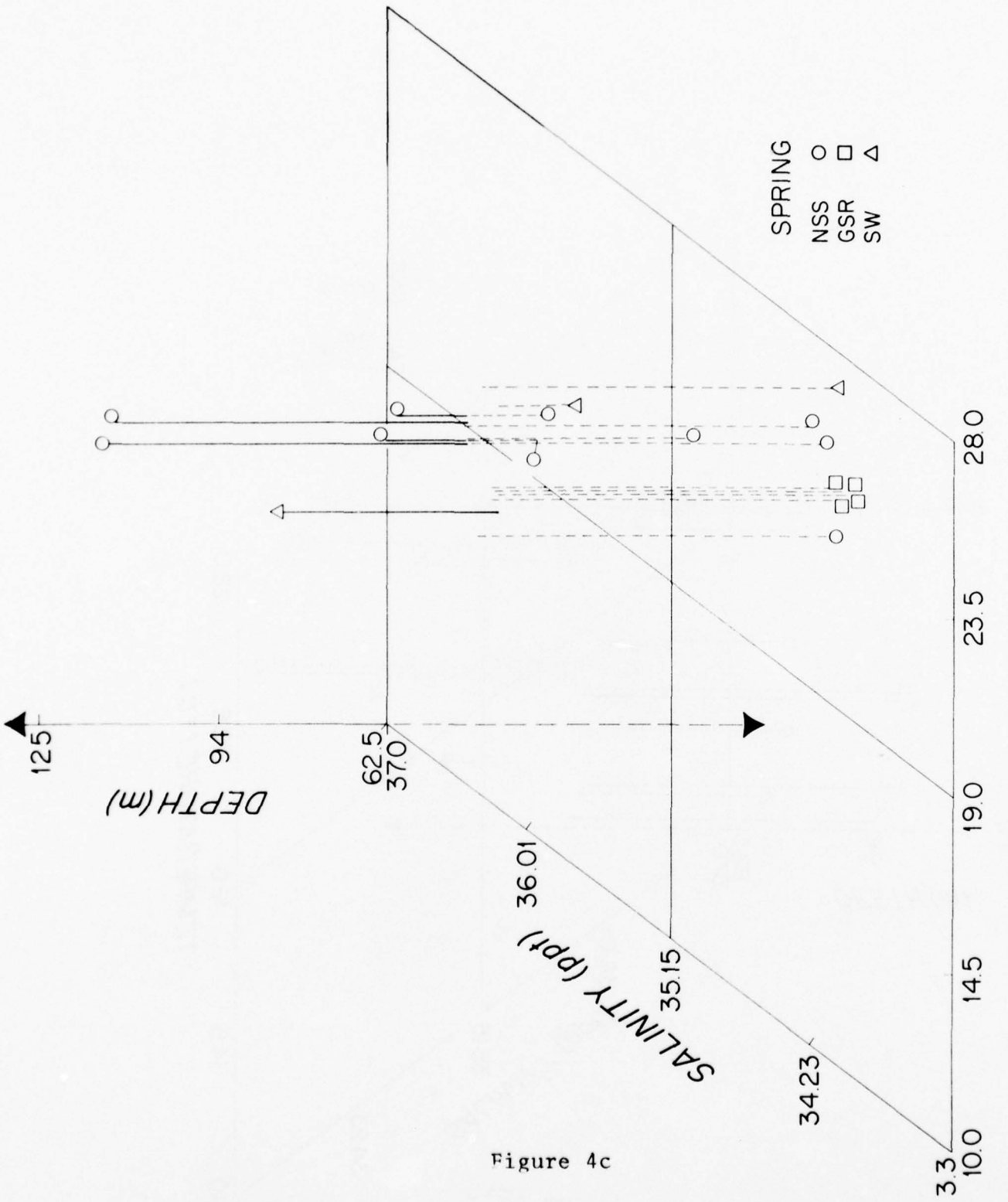

SPRING
NSS
GSR
SW
DEPTH (m)
125
94
62.5
37.0
SALINITY (ppt)
36.01
35.15
34.23
TEMPERATURE (°C)
28.0
23.5
19.0
14.5
10.0
3.3

Figure 4c

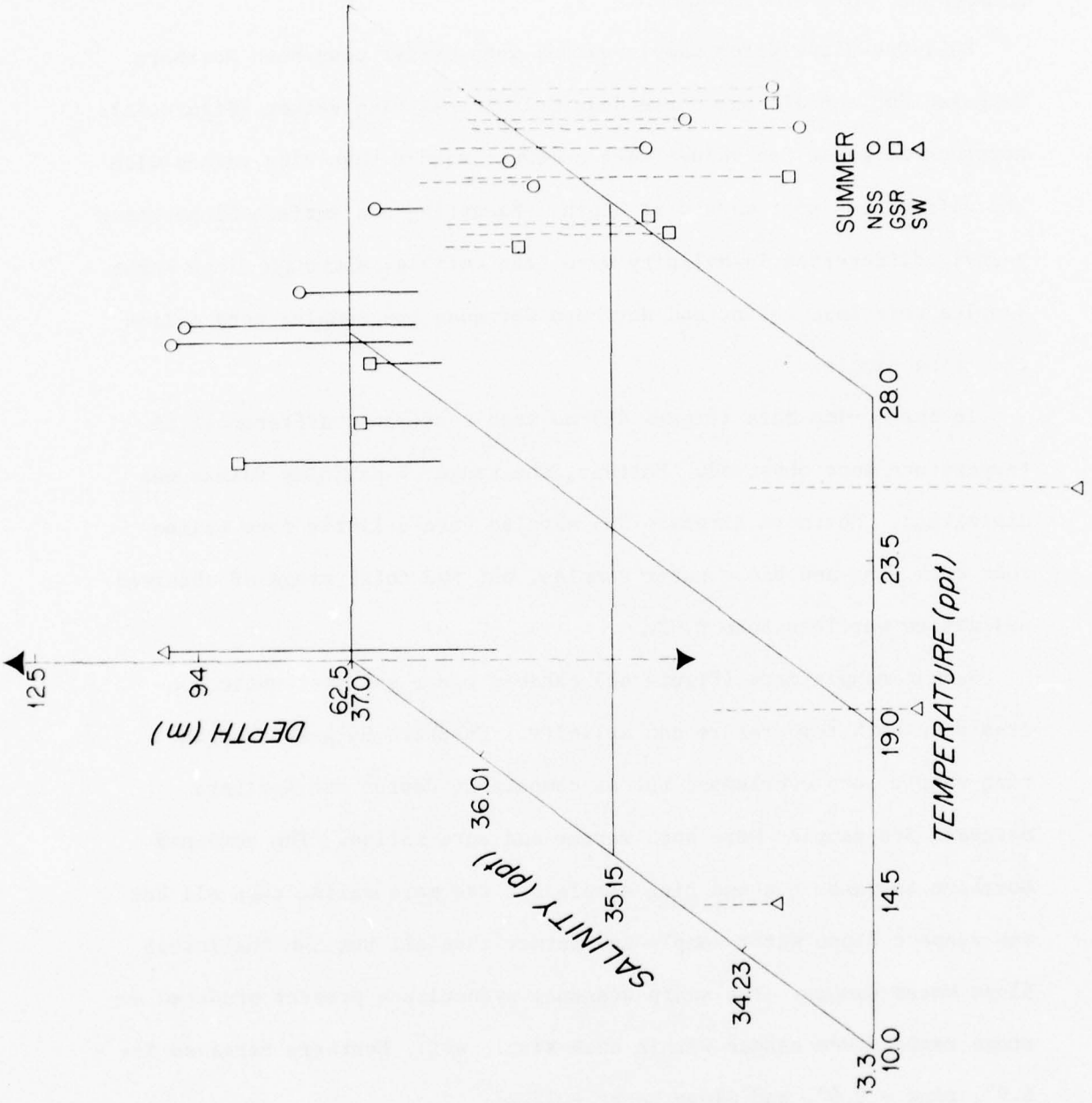

SUMMER
NSS ○
GSR □
SW △
TEMPERATURE (ppt)
28.0
23.5
19.0
14.5
10.0
3.3
SALINITY (ppt)
36.01
35.15
34.23
DEPTH (m)
125
94
62.5
37.0

Figure 4d

be used in the community analysis (see Figures 9-16). All three dimensional plots are isometric.

Fall-One Slope Water sample values were colder than both Northern Sargasso Sea and all but three deep Gulf Stream ring values (Figure 4a). Northern Sargasso Sea values were somewhat warmer than ring values with the differences most marked at depth. Excepting two surface Slope Water values, differences in salinity were less notable, although Slope Water samples were less saline and Northern Sargasso Sea samples more saline than ring samples.

In the Spring data (Figure 4b) no such systematic differences in temperature were observed. Further, the range of salinity values was diminished. Northern Sargasso Sea samples were a little more saline than both ring and Slope Water samples, but the total range of observed salinities was less than 0.3‰.

Summer sample data (Figure 4c) exhibit clear and systematic contrasts in both temperature and salinity. Northern Sargasso Sea and ring sample sets overlapped but at comparable depths the Northern Sargasso Sea samples were both warmer and more saline. The combined Northern Sargasso Sea and ring sample set was more saline than all but the deepest Slope Water sample and warmer than all but the shallowest Slope Water sample. The sharp seasonal pycnoclines present produced extreme temperature ranges within each sample set: Northern Sargasso Sea - 6.9°, ring - 9.6°, and Slope Water - 12.2°.

Samples obtained during Fall-Two (Figure 4d) show evidence of an initiation of winter-mixing processes. Contrasts in salinity were minimal - less than 1‰ over sample sets. Slope Water sample values were considerably cooler than all but the deepest Northern Sargasso Sea and

ring values. Apparently ring and Slope Water mixing was the more thorough. Samples within the upper 100 m in the ring and the upper 75 m in the Slope Water were near isothermal and isohaline. Mixing seemed to have been less complete in the Northern Sargasso Sea in that both 100 and 125 m samples were much cooler than 0-75 m Northern Sargasso Sea samples.

Average Environmental Properties

Table 8 presents average 0-125 m nutrient and chlorophyll concentrations in Slope Water, ring, and Northern Sargasso Sea sample sets and average regional 0-800 m macro-zooplankton biomass values for the same cruises. With the possible exception of the Spring data set, average 0-125 m nutrient and chlorophyll *a* concentrations are considerably higher in Slope Water samples than in either Northern Sargasso Sea or ring samples. Differences between Northern Sargasso Sea and ring sample sets are far less notable. That is, to a first approximation there is a gradient in chlorophyll *a* and nutrient concentrations such that Slope Water >> ring $\geq$ Northern Sargasso Sea. There is a similar direction of difference in regional zooplankton biomass. It must be remembered that averaging 0-125 m values markedly influences Slope Water : ring and Slope Water : Northern Sargasso Sea comparison. Due to systematic differences in the depths of the seasonal and permanent thermoclines (Worthington, 1976), with this averaging scheme contrasts in chlorophyll *a* concentration will be diminished, while contrasts in nutrient concentrations will be enhanced. Note that on all four cruises the ranges of Northern Sargasso Sea, ring, and Slope Water chlorophyll and nutrient values overlap. Comparing samples obtained at the same depth, however,

Table 8

Average environmental properties[a] (mean and range)

	Chlorophyll µg/L		Temperature at 300 m		Nitrate (µg-atom-N/L)		Nitrite (µg-atom-N/L)		Phosphate (µg-atom-P/L)		Silicate (µg-atom-Si/L)		Zooplankton Biomass (mg/m^2)	
	$\bar{x}$	W	$\bar{x}$	W	$\bar{x}$	W	$\bar{x}$	W	$\bar{x}$	W	$\bar{x}$	W	$\bar{x}$	W
Fall-One														
SW	.75	.07-2.43	8.37	7.8-	4.63	.35-22.4	.16	.05-.33	.42	.09-.92	b	b	6.06	3.60-7.74
GSR	.45	.04- .98	12.8	10.8-16.4	1.03	.03- 5.99	.06	.02-.11	.13	.04-.32	b	b	3.67	3.15-4.33
NSS	.30	.24- .44	18.0	b	0.18	.12- 0.35	.06	.04-.07	.05	.04-.18	b	b	2.47	b
Spring														
SW	.50	.09-1.05	b	b	2.42[c]	.6-06.5[c]	b	b	.28	.08-.54	b	b	5.74	2.02-9.14
GSR	.48	.13-1.08	b	b	1.09[c]	.18-01.82[c]	b	b	.22	.04-.64	b	b	3.10	2.56-4.98
NSS	.40	.26- .92	b	b	0.74	.2-01.56	b	b	.07	.03-.15	b	b	2.34	1.76-3.21
Summer														
SW	.22	.01- .89	9.4	b	8.19	.5-12.5	.17	.09-.34	.42	.00-.70	3.88	1.65-5.41	9.10	6.85-11.35
GSR	.10	.03- .23	12.6	12.4-12.8	1.05	.00-04.65	.16	.11-.31	.02	.00-.14	2.19	.90-5.97	2.26	1.73- 2.57
NSS	.10	.04- .21	18.5	18.2-18.7	0.15	.00- 0.79	.19	.12-.39	.00	b	1.24	.75-1.75	1.49	.90- 1.97
Fall-Two														
SW	.37	.01- .62	11.7	b	4.46	.65-13.32	.47	.13-1.49	.23	00 -.71	3.56	.75-6.41	3.43	2.77-4.03
GSR	.07	.05- .1	b	b	0.28	0.0 -02.02	.24	.08- .37	.02	00 -.35	1.75	.85-5.00	1.09	.72-1.35
NSS	.07	.02- .18	18.4	b	0.18	.02- .53	.15	.1- .29	.00	b	2.45	1.35-4.94	.83	.70-0.86

a
Arithmetic mean of values (0-125 m) on hydrocast from which samples were drawn for phytoplankton species enumeration.

b
Values missing or range not computed since values identical

c
Actually Nitrate + Nitrite.

the average gradient described above would exist. The data in Table 8 are discussed more fully both in Wiebe *et al.* (1976a) and Chapters one, three, and four. In those contexts, considerable ancillary and replicate data are provided.

Average Population Properties in the Mixed Layer

Prior to examining the vertical distributions of particular taxonomic groups, or the species composition of specific samples, we will summarize average phytoplankton population properties characteristic of Northern Sargasso Sea, Slope Water, and ring samples. Averaged over 0-200 m, estimates of total cells/l were not systematically different in Northern Sargasso Sea, Slope Water, and ring sample sets (Table 9). For instance, on two cruises to the same ring (Summer, Fall-Two), Slope Water average column cells/l exceeded ring and Northern Sargasso Sea average cells/l, while on the two earlier cruises (Fall-One, Spring) Northern Sargasso Sea average cells/l had exceeded Slope Water cells/l. In all regions on every cruise sample counts declined abruptly beneath the depth of the summer mixed-layer (Table 9). Again, the depth of this mixed-layer is systematically less in the Slope Water (about 50 m) than in either the Northern Sargasso Sea or in the ring (about 75 m). Thus averaging 0-200 m values obscures actual regional population differences. Therefore, in this section we will compare samples above 75 m in the Slope Water with those above 125 m in the Northern Sargasso Sea and ring. Averaged in this way, cells/l in the Slope Water, Northern Sargasso Sea and ring were 20,600, 11,600, and 6400 respectively. Despite having sampled a dramatic Northern Sargasso Sea bloom (Spring) and not having sampled at least one Slope Water value likely to have been rather high (Spring:

Table 9

Average population properties

SLOPE WATER

Depth (m)	FALL-ONE Cells	sp.	ngC	$H_{\#}$	$E_{\#}$	H_c	E_c	N	SPRING Cells	sp.	ngC	$H_{\#}$	$E_{\#}$	H_c	E_c	N
0	16,683	24	8868	2.03	.64	2.05	.65	3	17,580	20	602	1.25	.42	1.99	.66	2
25	14,540	18	15945	1.96	.68	1.46	.51	3	-	-	-	-	-	-	-	-
50	10,013	19	3767	2.16	.73	1.95	.66	3	16,680	14	1132	.77	.29	.86	.33	1
75	2203	15	468	2.03	.75	1.56	.58	3	-	-	-	-	-	-	-	-
100	960	8	197	1.54	.74	1.43	.69	2	360	6	13	1.47	.82	1.44	.80	1
125	337	7	123	1.54	.79	1.19	.61	3	270	3	124	.68	.62	1.01	.92	1
150	130	1	151	b	b	b	b	3	180	5	19	.67	.42	.49	.30	1
175	70	2	43	b	b	b	b	3	-	-	-	-	-	-	-	-
200	100	2	82	b	b	b	b	3	-	-	-	-	-	-	-	-
$\bar{X}^c$	4072	9.2	2797	1.88[e]	.62[e]	1.61[e]	.62[e]		7405[d]	8.9[d]	415[d]	.97[e]	.51[e]	.97[e]	.60[e]	

Depth (m)	SUMMER Cells	sp.	ngC	$H_{\#}$	$E_{\#}$	H_c	E_c	N	FALL-TWO Cells	sp.	ngC	$H_{\#}$	$E_{\#}$	H_c	E_c	N
0	8670	13	584	.45	.18	.71	.28	1	23,730	28	4124	2.29	.69	2.49	.75	2
25	16,680	11	3931	1.18	.49	.54	.23	1	17,840	25	2170	1.60	.50	2.32	.72	2
50	62,650	15	7849	1.94	.72	1.68	.62	1	22,083	24	2282	1.48	.47	2.25	.71	2
75	1320	12	106	2.03	.82	1.78	.72	1	6617	19	989	1.85	.63	1.79	.61	2
100	150	2	7	b	b	b	b	1	510	8	41	1.79	.86	1.53	.74	2
125	510	3	37	.87	.79	.39	.35	1	112	3	9	.96	.87	.61	.56	2
150	60	2	2	b	b	b	b	1	165	3	154	.99	.90	.26	.23	2
175	60	1	4	b	b	b	b	1	240	4	14	1.37	.98	1.12	.81	2
200	90	3	91	1.10	1.00	.60	.55	1	210	4	61	1.79	1.29	1.07	.77	2
$\bar{X}^c$	9534	6.0	1464	1.26[e]	.67[e]	.85[e]	.46[e]		6615	11.3	861	1.57[e]	.80[e]	1.49[e]	.66[e]	

a) All values represent arithmetic means of N samples. Cells (total cells), sp. (total species), and ngC (ngCarbon) are normalized to per liter estimates. H = Shannon-Weaver sample diversity computed upon either species abundance or carbon content. E = sample evenness (Pielou, 1966)- i.e., H/H_{max} where $H_{max} = \log_e S$. N=number of samples enumerated.

b) sp. ≤ 2, H not computed.

c) Column estimate is calculated by first estimating values per 25 m depth interval (i.e., averaging interval end points), and then averaging the derived depth interval estimates.

d) Column estimated for only 150 m column - missing values interpolated.

e) Values are arithmetic means of column values.

Table 9 (Continued)

GULF STREAM COLD CORE RING

Depth (m)	Cells	sp.	ngC	H#	E#	H_c	E_c	N	Cells	sp.	ngC	H#	E#	H_c	E_c	N
	FALL ONE								SPRING							
0	9593	12	227	.43	.17	1.14	.46	3	10,208	17	717	1.54	1.54	2.19	.77	4
25	9790	13	274	.46	.18	1.38	.54	3	-	-	-	-	-	-	-	-
50	13,790	11	391	.35	.15	1.04	.43	3	-	-	-	-	-	-	-	-
75	11,650	12	380	.35	.14	1.23	.49	3	-	-	-	-	-	-	-	-
100	6720	7	273	.57	.29	1.01	.52	3	-	-	-	-	-	-	-	-
125	3573	4	103	.38	.27	.69	.50	3	-	-	-	-	-	-	-	-
150	2060	4	65	.73	.53	.83	.60	3	-	-	-	-	-	-	-	-
175	470	2	17	b	b	b	b	3	-	-	-	-	-	-	-	-
200	1570	2	54	b	b	b	b	3	465	5	44	1.19	.74	1.28	.80	2
$\bar{X}$ [c]	5959	6.6	183	.47[e]	.25[e]	1.05[e]	.51[e]					1.37[e]	.64[e]	1.74[e]	.79[e]	
	SUMMER								FALL-TWO							
0	2955	17	272	1.92	.68	2.23	.79	2	3845	16	236	1.42	.51	2.17	.78	3
25	4440	17	381	1.69	.60	2.03	.72	2	3220	18	219	1.82	.63	2.23	.77	3
50	7975	14	525	1.16	.44	1.40	.53	2	3260	17	240	1.77	.62	2.13	.75	3
75	4082	13	282	1.78	.69	1.75	.68	2	3980	15	210	1.23	.45	2.09	.77	3
100	2100	14	283	2.00	.76	2.19	.83	1	4580	17	256	1.61	.57	2.35	.83	3
125	1420	13	82	2.07	.81	2.01	.78	1	790	8	65	1.69	.81	1.39	.67	3
150	960	4	69	1.26	.91	1.35	.97	1	230	4	20	1.19	.86	1.05	.76	3
175	210	3	12	.80	.73	.78	.71	1	152	3	20	.92	.84	.75	.68	2
200	-	-	-	-	-	-	-	1	150	4	11	1.19	.86	1.18	.85	2
$\bar{X}$[c]	2518	9.6	197	1.41[e]	.70[e]	1.72[e]	.75[e]		2023	10.2	128	1.43[e]	.68[e]	1.70[e]	.76[e]	

Table 9 (Continued)

NORTHERN SARGASSO SEA

Depth (m)	FALL-ONE Cells	sp.	NgC	$H_{\#}$	$E_{\#}$	H_c	E_c	N	SPRING Cells	sp.	NgC	$H_{\#}$	$E_{\#}$	H_c	E_c	N
0	11,250	17	733	.72	.25	1.88	.66	1	15,370	15	586	.93	.34	1.80	.66	3
25	12,270	20	885	.86	.29	2.05	.68	1	40,150	15	893	.48	.18	1.12	.41	1
50	10,070	23	3386	1.51	.48	1.39	.44	1	33,325	10	972	.44	.19	1.08	.47	2
75	9330	16	347	.72	.26	1.81	.65	1	3778	10	160	1.34	.58	1.63	.71	2
100	6000	17	366	.81	.29	1.94	.68	1	51,420	15	1070	.36	.13	.81	.30	1
125	6120	15	292	.71	.26	1.90	.70	1	9460	8	202	.42	.20	.79	.38	2
150	120	2	2	b	b	b	b	1	810	2	73	b	b	b	b	1
175	120	2	3	b	b	b	b	1	480	5	17	1.36	.85	1.50	.93	1
200	60	1	1	b	b	b	b	1	165	2	24	b	b	b	b	2
$\bar{X}^c$	5521	11.6	628	.89[e]	.31[e]	1.83[e]	.64[e]		16,353	8.2	410	.76[e]	.35[e]	1.25[e]	.55[e]	
				SUMMER								FALL-TWO				
0	5025	21	452	2.40	.79	2.45	.80	2	5850	24	260	1.97	.62	2.62	.82	1
25	3300	16	259	2.09	.75	2.20	.79	2	4800	20	235	1.59	.53	2.35	.78	1
50	3890	20	295	2.15	.72	2.32	.77	2	4860	16	195	1.38	.50	2.16	.78	1
75	3405	18	211	1.95	.67	2.20	.76	2	5130	16	196	1.27	.46	2.04	.74	1
100	1470	13	88	2.07	.81	2.02	.79	3	1080	7	38	1.26	.65	1.47	.76	1
125	990	9	118	1.74	.79	1.44	.66	2	150	3	11	1.27	1.16	1.30	1.18	1
150	165	4	16	1.29	.93	1.07	.77	2	30	1	2	b	b	b	b	1
175	120	2	21	b	b	b	b	2	60	2	2	b	b	b	b	1
200	120	3	7	1.04	.95	.80	.73	1	60	2	3	b	b	b	b	1
$\bar{X}^c$	1768	10.4	138	1.84[e]	.80[e]	1.81[e]	.76[e]		2119	8.7	90	1.46[e]	.65[e]	1.99[e]	.84[e]	

25 m), average cells/l in the upper water column of the Slope Water markedly exceeded cells/l in either the Northern Sargasso Sea or ring. The Northern Sargasso Sea/ring discrepancy is probably a sampling artifact due to the paucity of Spring ring samples. Two profiles deserve mention. One, noted above, is a remarkable Northern Sargasso Sea bloom consisting almost entirely of a coccolithophore, *C. huxleyi* (Northern Sargasso Sea: Spring). The second is a massive cell concentration atop an extremely sharp seasonal pycnocline (Slope Water: Summer). This latter concentration was composed of two pennate diatoms, an undetermined athecate dinoflagellate, another undetermined coccoid cell, and *C. huxleyi*.

Inter-regional comparisons of estimated total C/l are a little more consistent than were like comparisons of estimated total cells/l (Table 9). On every cruise Slope Water 0-200 m estimates of C/l exceed those for the Northern Sargasso Sea or ring. Considering only upper water column samples, Slope Water average C/l was approximately an order of magnitude greater than either Northern Sargasso Sea or ring average C/l. Average total C/l values obtained were 4760, 580, and 320 respectively. Here, too, the Northern Sargasso Sea/ring discrepancy probably resulted both from the paucity of ring : Spring samples and from the fact that we sampled on one occasion a remarkable Northern Sargasso Sea bloom (NSS: Spring). On our two cruises to the same ring (Summer, Fall-Two) ring C/l values above 125 m were approximately 30% greater than Northern Sargasso Sea C/l values averaged over the same interval.

The diversity and evenness values reported in this and the following paragraph apply, strictly, only to the volumes of water actually sampled. That is, they are dependent on the relationship between our sample size and the true population parameters. Further, since the species counts

are not exhaustive (see Discussion) all the computed diversities and their relative values apply only to that portion of the community actually enumerated. Column estimates of average Shannon-Weaver (1963) numeric sample diversity (H#) were highly variable (Table 9). Slope Water, Northern Sargasso Sea and ring average H# were each largest on at least one cruise. In this case averaging only upper water column values does little to clarify the situation. When the physical stabilities of Slope Water, ring and Northern Sargasso Sea environments were maximal (Summer), their average upper water column H# were 1.09, 1.71, and 2.13 respectively. This gradient resulted both from the average sp/l observed - 13, 15, and 18 respectively, and from the evenness of the distributions of species abundances (E#: Pielou, 1966) - .46, .63, and .75 respectively.

Shannon-Weaver diversity may also be computed after weighting each species abundance according to that species average carbon content. The diversity measure so derived (H_c), like H#, may be partitioned into an evenness component (E_c) and a species-richness component. The latter would, of course, be the same for H_c as it was for H#. The former, E_c, would differ from E# since it is effected by the weighting. E_c has ecological import in that it relates to the distribution of phytoplankton carbon in the volume sampled. Consider once again the upper water column which is relatively both species-rich and high in phytoplankton carbon in Slope Water, ring, and Northern Sargasso Sea sample sets. Average C/l values in the Slope Water, ring, and Northern Sargasso Sea were more evenly partitioned amongst the phytoplankton species in the Northern Sargasso Sea and ring, than in the Slope Water. In fact, the differences were slight on the Spring and Fall-One cruises but large on the Summer and Fall-Two cruises.

If we separately consider the major taxa comprising the populations discussed in this section, we find that their distributions and relative importance vary at different depths, in different regions, on different cruises.

Diatom Distribution

Diatom species per liter (sp/l), cells/l, and C/l observed during a cruise were often very different in adjacent water masses (Table 10). The pooled abundance in each hydrocast of some common diatoms is presented in Appendix C.

The vertical distributions and overall levels of diatoms sp/l, C/l, and cells/l reflected the hydrographic situation at the time of sampling. In the Slope Water when growth conditions were favorable and vertical mixing had apparently provided a sufficiency of nutrients - Fall-One and Fall-Two - generally high values were maximal either at the surface or at a depth of 25 m (Table 10). When the water column was strongly stratified - Summer - lower values were maximal just above the seasonal pycnocline (50 m). In the Northern Sargasso Sea a parallel pattern was observed but at somewhat deeper depths. When growth conditions were relatively good - Fall-One - moderately high values were maximal at a depth of 50 m in the middle of a well-mixed upper water column. With strong stratification - Summer and Fall-Two - values were lower and the data suggest maxima in the upper seasonal pycnocline (100 m, 125 m). Regardless of upper water column mixing processes, ring values were generally low although diatom abundance did appear to increase in response to an erosion of the seasonal thermocline - Fall-Two.

Table 10

Diatom distribution[a]

	FALL-ONE			SPRING			SUMMER			FALL-TWO		
Depth (m)	Cells/l	Sp/l	ng C/l	Cells/l	Sp/l	ng C/l	Cells/l	Sp/l	ng C/l	Cells/l	Sp/l	ng C/l
					SLOPE WATER							
0	9493	14	8335	1650	9	72.1	210	2	2	8850	18	3606
25	11647	11	15768	-	-	-	30	1	<1	3780	13	1633
50	6983	14	3600	2520	4	822	35400	5	2719	4470	13	1463
75	1307	10	404	-	-	-	390	4	31	2202	13	554
100	380	3	106	180	3	17	30	1	<1	75	3	18.5
125	187	3	78	0	0	0	510	3	37	35	1	<1
150	120	1	148	30	1	13	30	1	<1	15	1	<1
175	30	1	39	-	-	-	0	0	0	100	2	<1
200	50	1	70	-	-	-	0	0	0	45	1	<1
					GULF STREAM COLD-CORE RING							
0	90	1	4	1643	6	294	30	1	<1	100	1	7
25	60	1	1	-	-	-	100	1	<1	110	2	2
50	30	1	63	-	-	-	105	1	<1	150	1	32
75	50	1	87	-	-	-	165	1	<1	40	1	<1
100	290	1	122	-	-	-	0	0	0	80	1	16
125	0	0	0	-	-	-	0	0	0	180	2	4
150	10	1	1	-	-	-	0	0	0	30	1	<1
175	0	0	0	-	-	-	0	0	0	0	0	0
200	0	0	0	30	1	11	0	0	0	0	0	0
					NORTHERN SARGASSO SEA							
0	690	11	341	280	3	95	90	2	20	300	3	7
25	600	11	330	450	2	6	75	1	2	60	1	1
50	2780	11	2979	715	4	333	90	1	1	30	1	1
75	270	4	40	305	2	33	45	2	2	90	1	1
100	300	7	83	400	2	7	210	2	20	510	2	5
125	360	4	115	150	2	2	495	4	101	120	1	1
150	30	1	1	510	2	67	60	1	7	0	0	0
175	0	0	0	90	1	1	90	2	16	30	1	1
200	0	0	0	0	0	0	0	0	0	0	0	0

[a]The distribution of samples on which this composite picture is based can be obtained from Table 9.

We can assess the relative contribution of diatoms to total regional phytoplankton populations by comparing Tables 9 and 10. Excepting Summer, diatoms consistently comprised a very large fraction of Slope Water phytoplankton sp/l, C/l, and cells/l. On the Fall-One cruise diatoms were as well a conspicuously important fraction of Northern Sargasso Sea phytoplankton. This was particularly true in the upper 50 m. On all other cruises diatoms represented a moderately small but rather stable fraction of Northern Sargasso Sea phytoplankton. Their relative importance was greater at depth, because total phytoplankton values declined markedly with depth while diatom values either rose slightly or remained similar. In contrast, on three cruises - Fall-One, Summer, Fall-Two, diatoms were a minor fraction of total ring sp/l, C/l and cells/l. The limited data obtained suggest little or no disparity in diatom species/l between Northern Sargasso Sea and ring samples obtained on the Spring cruise.

Coccolithophore Distribution

Like diatom sp/l, coccolithophore sp/l greatly differed in samples collected during the same cruise from contiguous water masses (Table 11). The pooled abundance in each hydrocast of some common coccolithophores is presented in Appendix C.

The vertical distributions and overall levels of coccolithophore sp/l, cells/l and C/l can be readily related to the stability of the upper water column. In the Slope Water during Fall-One, Fall-Two, and Spring cruises moderately high values were maximal near the surface and declined with depth (Table 11). During Summer, a definite subsurface

Table 11

Coccolithophore distribution[a]

Depth (m)	FALL-ONE Cells/l	Sp./l	ng C/l	SPRING Cells/l	Sp./l	ng C/l	SUMMER Cells/l	Sp./l	ng C/l	FALL-TWO Cells/l	Sp./l	ng C/l
					SLOPE WATER							
0	4540	4	180	12360	5	276	90	3	2	13087	5	314
25	2797	6	164	-	-	-	0	0	0	11940	6	254
50	2853	3	155	1830	10	289	12150	2	264	14760	6	306
75	703	3	52	-	-	-	420	4	43	3747	5	289
100	260	2	26	240	3	67	0	0	0	180	2	8
125	117	3	3	270	3	12	0	0	0	75	2	7
150	10	1	2	120	3	6	0	0	0	60	1	1
175	40	1	4	-	-	-	0	0	0	60	2	2
200	40	1	7	-	-	-	0	0	0	75	1	
					GULF STREAM COLD-CORE RING							
0	9213	6	206	6315	5	180	570	6	60	3180	10	111
25	9560	8	254	-	-	-	390	6	36	2050	8	78
50	13700	8	253	-	-	-	210	6	17	2110	8	115
75	11460	9	277	-	-	-	2355	7	176	3500	10	122
100	6240	5	143	-	-	-	660	5	27	847	8	131
125	3563	3	91	-	-	-	330	5	10	20	1	36
150	2030	3	64	-	-	-	660	2	20	10	1	2
175	470	2	17	-	-	-	30	1	1	45	2	5
200	1570	2	36	405	4	31	0	0	0	75	2	5
					NORTHERN SARGASSO SEA							
0	10500	4	360	12950	6	469	1695	9	145	3811	15	145
25	11160	6	402	38700	8	839	1590	11	145	3960	15	107
50	6810	6	184	32095	4	1040	1200	12	98	3690	9	132
75	8760	9	278	23860	8	116	1920	10	66	4260	12	148
100	5610	8	128	50250	9	1015	660	7	26	120	2	12
125	5670	10	139	9100	6	185	330	2	13	30	1	3
150	90	1	1.6	330	1	6	30	1	<1	0	0	0
175	0	0	0	330	3	12	0	0	0	0	0	0
200	0	0	0	160	2	24	15	1	1	0	0	0

[a] The distribution of samples on which this composite picture is based can be obtained from Table 9.

Slope Water maxima was observed in cells/l and C/l just above the seasonal pycnocline (50 m). In ring and Northern Sargasso Sea sample sets a similar pattern was obtained, once again, at somewhat deeper depths. In the absence of strong stratification - ring: Fall-One, Fall-Two; Northern Sargasso Sea: Fall-One, Spring, values were high to depths as great as 125 or 150 m. With strong stratification - ring: Summer; Northern Sargasso Sea: Summer, Fall-Two, values were lower with small maxima often present at a depth of 75 m.

We can assess the relative contribution of coccolithophores to total regional phytoplankton populations by comparing Tables 9 and 11. Excepting Summer, coccolithophores comprised a substantial fraction of total Slope Water sp/l and cells/l at nearly all depths. Due to their generally small size, however, even when abundant their contribution to Slope Water C/l was not very large. For example, on Fall-Two coccolithophores represented 62% of total cells/l and 23% of the total sp/l in the upper 75 m, but only 12% of total C/l in the same depth interval.

The relative contribution of coccolithophores to ring and Northern Sargasso Sea total phytoplankton was in general larger but rather more variable than was the case in the Slope Water. They frequently contributed almost one-half of total Northern Sargasso and ring sp/l. Their contribution to total cells/l could be even more substantial. Coccolithophores were particularly important components of Northern Sargasso Sea phytoplankton. On Fall-One they represented 87% of total Northern Sargasso Sea cells/l. On Spring and Fall-Two their percentage contributions were nearly as dramatic. Again in contrast to the Slope Water coccolithophore contribution to Northern Sargasso Sea and ring total C/l could be

significant. For example on Fall-Two they comprised 58% of total Northern Sargasso Sea C/l.

Dinoflagellate Distribution

Regional and seasonal contrasts in dinoflagellate sp/l were less marked and less consistent than was true of either the diatom or coccolithophore data (Table 12). The pooled abundance in each hydrocast of some common dinoflagellate species is presented in Appendix C.

There is some evidence that the vertical distribution of dinoflagellates is related to upper water column stability. In the most strongly stratified regime sampled - Slope Water: Summer, there may have been a subsurface maximum in dinoflagellate cells/l and C/l (Table 12). This maximum occurred just above the seasonal pycnocline (50 m). In contrast to the diatom and coccolithophore data, this Slope Water observation was unique.

We can assess the relative contribution of dinoflagellates to total regional phytoplankton populations by comparing Tables 9 and 13. Only during Summer did dinoflagellate sp/l exceed 20% of total Slope Water sp/l. Likewise, dinoflagellate contribution to total Slope Water C/l was substantial (22%) only at that same station. On a cells/l basis dinoflagellates were an invariably minor fraction of Slope Water total phytoplankton. Dinoflagellate contribution to ring and Northern Sargasso Sea total phytoplankton was more significant. In respect to cells/l, C/l, or sp/l they represented only a small fraction of the total population on Fall-One. Dinoflagellates constituted approximately one-fourth of total Northern Sargasso Sea and ring cells/l and C/l during

Table 12

Dinoflagellate distribution[a]

SLOPE WATER

Depth (m)	FALL-ONE cells/l	sp./l	ngC/l	SPRING cells/l	sp./l	ngC/l	SUMMER cells/l	sp./l	ngC/l	FALL-TWO cells/l	sp./l	ngC/l
0	2080	4	207	1695	7	133	330	6	103	668	5	70
25	97	2	13	-	-	-	630	7	173	720	6	88
50	120	1	6	0	0	0	5200	6	2475	780	4	350
75	30	1	2	-	-	-	90	2	5	110	1	171
100	0	0	0	0	0	0	0	0	0	45	2	5
125	33	1	9	0	0	0	0	0	0	15	1	2
150	0	0	0	0	0	0	0	0	0	15	1	299
175	0	0	0	-	-	-	0	0	0	90	1	8
200				-	-	-	30	1	19	60	2	67

GULF STREAM COLD-CORE RING

0	80	2	5	1433	5	184	1230	10	143	150	3	92
25	90	2	15	-	-	-	1500	10	194	380	6	100
50	30	1	2	-	-	-	1915	8	146	350	6	53
75	40	1	12	-	-	-	465	5	35	130	4	70
100	20	1	3	-	-	-	480	6	53	350	5	5
125	10	1	12	-	-	-	390	6	13	50	1	5
150	0	0	0	-	-	-	90	1	8	110	2	12
175	0	0	0	-	-	-	30	1	1	30	1	11
200	0	0	0	30	1	1	0	0	0	30	1	3

NORTHERN SARGASSO SEA

0	20	2	10	1190	5	126	1830	10	202	570	5	59
25	120	3	146	350	4	18	420	4	38	360	3	42
50	300	4	200	65	1	4	1160	6	110	330	4	25
75	120	2	16	50	1	3	605	7	7	90	2	5
100	30	1	86	100	2	6	100	2	8	0	0	0
125	90	2	38	100	1	6	75	2	5	30	1	4
150	0	0	0	0	0	0	30	1	2	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	30	1	2

[a] The distribution of samples on which this composite picture is based can be obtained from Table 9.

Summer, but by Fall-Two they represented only 6% of total ring or Northern Sargasso Sea cells/l. At some depths during Summer, dinoflagellate sp/l were greater than one-half the total sp/l of a species-rich population, but by Fall-Two they rarely exceeded 25% of total ring or Northern Sargasso Sea sp/l.

Comparison of Ordination Approaches

In respect to most of the average population properties examined earlier, the Northern Sargasso Sea and ring do not appear to be very different. However, if we now analyze the species composition of individual samples and order them with respect to their relative similarity, we find significant differences do exist. Although it has been employed in some ecological studies, CA has not been applied to phytoplankton species counts. Before adopting it as our primary method of ordination we applied other mathematical methods to one subset of our data. While these results are not strictly comparable, all approaches defined the same basic pattern of inter-relationships between individual samples of the data set.

Williams (1971) reviewed the complicated subject of choosing an appropriate clustering strategy. We employed a non-weighted group average clustering strategy. In Williams's terminology this approach is exclusive, intrinsic, hierarchical, and agglomerative. We used this strategy to cluster samples based on two measurements of the similarity between sample pairs: percent-similarity (Whittaker and Fairbanks, 1958) and normalized-expected-species-shared or NESS (Grassle and Smith, 1976). We have applied the former in an earlier study (Wiebe

et al., 1976a). The latter has been shown to be less biased than older similarity measures (Grassle and Smith, 1976). We have applied NESS with a random sample size m that represented 300 individuals/liter.

The dendrograms representing the results of clustering samples obtained on Fall-One and Fall-Two according to their present-similarity or NESS similarity are shown in Figures 5 and 6. Samples entered are $\leq$ 125 m in depth in the Northern Sargasso Sea and ring, but $\leq$ 100 m in depth in the Slope Water. To avoid overestimating similarity due to lumping dissimilar taxa assigned the same taxonomic heading, e.g., dinoflagellate spp., data for only the taxonomic categories identified with species names (i.e., 135 of 151) are included. Some features common to both presentations are: a) clusters of ring samples are linked at relatively high levels of similarity; b) Slope Water samples are linked at relatively low levels of similarity; c) Fall-One and Fall-Two sample sets are to some degree distinguishable. In the NESS representation (Figure 6) the resolution of ring, Slope Water, and Northern Sargasso Sea sample sets is better within the Fall-One sample set than within the Fall-Two sample set. In the percent-similarity representation (Figure 5), no such distinction between cruises is evident. Had we chosen a higher m, NESS would have become more dependent upon rare species and the two dendrograms would have been more dissimilar.

Clustering methods can be confusing and hard to interpret in that by examining a dendrogram it is difficult to discover the level of association between samples sorted into different clusters. A number of multivariate classificatory methods have been offered that are readily

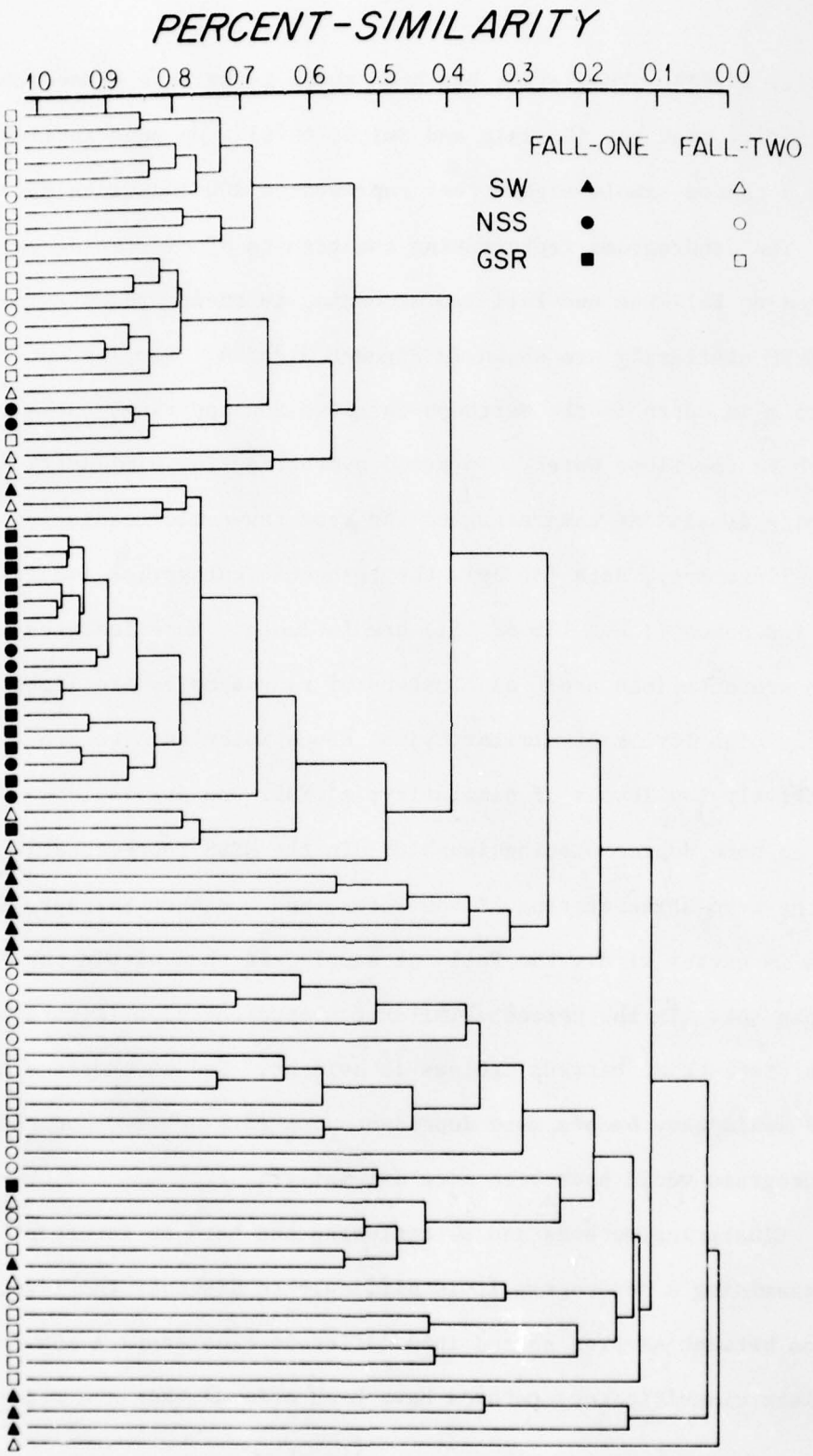


Figure 5. Cluster dendrogram representing percent-similarity relationships amongst Fall-One and Fall-Two samples.

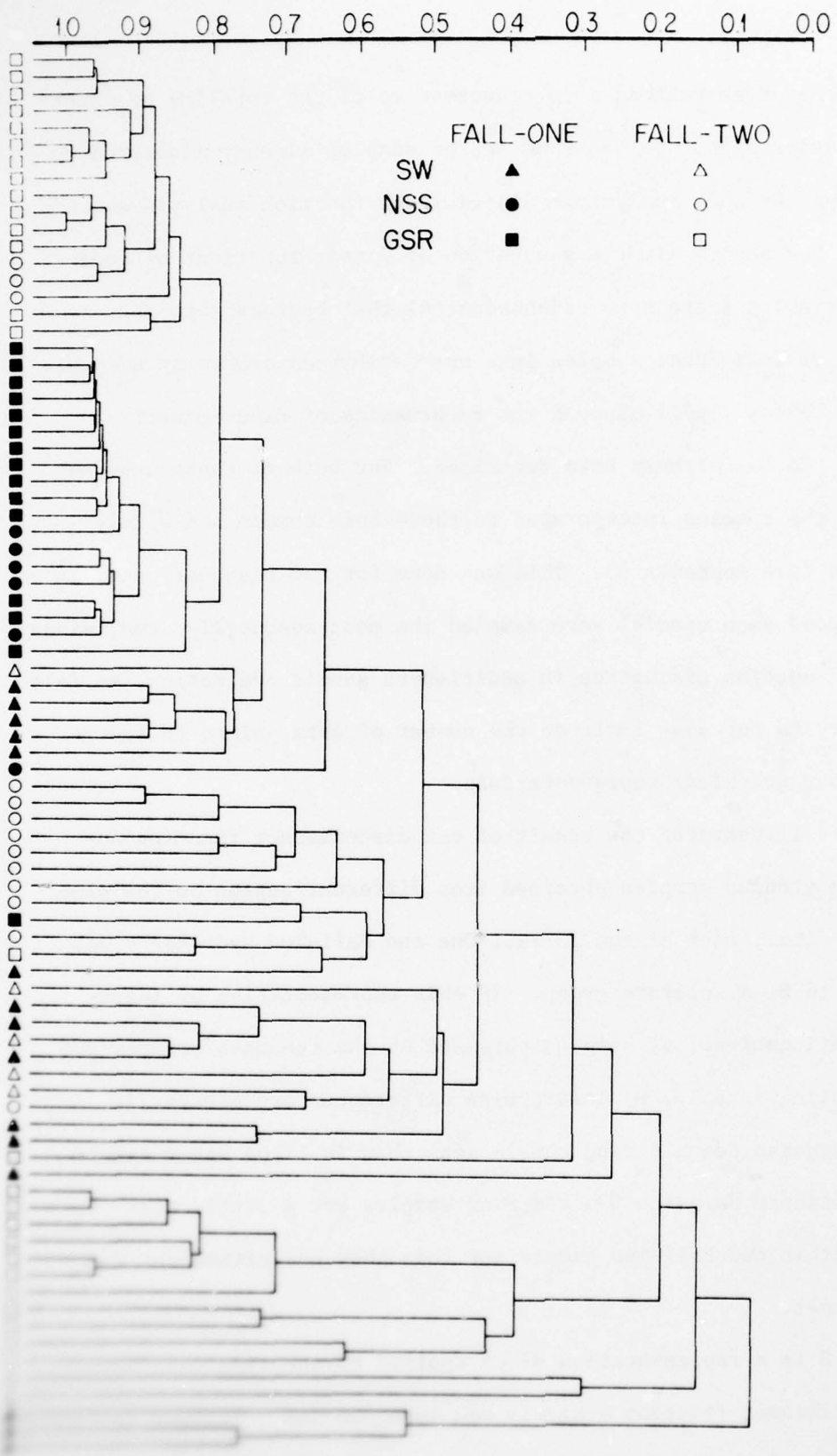


Figure 5. Cluster dendrogram representing normalized-expected-species-shared relationships amongst Fall-One and Fall-Two samples.

amenable to representations more conservative of the totality of inter-sample relationships. To the same set of samples already clustered we have applied two such analyses - discriminant function analysis and CA. The former has as its aim the generation of linear functions of independent variables (here species abundances) that best express the assignment of individual samples into *pre-determined groups of samples*. Cooley and Lohnes (1971) discuss the mathematics of discriminant functions. CA has already been described. For both of these analyses we limited the species incorporated to those both common and widely distributed (see Appendix B). This was done for two reasons: one, in all likelihood such species were sampled the most adequately; two, since CA produces species ordination in addition to sample ordination, we felt it necessary to put some limit on the number of data points to be included in our graphical representations.

Figure 7 illustrates the result of our discriminant function analysis. We grouped samples obtained from different depths on the same hydrocast - i.e., each of the 13 Fall-One and Fall-Two hydrocasts was considered to be a separate group. In this representation of inter-sample relationships: a) samples obtained on the separate cruises are readily distinguishable; b) intercruise differences are greater in Northern Sargasso Sea and ring sample sets than in Slope Water sample sets; c) Northern Sargasso Sea and ring samples are a little more distinct within the Fall-Two sample set than they are within the Fall-One sample set.

Figure 8 is a representation of CA applied to the same data base to which discriminant function analysis had been applied. Primary features

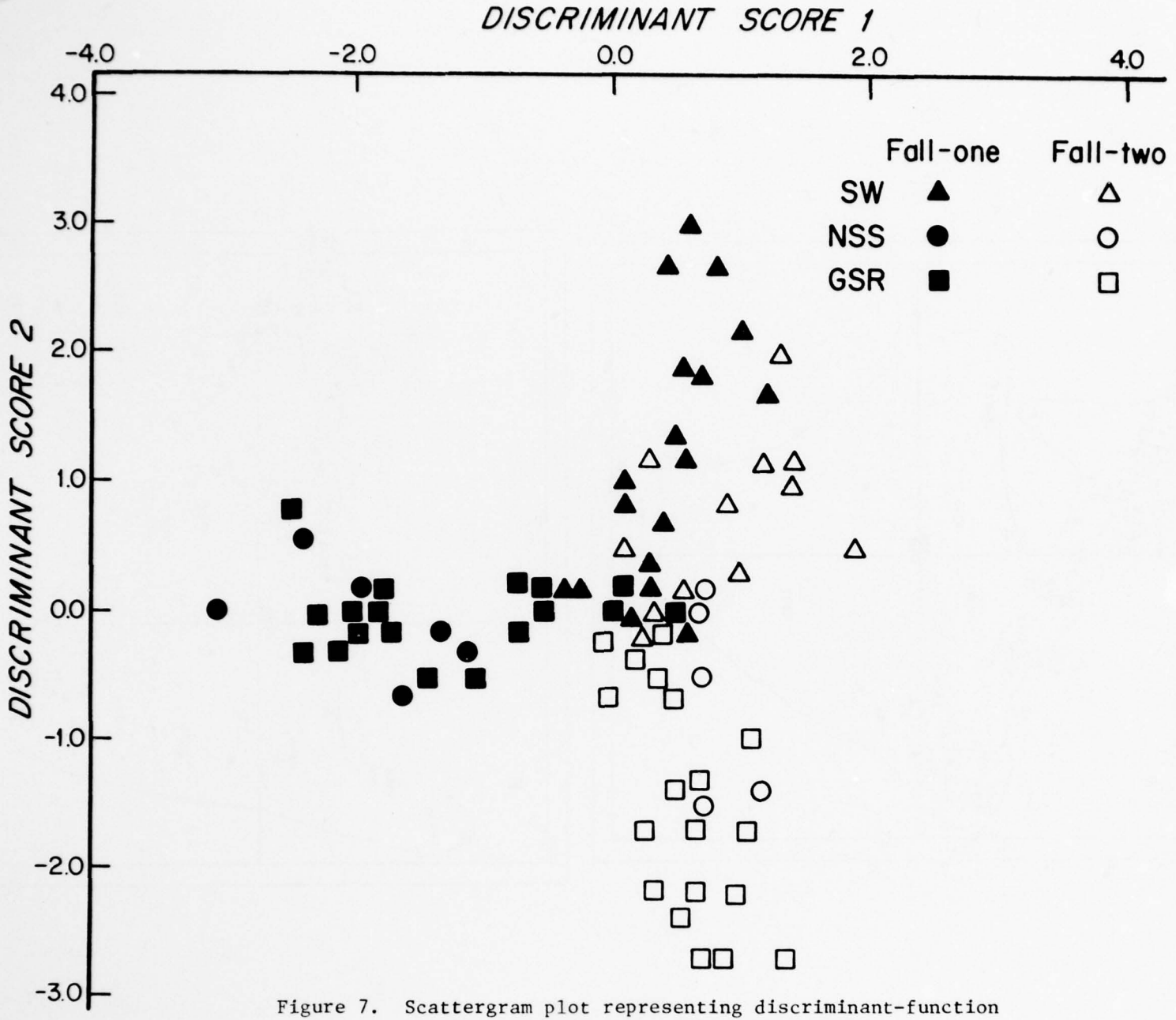


Figure 7. Scattergram plot representing discriminant-function analysis of Fall-One and Fall-Two samples.

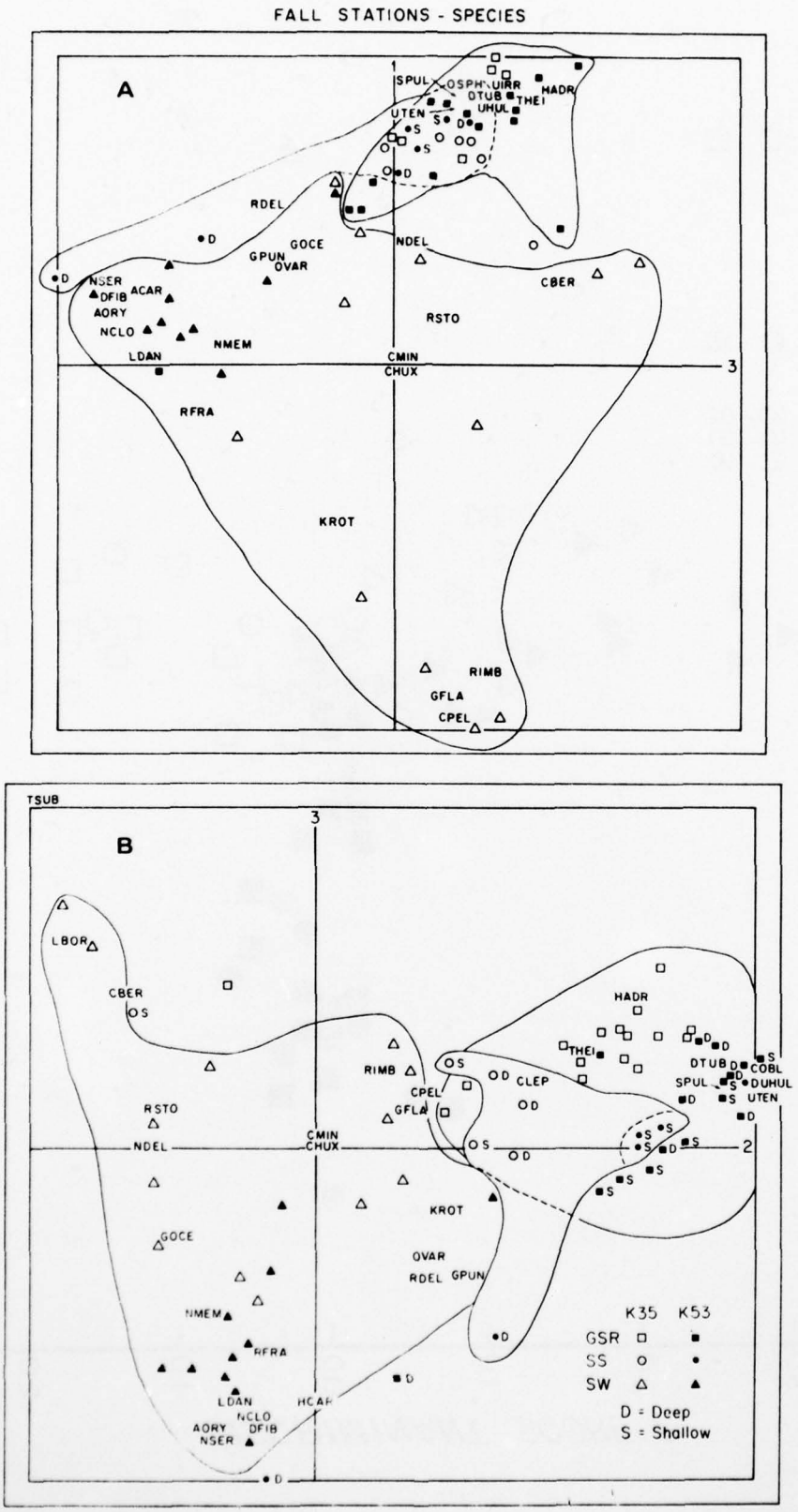


Figure 8a-b. Scattergram plots representing correspondence analysis of Fall-One and Fall-Two samples. The axes in a) are the first and third eigenvectors extracted by CA. The axes in b) are the second and third eigenvectors extracted by CA.

already noted include: a) Fall-One and Fall-Two sample sets are readily distinguishable; b) Northern Sargasso Sea and ring sample sets are more closely related than either is to the Slope Water sample set; c) Fall-Two is particularly well resolved in that Slope Water, Northern Sargasso Sea and ring sample sets are more distinct. Further, species characteristic of the biota of different sample clusters are determinable by inspection (e.g., Chux = *Coccolithus huxleyi*).

These conclusions are based on our subjective estimates of inter-sample distance in Figure 8. These estimates can be made more objective. If we consider CA factor scores as defining positions along linear axes, then the three axes depicted define a volume. We can calculate the distance between all possible pairs of points in Figure 6 and find the ten nearest-neighbors of each point. To investigate relative ring, Slope Water and Northern Sargasso Sea sample set integrity we simply sum the number of times a member of each set of samples has as one of its ten nearest-neighbors a member of each of the three sets. We then compare the distribution of these matches and mismatches with random expectation - i.e., the probability of selecting at random a particular sample pair, times the sum of the number of occurrences in each of the two sample sets, times ten. We obtain the following:

	Actual				Theoretical		
	Northern Sargasso Sea	Slope Water	Gulf Stream Ring		Northern Sargasso Sea	Slope Water	Gulf Stream Ring
NSS	40			NSS	20		
SW	66	189		SW	80	80	
GSR	153	108	170	GSR	120	240	180

It would be difficult to rigorously define the underlying distribution, but the expected frequencies are exact. Overall, the distribution obtained is significantly different from that expected ($p << .005$, chi-squared), sample sets are distinguishable, and Northern Sargasso Sea and ring sample sets are more closely related than either is to the Slope Water sample set. Since CA generates sample ordinations at least as good as those generated by the other classificatory methods, and at the same time produces species ordinations, we apply CA to the remainder of our data.

Correspondence Analysis Sample Ordination

In the sections to follow we present results obtained applying CA to various subsets of our samples obtained at depths $\leq$ 125 m. At greater depths species per sample were felt to be too low to justify community analysis. Species included are both common and widely-distributed (see Appendix C). In the sections immediately following we first investigate intra-cruise sample variability and then Northern Sargasso Sea, Slope Water, and ring sample variability.

The results of our analysis are graphically represented as three-dimensional isometric scattergrams showing samples or species positioned in volumes whose axes are the first three eigenvectors extracted by CA (Figures 9-16). In interpreting these plots note: a) two samples near each other are relatively similar in species composition, b) two species near each other exhibit relative agreement as to which samples represent the most suitable habitats, c) if a species were near a sample it would be relatively characteristic of that sample's flora (as in Figure 8). Distance

above the plane of axes 1 and 2 is represented by a solid line and distance below this plane by a dashed line. Symbols not associated with either a solid or a dashed line are in the plane of axes 1 and 2. An arrow leading to a species or sample symbol indicates a considerable distance in the defined direction.

CA of Fall-One samples is represented in Figure 9a-b. The three axis eigenvectors account for 60% of total chi-square deviation. The Slope Water sample set is quite variable and well separated from the envelope embracing both Northern Sargasso Sea and ring sample sets (Figure 9a). That is, Northern Sargasso Sea and ring sample sets are far more similar to each other than either is to the Slope Water sample set. Figure 9b provides greater resolution of the finer details of Northern Sargasso Sea and ring sample relationships. While considerable overlap is evident, the latter two sets are to some degree distinguishable. Neither is demonstrably more similar to the Slope Water sample set.

CA of Spring samples is represented in Figure 10. The three axis eigenvectors account for 65% of total chi-square deviation. Data points for this cruise are particularly sparse. All sample sets exhibit considerable variability. Ring samples are well separated from both Northern Sargasso Sea and Slope Water sample sets. The latter two are hardly distinguishable.

CA of Summer samples is represented in Figure 11. The three axis eigenvectors account for 53% of total chi-square deviation. "S" and "D" distinguish samples collected at or above the seasonal thermocline from those collected in or beneath it. The letter "S" with a Northern

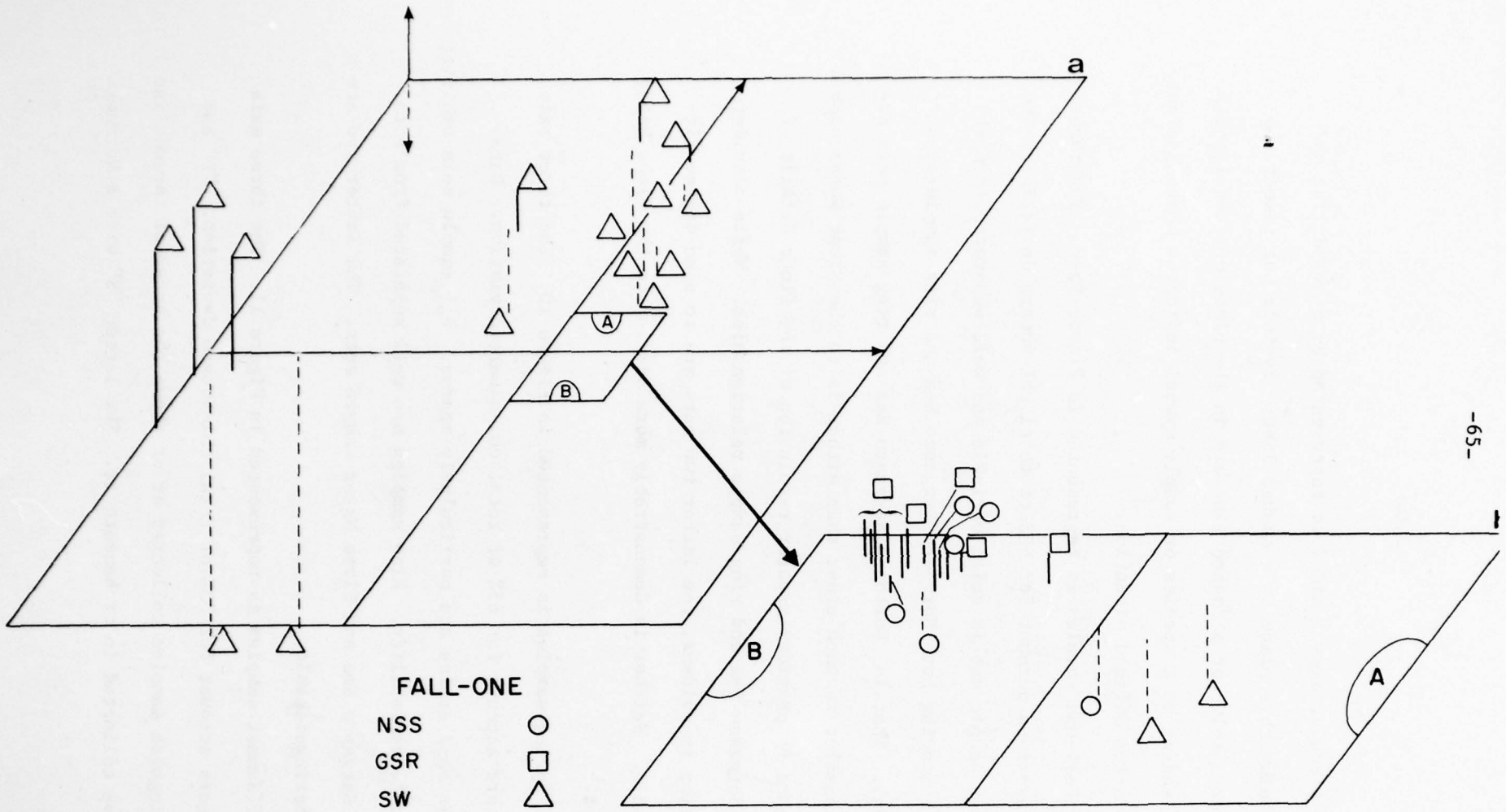


Figure 9a-b. Scattergram plots representing correspondence analysis of Fall-One samples.

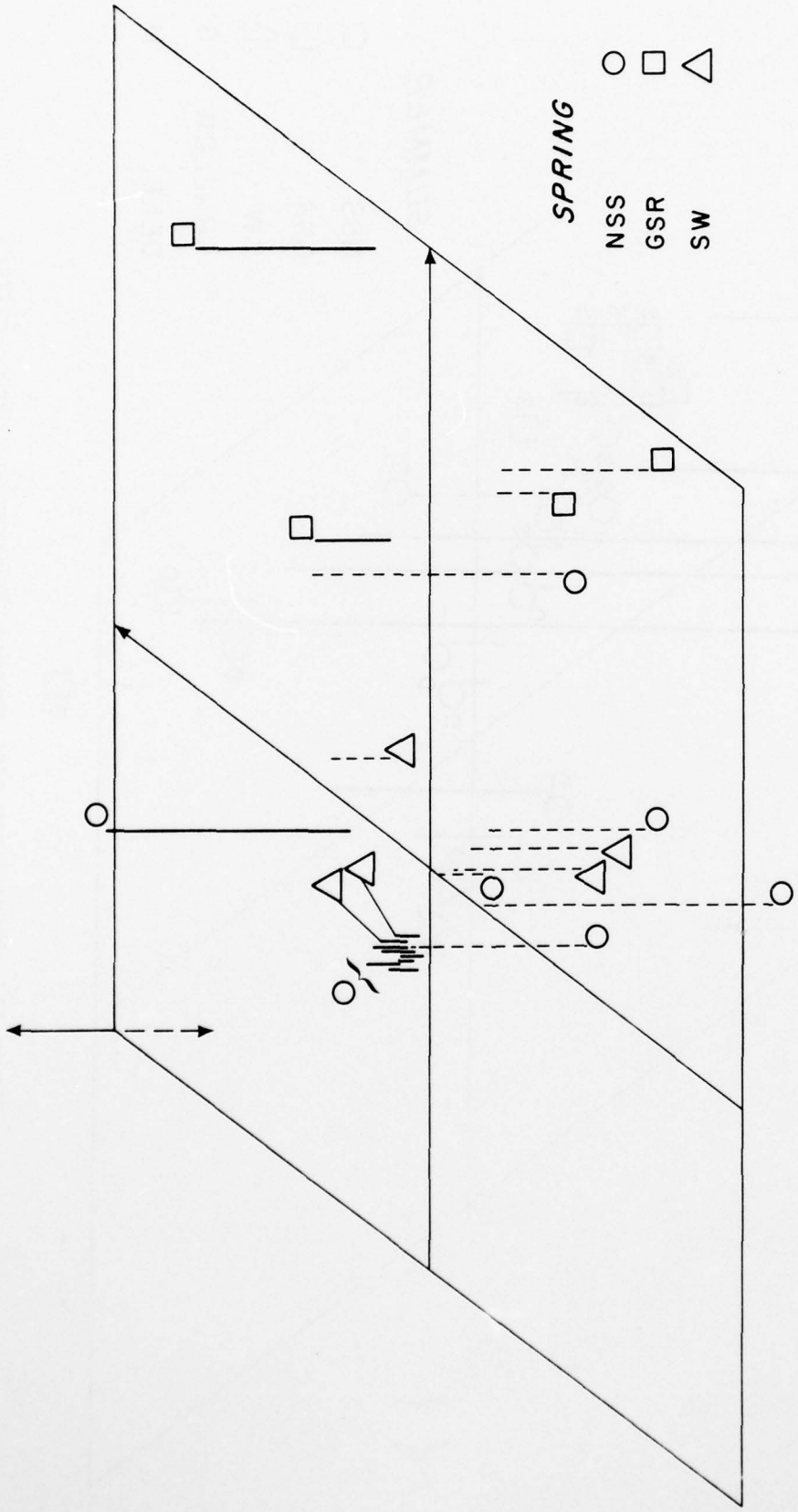


Figure 10. Scattergram plot representing correspondence analysis of Spring samples.

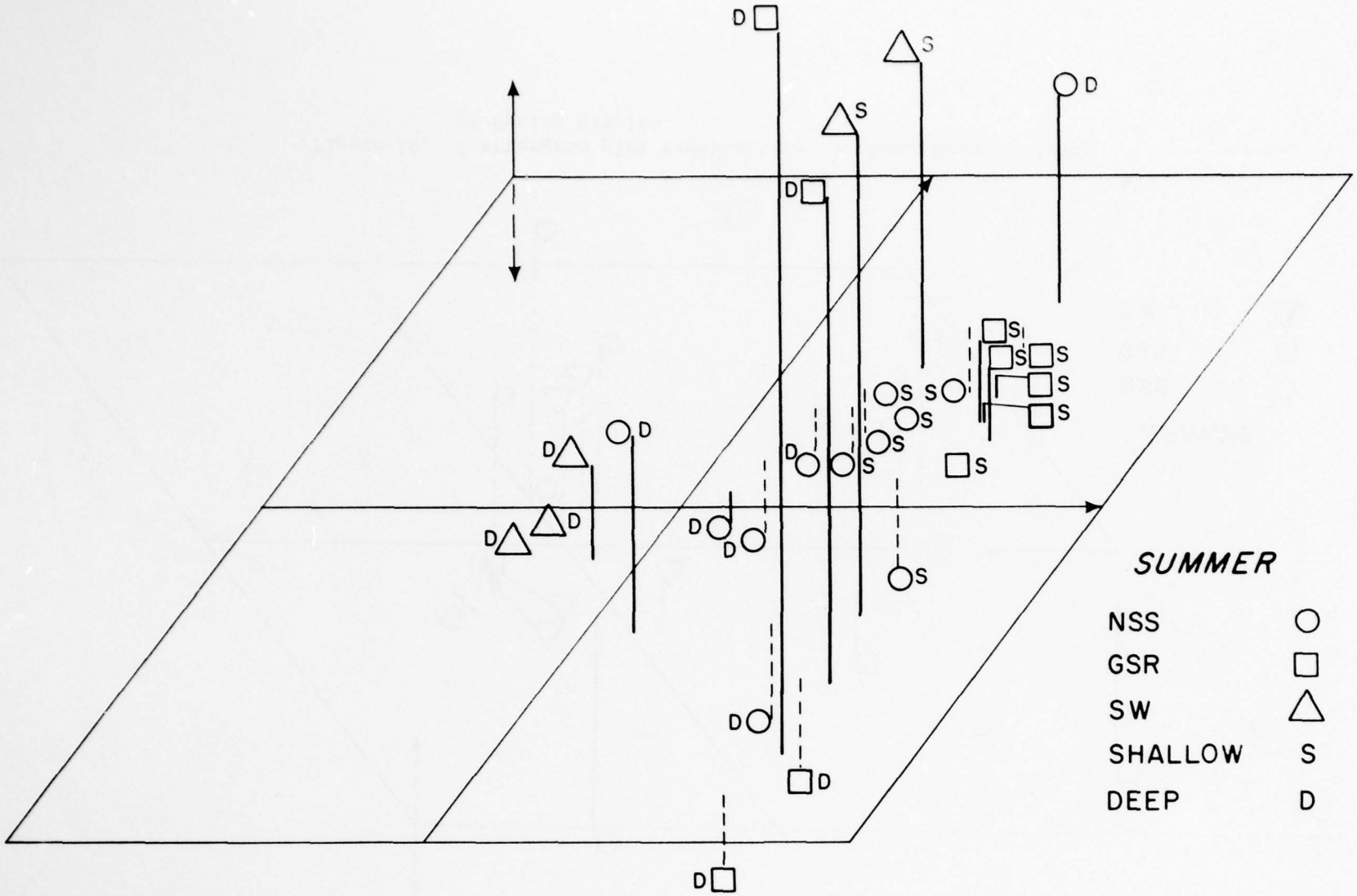


Figure 11. Scattergram plot representing correspondence analysis of Summer samples.

Sargasso Sea or ring symbol indicates a sampling depth $\leq$ 75 m; "D" indicates a sampling depth $\geq$ 100 m. In Slope Water samples "S" indicates a sampling depth $\leq$ 50 m, while "D" indicates a sampling depth $\geq$ 75 m. Within each sample set deep samples are reasonably well separated from shallow samples. In both Northern Sargasso Sea and ring sample sets shallow samples are relatively both homogeneous and similar. In the Slope Water sample set, however, the deep samples are the more tightly clustered. As was true for Spring samples, this analysis suggests that the Northern Sargasso Sea sample set is more similar to the Slope Water sample set than it is to the ring sample set. All sets are quite variable, with ring samples perhaps the most variable of all. Those Northern Sargasso Sea and ring samples most closely associated with Slope Water samples are all deep samples. This last association occurs in respect to both shallow and deep Slope Water sample clusters.

CA of Fall-Two samples is represented in Figure 12. The three axis eigenvectors account for 53% of the total chi-square deviation. "S" and "D" sample designation has not been continued, because deep and shallow samples were not well separated. A suggestion of such a separation might have been present in the Northern Sargasso Sea sample set (see Figure 8). The Slope Water sample set is distinct from both Northern Sargasso Sea and ring sample sets. The latter two sets exhibit considerable overlap. As in the previous analysis CA suggests that the Northern Sargasso Sea sample set is more similar to the Slope Water sample set than the ring sample set is to the Slope Water sample set. In this case Slope Water and ring sample sets constitute end points of overall

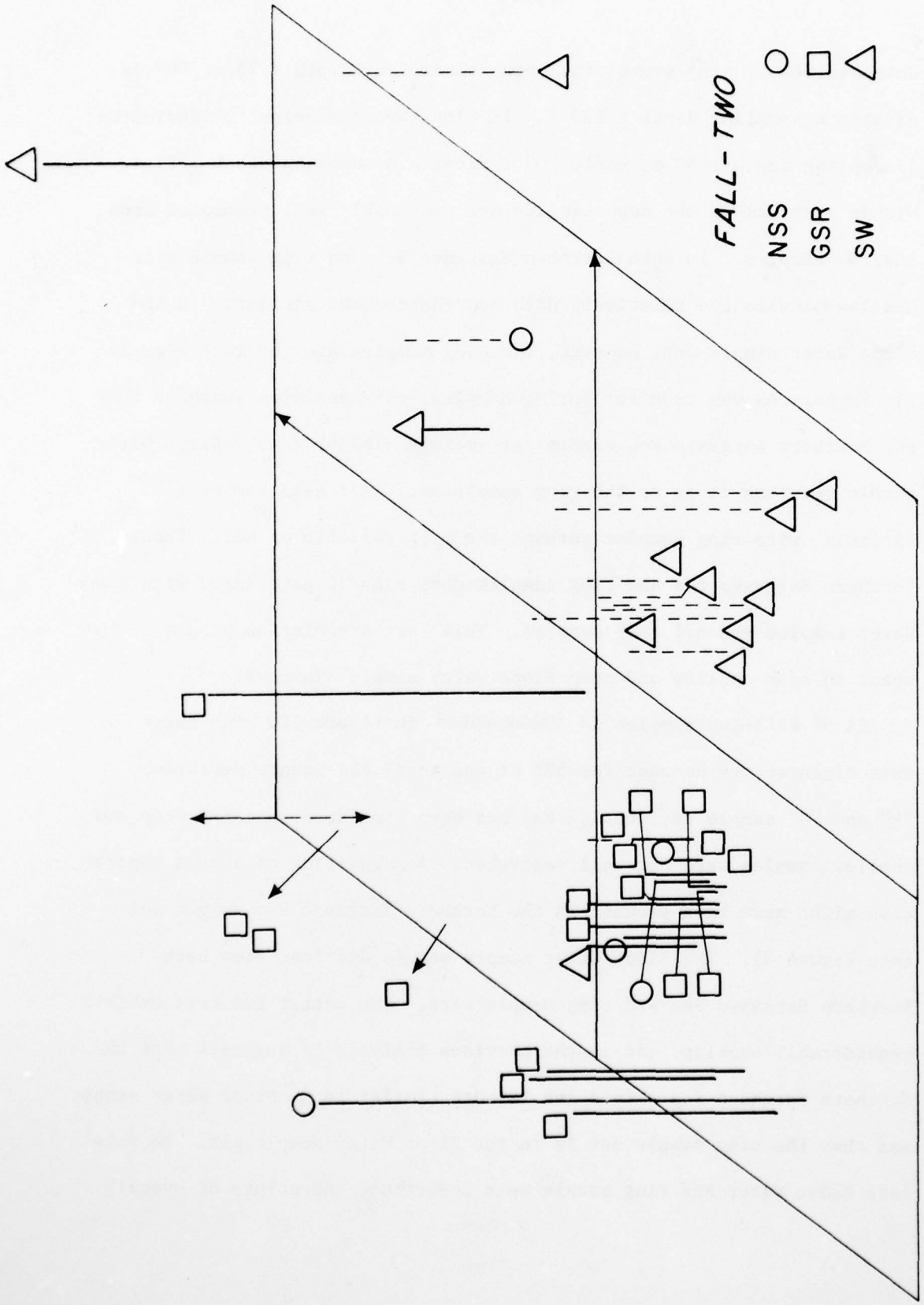


Figure 12. Scattergram plot representing correspondence analysis of Fall-Two samples.

sample position along the horizontal axis representing the first eigenvector extracted.

CA of Slope Water samples from all four cruises is represented in Figure 13. The three axis eigenvectors account for 52% of total chi-square deviation. Samples from Fall-One were particularly variable and in general well removed from those obtained on the other cruises. While somewhat more widely dispersed, the set of Fall-Two samples exhibits considerable overlap with the set of Spring samples. Shallow (0 and 25 m) Summer samples are associated with Fall-Two and Spring samples, but the deeper Summer samples form a distinct and distant cluster.

CA of Northern Sargasso Sea samples from all four cruises is represented in Figure 14a-b. The three axis eigenvectors account for 55% of total chi-square deviation. Two main clusters are apparent. That depicted in Figure 14a is composed of Summer and Fall-Two samples. This assemblage is relatively variable. A far tighter cluster composed of samples from Spring and Fall-One is shown in Figure 14b. The positions of the sample sets contained therein can be viewed as representing a gradient in similarity. The sequence of sets along this gradient would be Spring-Fall-One-Fall-Two-Summer. This approximates a gradient in upper water column stratification (see Figure 4a-d).

CA of ring samples is represented in Figure 15a-b. The three axis eigenvectors account for 56% of total chi-square deviation. Once again we note two principal sample clusters. The more widely dispersed is depicted in Figure 15a. It is composed of Summer and Fall-Two samples. The two Fall-Two samples included were both obtained at a depth of 125 m. A far tighter central cluster is seen in Figure 15b. This last cluster can

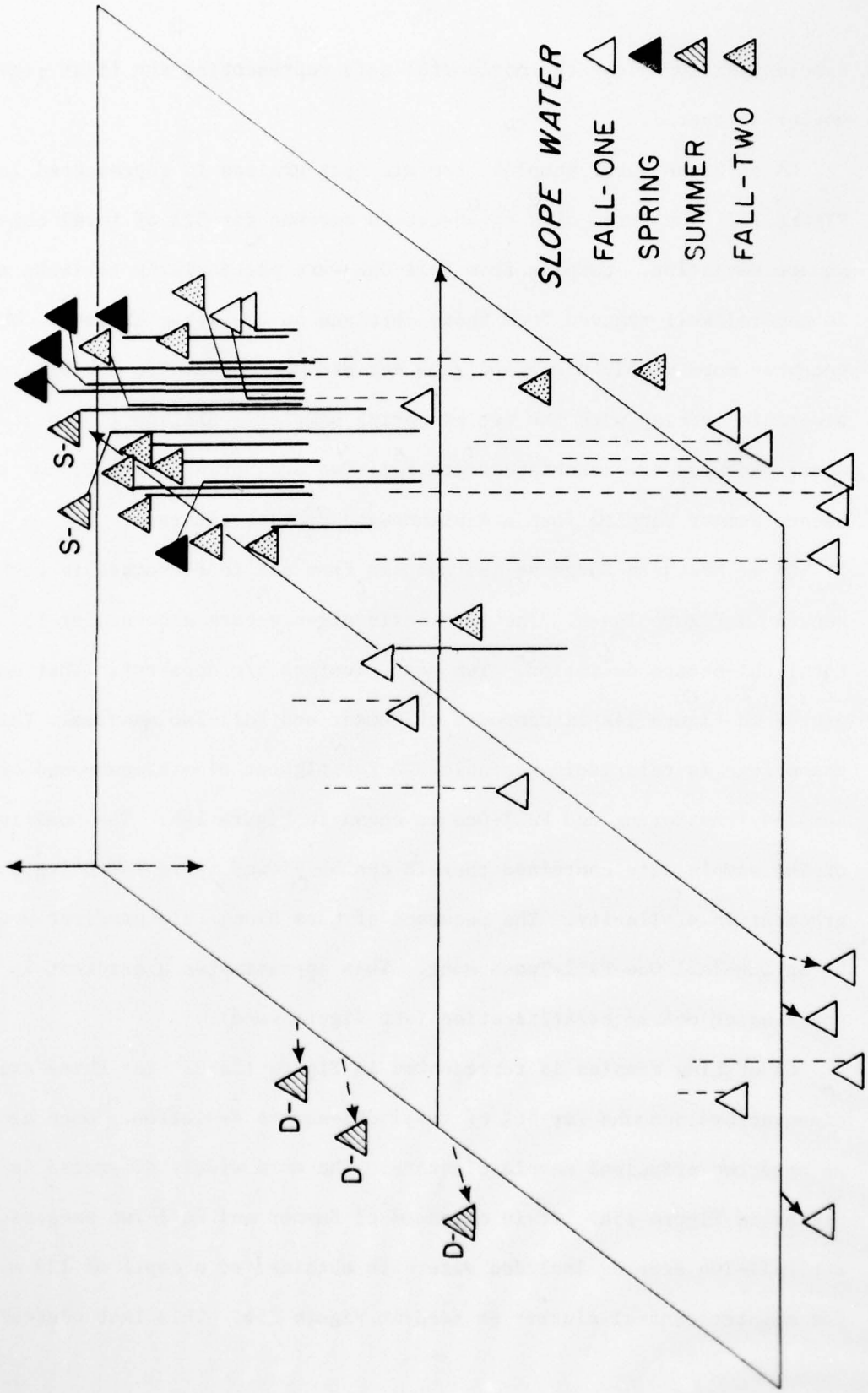
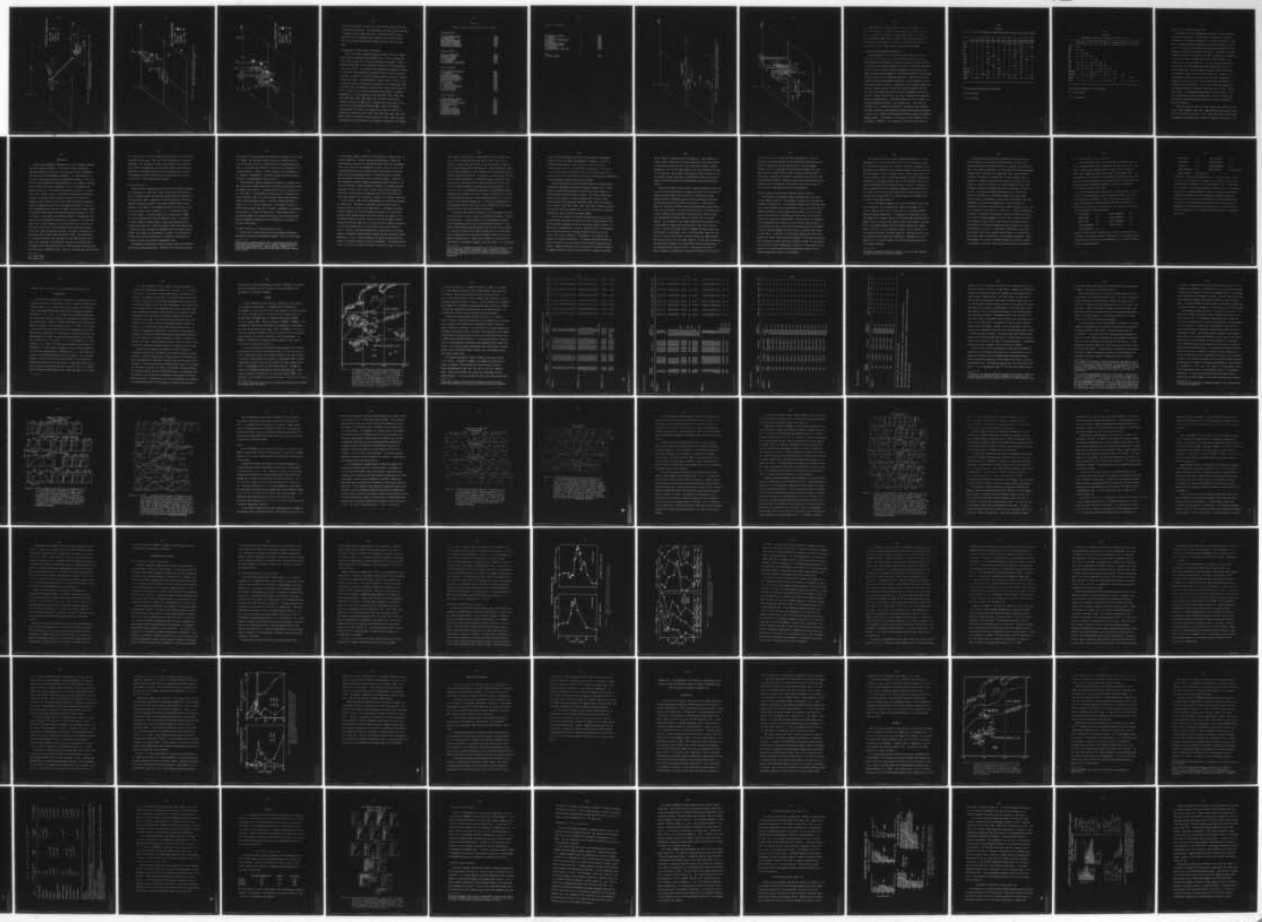


Figure 13. Scattergram plot representing correspondence analysis of Slope Water samples.

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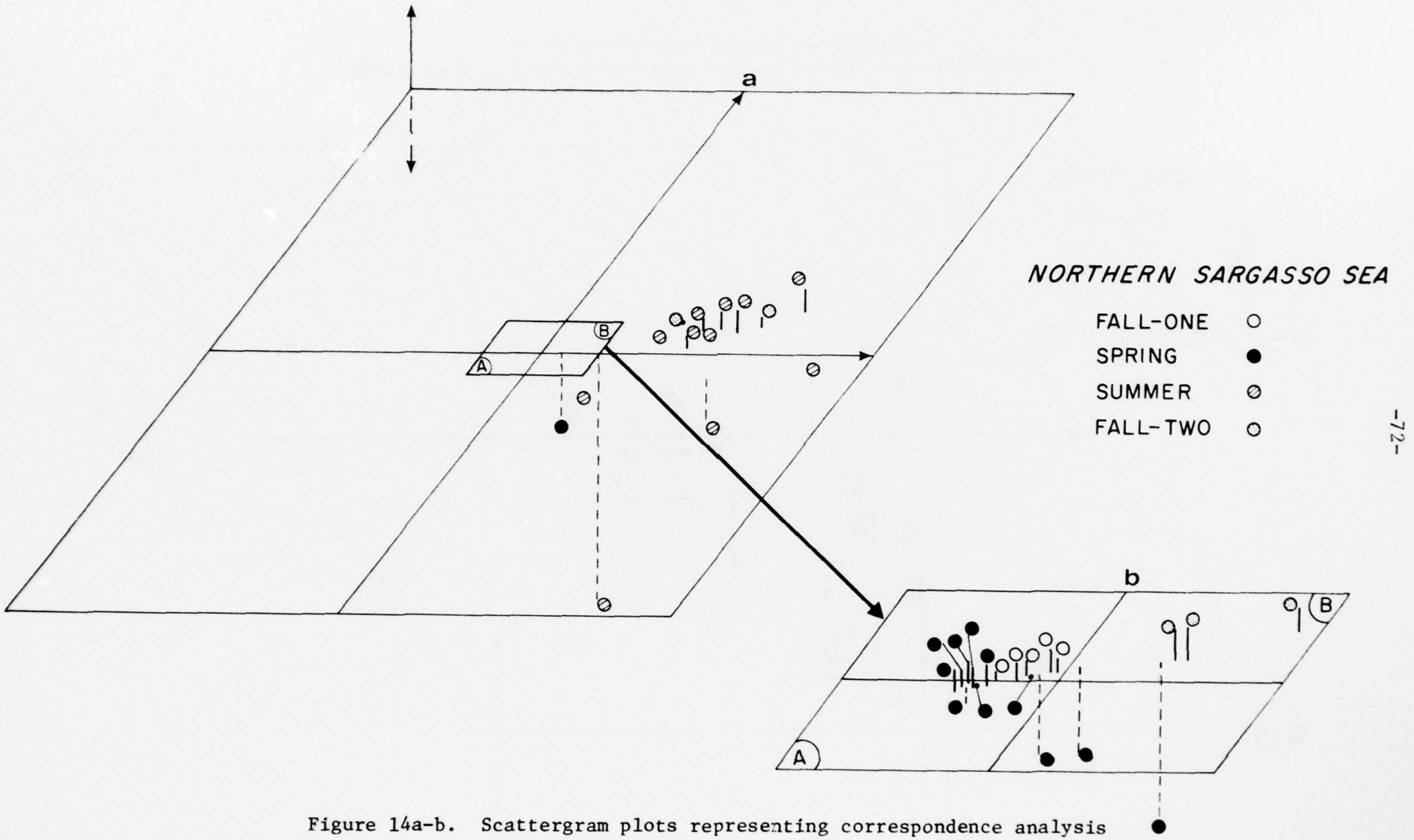


Figure 14a-b. Scattergram plots representing correspondence analysis of Northern Sargasso Sea samples.

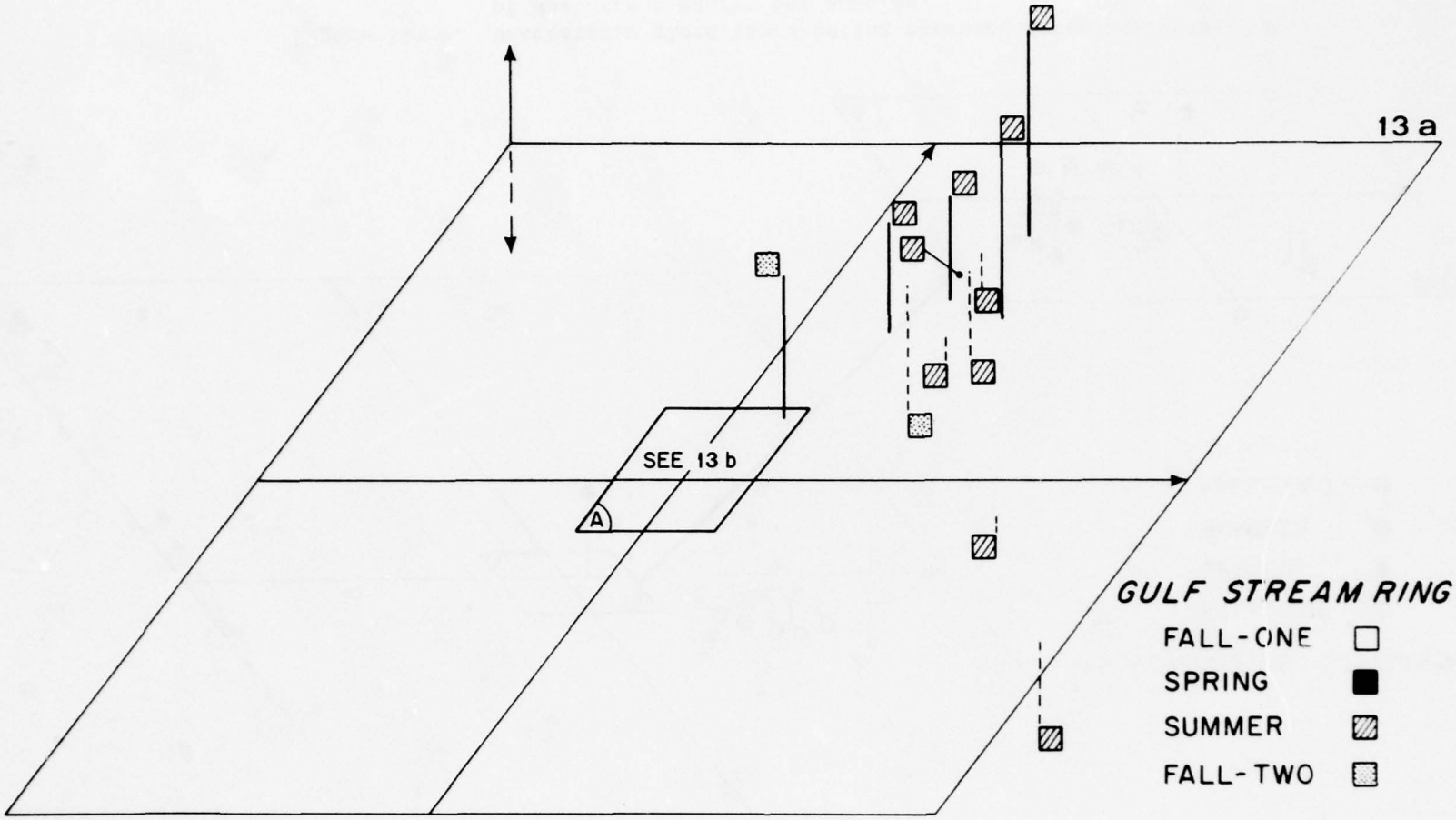


Figure 15a-b. Scattergram plots representing correspondence analysis of Gulf Stream ring samples.

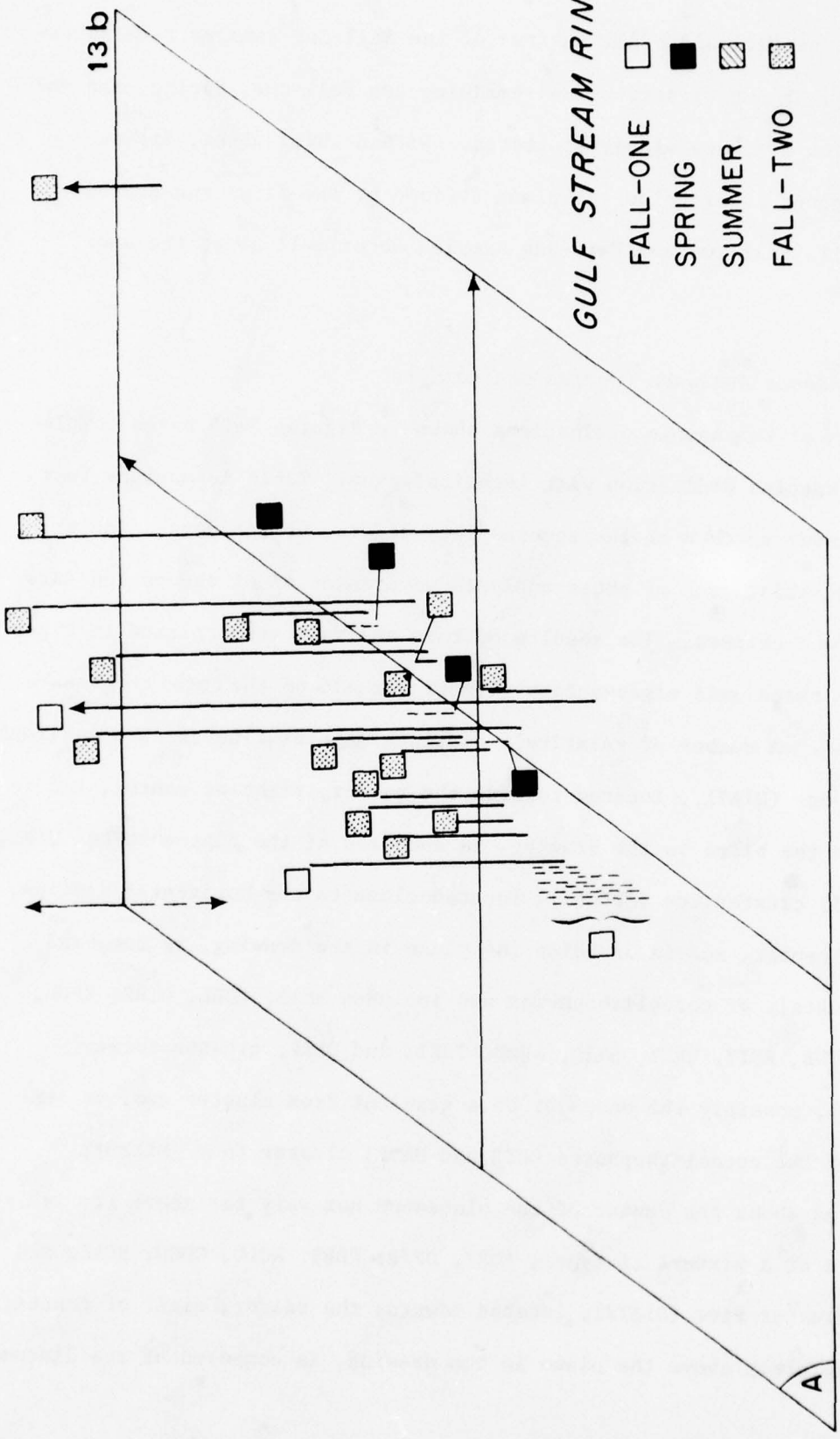


Figure 15b

itself be partitioned. All but two of the Fall-One samples form an extremely tight sub-cluster. The remaining two Fall-One, Spring, and Fall-Two samples are more widely scattered. Within this subset, Spring samples occur in or below the plane defined by the first and second axes, while Fall-Two and Fall-One samples occur well above the same plane.

Correspondence Analyses Species Ordinations

Each of the sample ordinations shown in Figures 9-15 has a complementary species ordination with identical axes. Table 13 assigns four letter codes to each of the species included in our analyses. Rather than describing each of these analyses we present CA of the pooled data of all four cruises. The results of this analysis are depicted in Figure 16. The three axis eigenvectors account for 43% of the total chi-square deviation. A number of relatively distinct species clusters are apparent: cluster one (DIAT1), located towards the reader, right of center, and in or below the plane in the drawing, is composed of the diatoms GFLA, RIMB, and TNIT; cluster two (COCCO1), located close to the horizontal midline, left of center, and in or below the plane in the drawing, is composed predominately of coccolithophores and includes RHIS, COBL, UIRR, SPUL, GPUN, DTUB, RSTY, UHUL, SMED, AROB, THEI, and CLEP; cluster three (COCCO2), possibly the endpoint of a gradient from cluster two, is composed of the coccolithophores CHUX and HADR; cluster four (MIXED); scattered about the center of the plane and not very far above it, is composed of a mixture of types, AORY, DFIB, POBT, NCLO, GOCE, RCAL, and CTER; cluster five (DIAT2), located towards the reader, right of center, and moderately above the plane in the drawing, is composed of the diatoms

Table 13

Codes of species used in correspondence analyses

Dinoflagellates		
Oxytoxum sphaeroideum	-	OSPH
O. variabilium	-	OVAR
Gymnodinium punctatum	-	GPUN
Katodinium rotundatum	-	KROT
Pronoctiluca pelagica	-	PPEL
Prorocentrum obtusidens	-	POBT
Pennate Diatoms		
Navicula membranacea	-	NMEM
Nitzschia seriata	-	NSER
N. delicatissima	-	NDEL
N. closterium	-	NCLO
Thalassionema nitzschiodes	-	TNIT
Centric Diatoms		
Bacteriastrum delicatulum	-	BDEL
B. hyalinium	-	BHYA
Cerataulina bergonii	-	GFLA
Hemiaulus membranaceus	-	HMEM
Leptocylindricus danicus	-	LDAN
Rhizosolenia alata	-	RALA
R. calcaravis	-	RCAL
R. fragilissima	-	RFRA
R. imbricata shrubsolei	-	RIMB
R. stolterfothii	-	RSTO
Chaetoceros teres	-	CTER
Coccolithophores		
Calyptrosphaera oblonga	-	COBL
Coccolithus huxleyi	-	CHUX
Cyclococcolithus leptoporus	-	CLEP
Anthosphaera oryza	-	AORY
A.robusta	-	AROB
Discoshaera tubifer	-	DTUB
Halopappus adriaticus	-	HADR
Helicosphaera carteri	-	HCAR
Gephyrocapsa oceanica	-	GOCE

Table 13 (continued)

Rhabdosphaera hispida	-	RHIS
R. stylifer	-	RSTY
Syracosphaera mediterranea	-	SMED
S. pulchra	-	SPUL
Thoracosphaera heimii	-	THEI
Umbellosphaera tenuis	-	UTEN
U. irregularis	-	UIRR
Umbilicosphaera hulburtiana	-	UHUL
Other		
Dictyocha fibula	-	DFIB

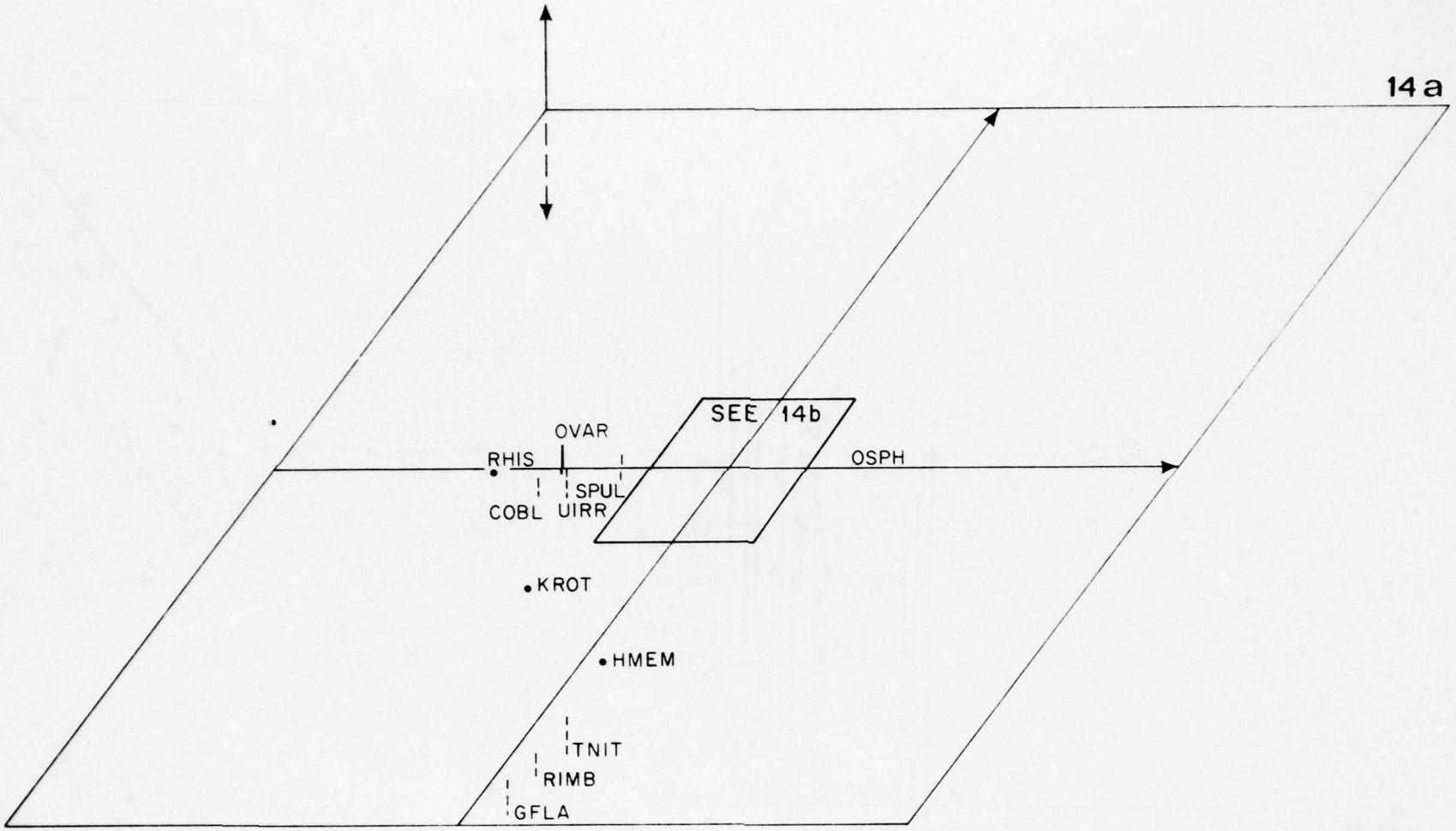


Figure 16a-b. Scattergram plots representing correspondence analysis of Fall-One Spring, Summer, and Fall-Two species.

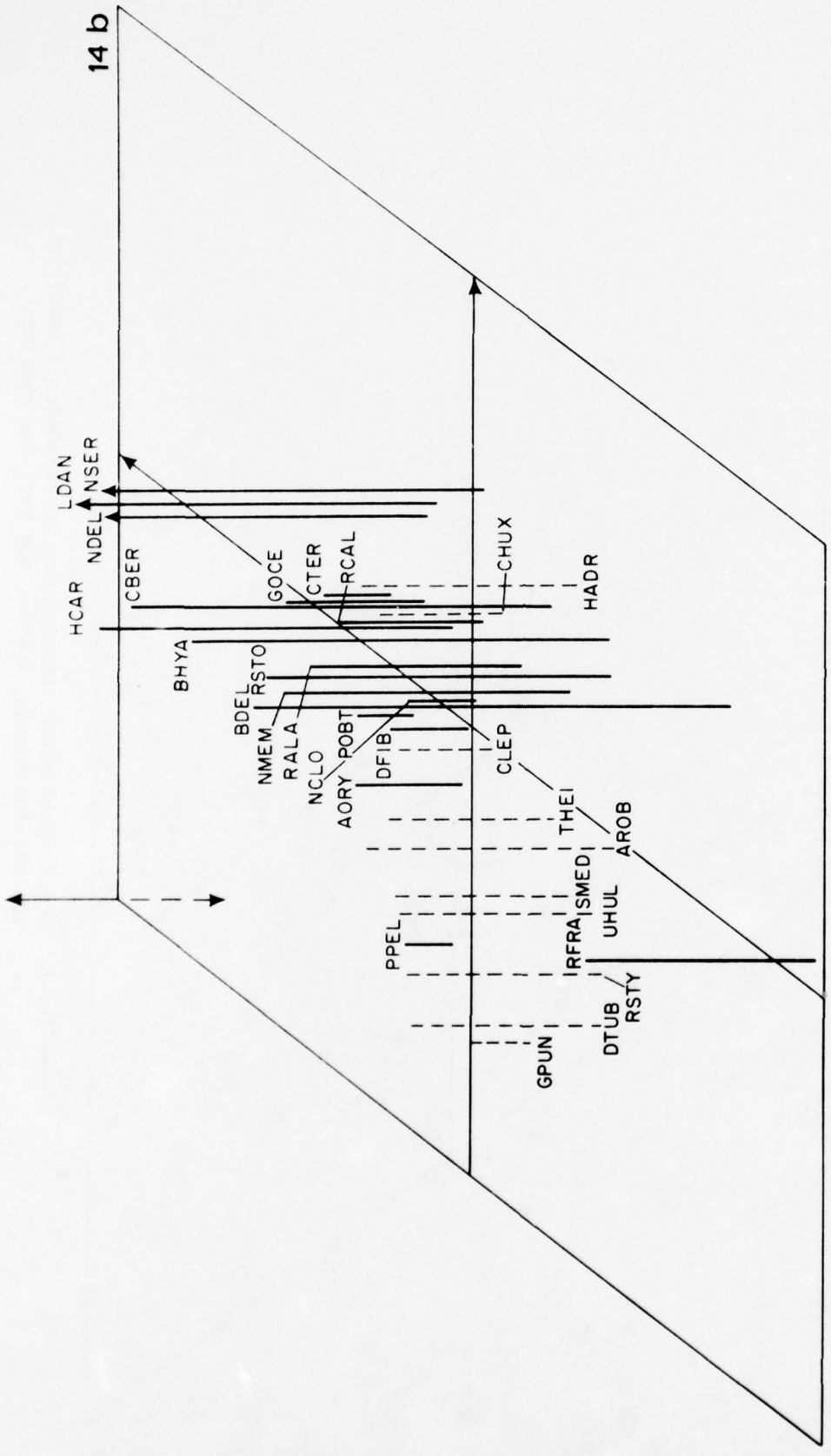

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LDAN
NSER
NDEL
HCAR
CBER
GOCE
CTER
RCAL
CHUX
HADR
BHYA
BDEL
RSTO
NMEM
RALA
NCLO
AORY
POBT
DFIB
CLEP
THEI
AROB
ISMED
UHUL
PPEL
IRFRA
DTUB
RSTY
GPUN

Figure 16b

BDEL, CBER, BHYA, RALA, NMEM, and RSTO; cluster six (DIAT3), perhaps merely the endpoint of a gradient from cluster five, located very much above the plane in the drawing, is composed predominately of diatoms and includes HCAR, NDEL, LDAN, and NSER. OVAR, KROT, OSPH, HMEM, PPEL, and RFRA remain unassigned. Separate CA of Fall-One, Spring, Summer, and Fall-Two cruises isolated much the same species groupings.

Species Group Environmental Correlations

Species groups have been defined by CA purely with respect to variability in the distribution of their constituent species. We now examine correlation coefficients to discover if species clusters isolated by CA differ in how their abundance is related to environmental properties. Table 14a lists correlations between unassigned non-zero species abundances, non-zero pooled abundance of the individual species in the species clusters, and a set of environmental properties. Table 14b lists correlations between the environmental parameters. The environmental properties entered include, in order: temperature at 300 m, sample temperature; salinity; nitrate; nitrite; nitrate plus nitrite; phosphate; silicate; the ratio of the sum of nitrate plus nitrite to phosphate; the ratio of the sum of nitrate plus nitrite to silicate; estimated macro-zooplankton biomass; and sample depth. Zooplankton biomass has been calculated from the data presented in Figures 1 and 2 (Chapter One). Those data are cc/1000 m^3 in 25 m intervals from 0-200 m. Appropriate point estimates have been calculated by averaging day and night observations and assuming a linear rate of change in macrozooplankton biomass between phytoplankton sampling depths. For example, a 25 m estimate is the average of 0-25 m and 25-50 m cc/1000 m^3. A 0 m estimate is the 0-25 m value times two

Table 14a

Species cluster-environmental parameter Kendall rank-order correlations (Tau)[a]

	OSPH	HMEM	RFRA	KROT	PPEL	OVAR	DIAT1	DIAT2	DIAT3	COCCO1	COCCO2	MIXED
T300	*	*	*	*	*	*	*	-.40	-.36	+.31	*	*
TEMP	*	*	*	+.36	*	*	*	*	*	+.30	*	-15[b]
SAL	*	*	*	*	*	*	-.38	-.33	-.29	+.18	*	*
NO_3	*	*	*	-.19[b]	*	*	*	*	+.22[b]	-.45	*	*
NO_2	*	*	*	*	+.39[b]	*	*	*	+.36	-.15	*	+.34
TOTN	*	*	*	-.20[b]	*	+.22	*	*	*	-.37	-.12[b]	*
PHOS	*	*	*	-.34	*	*	*	*	*	-.29	*	*
SIL	*	*	*	*	+.63	*	*	*	+.56	-.19	*	*
TOTN/PHOS	*	*	*	*	*	+.26[b]	*	*	*	-.25	*	*
TOTN/SIL	*	*	*	-.24[b]	*	+.24[b]	*	*	*	-.46	*	*
ZOOVOL	*	*	+.91[b]	+.27	*	+.27	+.70	+.53	+.49	*	*	+.31
DEPTH	*	+.65[b]	*	-.28	*	*	*	-.31	-.21	-.44	-.17	-.33

[a] Unless otherwise indicated $p<.05$, two-tailed.

[b] $p<.10$, two-tailed.

* $p\geq.10$, two-tailed.

Table 14b

Environmental parameter Kendall rank-order correlations (Tau)[a]

	T300	TEMP	SAL	NO3	NO2	TOTN	PHOS	SIL	TOTN/PHOS	TOTN/SIL	ZOOVOL	DEPTH
T300	1.00											
TEMP	+.44	1.00										
SAL	*	+.31	1.00									
NO_3	-.42	-.61	-.35	1.00								
NO_2	*	*	*	*	1.00							
TOTN	-.36	-.56	*	+.83	+.25	1.00						
PHOS	-.53	-.52	-.38	+.51	-.15	+.46	1.00					
SIL	-.21	-.33	-.20	+.43	*	+.41	+.41	1.00				
TOTN/PHOS	*	-.25	*	+.58	+.29	+.51	+.73	*	1.00			
TOTN/SIL	*	-.50	-.29	+.66	+.31	*	+.59	*	*	1.00		
ZOOVOL	-.21	*	*	+.20	*	*	*	*	-.40	*	1.00	
DEPTH	*	-.20	*	+.22	*	+.22	+.20	+.24	+.20	+.23	-.29	1.00

[a] Unless otherwise indicated $p < .05$, two-tailed.

[b] $p < .10$, two-tailed

* $p \geq .10$, two-tailed

minus the 25 m estimate obtained above.

Temperature at 300 m distinguishes Slope Water, ring and Northern Sargasso Sea sample sets. Because T300 is assigned to all samples in a hydrocast it clearly is inexpressive of the vertical variation in the data. We employ the Kendall rank-order correlation statistic (tau) because we feel that any relationships between species abundances and the parameters listed would probably be non-linear. We used only non-zero abundances because of the nature of the data. Examination of Appendix C reveals that a number of common species were absent at many of the stations often for an entire cruise. Yet the 41 species used in our analysis were the most abundant and widely distributed of the 135 species enumerated. The environmental properties observed typically over-lapped in range on the four cruises (Table 8). Therefore, all correlations reported are strictly of the form "when present the abundance of species A is (or is not) significantly correlated with variability in the property X". No two of the data sets employed in calculating individual correlation coefficients are precisely identical with respect to the number and distribution of missing values. This not only obfuscates rigorous interpretation, but also precludes stepwise-multiple regression analysis because true partial correlations cannot be computed.

Correlation analysis has not provided insight into those factors related to OSPH abundance (Table 14a). HMEM abundance was greater at depth than at the surface (note tau = + .65). KROT, OVAR, DIAT1, DIAT2, DIAT3, and MIXED are all significantly related to zooplankton biomass ($p < .05$).

RFRA abundance may be positively correlated with zooplankton biomass, but the relationship is less significant ($p < .1$). It is interesting that the correlations between species clusters and zooplankton biomass are stronger and more consistently significant than the correlations between zooplankton biomass and the other environmental parameters (Table 14b). This result perhaps reflects the fact that zooplankton biomass is more or less directly dependent upon phytoplankton abundance but only indirectly dependent upon, for example, nutrient concentration. Had we correlated, as did Reid (1962), nutrients at 100 m (or in fact euphotic zone nutrient load) with integral zooplankton biomass (say cc/m^2), it is probable a more consistent relationship would have emerged.

The remaining species and species clusters are more convincingly related to either physical or chemical environmental parameters. Excepting PPEL, DIAT1, and OVAR, all are negatively correlated with depth (Table 14a) as one would expect from the average vertical distributions of most of their constituent species. A likely explanation for this correlation is the decline with depth in light available for photosynthesis.

The species groups DIAT1, DIAT2, and DIAT3 may be distinguished from COCCO1, KROT, and COCCO2 principally by their negative correlations with temperature at 300 m and salinity (Table 14a). These parameters, year-round, define the difference between the Slope Water and Northern Sargasso Sea. Of the former groups, only DIAT3 responds in a definitive manner to an increase in available nutrients. DIAT3 is positively correlated with silicate (tau = +.56), nitrite (tau = +.36), and perhaps nitrate (tau = +.22 but $p < .1$). That these correlations are positive despite the negative correlation of this group with depth, reflects the fact that the

species in DIAT3 often have a subsurface maxima in abundance at depths where nutrient concentrations begin to increase.

In contrast, COCCO1 and KROT are either uncorrelated or positively correlated with sample temperature, salinity, and temperature at 300 m. Further, those correlations with nutrients which are significant are all negative (Table 14a). COCCO2 is not significantly correlated with any of the measured parameters although there is some indication that COCCO2 is negatively correlated with nitrate plus nitrite (tau = -.12, but $p < .1$). Since COCCO2, COCCO1, and KROT are all negatively correlated with depth, which is in turn, positively correlated with nutrient concentrations (Table 14b), it is difficult to interpret the significance of these negative nutrient correlations.

The MIXED group alone exhibits a negative correlation with sample temperature (tau = -.15) albeit a weak one (Table 14a). Yet there is no significant correlation between MIXED and any other nutrient than nitrite. We do not have a convincing explanation either for this correlation or for the nutrient correlations of PPEL (PPEL-SIL:tau = +.63; PPEL-NO2:tau = +.39). The most significant species group-nutrient ratio correlations obtained were for COCCO1 (COCCO1-TOTN/PHOS:tau = -.46). These correlations approximately equal or exceed the correlations of COCCO1 with phosphate (tau = -.29) or with silicate (tau = -.19). OVAR is also correlated with TOTN/PHOS and TOTN/SIL but less significantly so ($p < .1$) than COCCO1. These correlations may be fortuitous consequences of the more significant correlations OVAR-TOTN (tau = +.22) and COCCO1-TOTN (tau = -.37).

DISCUSSION

We have some fundamental reservations as to our counting, sampling, and carbon-conversion methods. We believe our basic counting and sampling procedure is less than fully adequate in that it encompasses less than the total phytoplankton community. For a more general discussion of these points see Guillard and Kilham (in press). First, the smallest cells enumerated were approximately 4-5 μ in diameter, although data in Chapter Three clearly demonstrate that in the western North Atlantic as much as 75% of measured chlorophyll *a* can pass a 3 μ Nucleopore filter. Second, results of experiments assessing the chlorophyll *a* contents of both pellet and supernatant prepared as per Hulburt and MacKenzie (1971), indicate that as much as 50% of measured chlorophyll *a* remains in suspension despite the centrifugation employed.[9] Third, 67 μ mesh Clarke-Bumpus net hauls taken on Summer and Fall-Two caught a number of relatively large spinous dinoflagellate species not present, or rarely present, in the sample counts analyzed herein.[10] Presumably any rare species would be inadequately sampled as a consequence of our fixed 200 ml sample size. Fourth, sampling at 25 ml intervals can be seriously misleading as to the actual vertical distributions of both plant biomass (Strickland, 1968) and individual species, even within a supposedly well-mixed upper water column (Ryther and Hulburt, 1960). Our phytoplankton C/l values are flawed by their dependence on the sample species counts. Beyond that, defining a "representative" species cell-volume and applying general rather than species-specific volume-to-carbon conversion equations may lead to systematic errors. Last, our data base would have been much

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[9] See Chapter Three.

[10] See Chapter Four.

more representative if we had sampled during mid-winter and had obtained additional Spring counts. This lack limits investigation of seasonal variations. The generality of some of the results of our analysis is without doubt contingent upon the essentially unknown distribution and magnitude of the possible sources of error discussed above. Despite these admitted failings we believe that the conclusions we draw from our data are, at least qualitatively, correct.

Species Group Types

Species clusters identified by CA are not strictly Northern Sargasso Sea, Slope Water, or ring types. They are rather more like Venrick's (1971) "recurrent groups" and like them exhibit imperfect "fidelity" to particular water types. Examination of the distribution of individual species across species groups to some degree documents known floral gradients. For example, coccolithophore species below and well to the left of the central axis in Figure 16, e.g., *U. irregularis* (UIRR), *R. hispida* (RHIS), *R. stylifer* (RSTY), and *S. mediterraneana* (SMED), have been considered to be "oceanic warm-water" forms. In contrast, *C. huxleyi* (CHUX) is located right of center and beneath the diatom clusters (see Figure 16). Hulburt and Corwin (1969) have observed that *C. huxleyi* generally occupies an intermediate position between "neritic diatoms" and "oceanic coccolithophores" in regard to its distribution. McIntyre and Bé (1967) stated that of all Atlantic coccolithophores, *C. huxleyi* occupies the greatest biogeographic range.

Environmental correlations of species clusters (Table 14a) generally accord with previous observations. Venrick's (1971) "recurrent groups",

like some of our species groups were positively correlated with zooplankton biomass. As noted above, Hulburt and Corwin (1969) divided the tropical Atlantic flora into a diatom group and coccolithophore group. They felt the former were responsive, and the latter unresponsive to increased nutrients. Further, *C. huxleyi* appeared to be intermediate in its response. Environmental correlations (Table 14a) imply a similar division of the Northwestern Atlantic flora.[11]

"Responsiveness" implies considerable variability in observed abundance since the nutrient concentrations observed varied over many orders of magnitude (see Table 8). Calculating coefficients of variation, i.e., $CV = s/\bar{x}$, where s = one standard of deviation and $\bar{x}$ = arithmetic mean (Sokal and Rohlf, 1969), for non-zero pooled species group abundances, produces some interesting results. For DIAT1, DIAT2, and DIAT3, CV equals 3.45, 1.73, and 3.73 respectively. For COCCO1, CV equals .93. COCCO2, whose dominant species is *C. huxleyi*, and MIXED are intermediate with CV equally 1.47 and 1.21 respectively. These results parallel correlation analysis in dividing species groups into those whose abundance is apparently responsive to, and unresponsive to, variation in nutrient concentration.

The Gulf Stream Ring as a Phytohydrographic Entity

We have tried to compare and contrast phytoplankton assemblages associated with different hydrographic regimes. With CA we have sought

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[11] Naturally this division applies only to the nutrients measured and these results could be vitiated if, for example, NH_3-species ecotype correlations were significant. Ammonia has been thought to be of particular significance in open-ocean oligotrophic situations (Eppley *et al.*, 1973).

to order samples without reference to any property of a sample except its species composition. We have discussed phytohydrography rather than phytogeography, believing with Thorrington-Smith (1971) that biogeography in the ocean "differs from biogeography on land in that not only do the organisms themselves have a variable spatial distribution but the water masses are not geographically stable." We have been able to document phytohydrographic distinctions both in time and in space. Spatially, we have highlighted Northern Sargasso Sea/ring/Slope Water contrasts in the relative importance of major taxonomic categories, in average population parameters like C/l, sp/l, cells/l, and E_c, and in species composition. Temporally, we have related the magnitude and vertical distribution of these same properties to the presence or absence of a seasonal thermocline.

On all cruises to date CA has distinguished ring and Northern Sargasso Sea sample sets. The degree of difference noted was variable and not clearly related to the age of the rings sampled. For example, Fall-One Northern Sargasso Sea and ring (3 months old) sample sets overlap while Spring Northern Sargasso Sea and ring (10-12 months old) sample sets do not overlap (Figures 9 and 10). There was less overlap between Northern Sargasso Sea and ring sample sets for Fall-Two than for Summer although the same ring was sampled first at six and then at nine months (Figures 11 and 12). Further, ring phytoplankton species composition on no occasion appeared intermediate between Northern Sargasso Sea and Slope Water species composition. In fact, Northern Sargasso Sea samples were generally more similar to Slope Water samples than were ring samples. This observation contrasts both with the physical and chemical evolutionary course of cold core

rings (Wiebe, 1976a) and with the intermediate species composition of cold core ring euphausid populations (Wiebe, 1976). Examination of Appendix C reveals that such species as the dinoflagellate, POBT, and the coccolithophores, HADR, DTUB, AROB, SPUL, UTEN, and UHUL had higher pooled station abundances at ring stations than at either Slope Water or Northern Sargasso Sea stations. In addition, as noted earlier, on three of four cruises diatoms were a conspicuously minor fraction of total ring sp/l, C/l, and cells/l while diatom contributions to both Slope Water and Northern Sargasso Sea phytoplankton were significant. On occasion a ring can be remarkably homogeneous in phytoplankton species composition (see Figures 9 and 13b). On some occasions lack of success of ring diatoms may be due to enhanced downward mixing in the ring core relative to the Northern Sargasso Sea. Such physical mechanisms have been postulated (Schmitz and Vastano, 1975) although their rate may be insufficient to effect phytoplankton distribution.

The physical and chemical properties of our ring samples (see Table 8) indicated that a ring is a hybrid intermediate environment. Nonetheless some aspect of ring environment or history apparently confers a relative advantage upon at least some phytoplankton species.[12] Jahn (1976) observed that certain mesopelagic fish can also be more abundant in a ring than in either the Northern Sargasso Sea or the Slope Water. Similar observations have been made of euphausid species (W. H. Wiebe, personal communitcation). Chapter One, documents the unique vertical distribution of zooplankton biomass in cold core rings. It is conceivable

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[12]We have not yet exhaustively sampled in the Gulf Stream itself. An unknown contribution to ring "uniqueness" may be admixture of a Gulf Stream flora. Marshall's (1971) data suggest the Gulf Stream flora may be distinguishable both from that of the Slope Water and the Northern Sargasso Sea.

that the relative abundance and scarcity of particular phytoplankton species in cold core rings is determined by a complex of factors including grazing pressure, animal excretion, nutrient flux due to physical mixing processes, and trace-metal availability. In Chapter Four, data are presented suggesting that cold core ring trophic interactions can be rather different than in the surrounding Northern Sargasso Sea.

Northern Sargasso Sea/Slope Water Floral Contrasts

We have discussed cold core Gulf Stream rings as discernable phytohydrographic inhomogeneities within the Northern Sargasso Sea. In many respects, ring/Northern Sargasso Sea contrasts are minor compared to Northern Sargasso Sea/Slope Water contrasts. Our results substantially corroborate the results of earlier investigations into Slope Water/Northern Sargasso Sea differences (Marshall, 1966, 1968, 1971; Hulburt and co-workers, 1960, 1963a, 1963b, 1964, 1966, 1967), although we differ in some small details, presumably due in part to differences in sampling distribution, sample volume, and counting method.

We find that in general the Northern Sargasso Sea has a coccolithophore-dominated flora while the Slope Water has a diatom-dominated flora. Both the Northern Sargasso Sea and the Slope Water exhibit seasonal (i.e., intercruise) variations both in species composition and in the magnitude and vertical distribution of average population properties like C/l, cells/l, sp/l, and E_c (Table 9). These appear to be related to the presence of a seasonal thermocline. For example, Northern Sargasso Sea samples obtained on the two cruises in which a seasonal thermocline was present - Summer and Fall-Two, are well separated from Northern Sargasso Sea samples obtained on the two cruises in which a seasonal thermocline

was not present - Spring and Fall-One (Figure 14). Under similar extremely stable conditions, the Northern Sargasso Sea has a more diverse and species-rich flora than that of the Slope Water (Table 9: Summer). Averaging all data for the upper euphotic zone, the Slope Water has higher cell densities, and a greater phytoplankton carbon concentration than the Northern Sargasso Sea; however, phytoplankton carbon in the latter region is partitioned amongst the phytoplankton species more equitably (Table 9).

Differences between the salinities of samples obtained on either side of the Gulf Stream (see Figure 4) probably contribute little to Northern Sargasso Sea/Slope Water floral differences. Differences in sample temperatures were considerably greater as were differences in average nutrient concentrations (see Figure 4 and Table 8). These factors doubtless contribute to Northern Sargasso Sea/Slope Water floral differences. As noted earlier, the vertical distributions and "average values" of sample temperature and nutrient concentrations are closely coupled with systematically different depths of the mixed layer in the two regions. Yet, in regard to both sample temperature and nutrient concentrations Northern Sargasso Sea and Slope Water sample sets typically overlap. Note that the deeper Northern Sargasso Sea Summer samples are positioned by CA considerably closer to the Slope Water sample set (see Figure 11) than are the shallower Northern Sargasso Sea Summer samples. This was also true of the ring Summer samples. In both cases differences between Northern Sargasso Sea and Slope Water nutrient concentrations and temperatures were reduced at depth. Nonetheless, the degree of Northern Sargasso Sea/Slope Water separation as reflected by CA does not

definitively relate to ambient nutrient concentrations in that the resolution of Northern Sargasso Sea and Slope Water sample sets was no better for Spring and Fall-Two samples than for Fall-One samples (Figures 9, 10, 12); although, Fall-One Northern Sargasso Sea: Slope Water nutrient contrasts were the least strong we observed (Table 8). On Fall-One, contrasts in chlorophyll concentration were also the least strong observed (Table 8). Ambient nutrient concentrations would not be expected to be as ecologically informative as would be the history of local nutrient concentrations over the preceding weeks.

Northern Sargasso Sea/Slope Water Herbivore Habitat Contrasts

The differences in Northern Sargasso Sea/Slope Water flora imply that the euphotic zones of the two regions constitute very different environments for herbivores. In the Northern Sargasso Sea a herbivore would have to feed primarily upon coccolithophores, while in the Slope Water a herbivore would have to feed primarily upon diatoms. As well as being qualitatively different, coccolithophore species have on the average a smaller cell volume than diatom species. In this context it is probably of no significance that one group is motile and the other non-motile. A herbivore would for much of the year encounter more species in filtering a liter of Northern Sargasso Sea water than in filtering a like volume of Slope Water. In addition, in the Northern Sargasso Sea total phytoplankton C/l is more evenly partitioned amongst the phytoplankton species. These two generalizations imply that a herbivore capable of selecting its food would find it less advantageous in respect to carbon content to concentrate its attention upon particular phytoplankton species in the Northern Sargasso Sea than in the Slope Water.

Due to the fact that the seasonal thermocline develops at a depth of approximately 50 m in the Slope Water and 75 m in the Northern Sargasso Sea, the former environment can be viewed as relatively compressed. With compression the concentration of particulate material, but not necessarily the total quantity, rises. Averages over all cruises cells/l and C/l in the upper euphotic zone of the Northern Sargasso Sea were 11,600 and 580, respectively; in the upper euphotic zone of the Slope Water cells/l and C/l were 20,600 and 4760, respectively (data in Table 9). Therefore, to obtain a similar food ration a Northern Sargasso Sea herbivore would, on the average, have to filter nearly ten times the volume of water and in so doing would process nearly five times the number of individual cells as would a Slope Water animal.[13]

In both the Northern Sargasso Sea and the Slope Water we have shown that occasionally, but not necessarily, maxima in the numbers/l of specific taxa, in total cells/l and in total C/l are found atop well-developed seasonal thermoclines. A consequence of compression is that such maxima can be dramatic features in the Slope Water (see Slope Water: Summer, Table 9), but are either absent or mild and confined to specific taxa in the Northern Sargasso Sea (see Northern Sargasso Sea: Summer, Tables 9 and 10). It is not unlikely, however, that our failure to observe Northern Sargasso Sea maxima represents a sampling problem in that such maxima are more consistently expressed in ring:Summer data (see Tables 9, 10, 11) in which higher cell densities probably resulted in more adequate sampling

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[13]A similar computation was made in Chapter One, but in that analysis the data from only one cruise were included.

Differences between the Northern Sargasso Sea and Slope Water as herbivore habitats is seasonally variable; minimal contrast occurs during Spring bloom conditions and contrast is maximal with the development of the seasonal thermocline. On the Spring cruise Northern Sargasso Sea/Slope Water differences in average upper water column properties were minor (see Table 9), although the rich crops observed in both regions were composed of very different species (see Tables 10-12 and Figure 9). Relative variability is a second fundamental feature distinguishing the Northern Sargasso Sea and the Slope Water as herbivore habitats. Although species groups discussed are not restricted to either the Slope Water or the Northern Sargasso Sea, DIAT1, DIAT2, DIAT3 are typically predominant in Slope Water, while COCCO1 and COCCO2 predominate in the Northern Sargasso Sea. As noted earlier, coefficients of variation calculated for the former groups were 3.45, 1.73, and 3.73 while for the latter set, .93 and 1.47. A similar computation in respect to chlorophyll concentration results in a Slope Water value of 1.14 and a Northern Sargasso Sea value of .80. Primary productivity data presented by Ryther (1963) further support this generalization. Productivity at his Northern Sargasso Sea station varied from a high of .89 $gC/m^2/day$ to a low of .1-.2 $gC/m^2/day$; productivity at his Slope Water station varied from a maximum observed value of 1.93 $gC/m^2/day$ to values below limits of sensitivity for the methods he employed. Slope Water animals, in contrast to Northern Sargasso Sea forms are required to be adapted to very much larger seasonal variations in food resources.

Species Group/Nutrient Ratio Correlations

A few recent papers discuss the relationship of nutrient ratios to species competition and species composition observed in the field. This work has largely been conducted either in lakes or in the laboratory, (Rhee, 1974; Kilham and Titman, 1976; Titman, 1976; Tilman, 1976). The applicability of such insights is an important ecological issue; particularly so, in that competition for nutrients may not be a principal factor regulating species population abundance in the open ocean (Hulburt, 1970; Pasciak and Gavis, 1974, 1975).

Our correlation analysis results relate to this equation. As noted earlier the most significant species group-nutrient ratio correlations we obtained were for COCCO1. To see if these had any particular ecological significance we computed Kendall rank-order correlation coefficients not only for the nutrient ratios, but also for the nutrient sums and products, as presented below:

COCCO1:TOTN	-.37	COCCO1:TOTN+PHOS	-.42
COCCO1:PHOS	-.29	COCCO1:TOTN+SIL	-.36
COCCO1:SIL	-.19	COCCO1:TOTNxPHOS	-.35
COCCO1:TOTN/PHOS	-.25	COCCO1:TOTNxSIL	-.44
COCCO1:TOTN/SIL	-.46		

COCCO1 and DIAT3 are well separated by CA and have very different environmental correlations (Figure 16 and Table 14a). We computed similar correlations for the ratio of their abundances - i.e., RATIO = COCCO1/DIAT3, are presented below:

RATIO:TOTN	-.35	RATIO:TOTN+PHOS	-.36
RATIO:PHOS	-.30	RATIO:TOTN+SIL	-.72
RATIO:SIL	-.46	RATIO:TOTNxPHOS	-.69
RATIO:TOTN/PHOS	-.26	RATIO:TOTNxSIL	not significant
RATIO:TOTN/SIL	not significant		

Correlations presented are significant at $p < .05$, two-tailed. In only one case is the correlation of a product, sum, or ratio very much less than the larger correlation of its two constituent terms. In many cases the correlation of the complex expression exceeds that of its constituents. That it does so probably expresses a degree of statistical independence between the distributions of the constituent variable distributions. Nutrient ratios are of no more demonstrable utility than nutrient sums or products in explaining observed variability in either the non-zero abundances of a well-defined oceanic species group, or the ratio of the non-zero abundances of two such groups with very different environmental preferences.

SUMMARY

1. Corroborating previous studies the Gulf Stream represented a major ecological discontinuity separating two distinct phytohydrographic provinces: the Slope Water and the Northern Sargasso Sea.

2. In the summer, above well-established seasonal thermoclines, floral contrasts between the Slope Water and the Northern Sargasso Sea were maximal. Under bloom conditions characterized by more active mixing floral contrasts were minimal.

3. Although the Northern Sargasso Sea has been thought to be a relatively monotonous biogeographic province, within its geographic boundaries Gulf Stream cold core rings constituted large-scale floral inhomogeneities.

4. Some species, including *Prorocentrum obtusidens*, *Anthosphaera robusta*, *Discosphaera tubifer*, *Syracosphaera pulchra*, and others, were more numerous in Gulf Stream cold core rings than in either the Slope Water or the Northern Sargasso Sea. In contrast, on some occasions diatoms were less numerous in Gulf Stream cold core rings than in either the Northern Sargasso Sea or the Slope Water. As a result on all occasions, the species composition of the Gulf Stream cold core rings observed was significantly different from that of both the Slope Water and the Northern Sargasso Sea.

5. No common species was found in only the Slope Water, the Northern Sargasso Sea, or Gulf Stream cold core rings, i.e., none exhibited high-fidelity to a hydrographic regime.

6. The various species and species clusters sorted by correspondance analysis from the set of common species differed in their apparent responsiveness to nutrient concentration variation.

7. Due to systematic differences in the composition, quantity, distribution, and variability of their phytoplankton communities, the upper euphotic zones of the Slope Water and the Northern Sargasso Sea represent very different herbivore habitats.

CHAPTER THREE. AN ACCOUNT OF THE DEEP CHLOROPHYLL MAXIMUM - DCM

INTRODUCTION

In many oceanic environments accumulations of chlorophyll have been reported to occur at or below depths to which 1 percent of ambient light penetrates (Riley *et al.*, 1949; Steele, 1964; Yentsch, 1965; Anderson, 1969). This phenomenon has been called the Deep Chlorophyll Maximum - DCM (Venrick *et al.*, 1973). It is likely that a DCM will develop whenever the surface layers of the ocean are reasonably well-stratified for an extended period. Reports of a DCM in the western North Atlantic were among the earliest in the literature (Riley *et al.*, 1949). More recently the Pacific Ocean has been the focus of investigation into the DCM. Enhanced ATP concentration, ^{14}C productivity, oxygen concentration, and phytoplankton cell counts have been documented (Anderson, 1972; Saijo, 1973; Venrick *et al.*, 1973; Eppley *et al.*, 1973; Takahashi *et al.*, 1974; Gunderson *et al.*, 1976). They have rarely, however, been measured concommitantly. At other times, investigations have observed zooplankton concentrations associated with a DCM (Anderson *et al.*, 1972; Hobson and Lorenzen, 1972; Mullin and Brooks, 1972; and others). In no case were detailed vertically stratified macrozooplankton and microzooplankton samples both obtained on the same occasion. Models that account for observed variable distributions have been offered by Riley *et al.* (1949); Steele and Yentsch (1960); Kiefer *et al.* (1976) and Jamart *et al.* (1977).

The study described here and in Chapter Four was designed to investigate the trophodynamic significance of the DCM - i.e., to discuss if the DCM is a food resource being preferentially exploited by zooplankton. The western North Atlantic is a suitable study area because the Gulf Stream is one of the sharpest hydrographic and ecological discontinuities anywhere in the open ocean (Worthington, 1976; Chapter Two; Grice and Hart, 1962). As a consequence within only a few days a DCM may be conveniently studied in very different, but contiguous, oceanic environments: the Slope Water, the Northern Sargasso Sea, and Gulf Stream cold core rings. The latter are biologically, physically, and chemically quite distinct from the surrounding Northern Sargasso Sea (Wiebe *et al.*, 1976a; Wiebe, 1976; Chapter One and Chapter Two). To assess the trophodynamic significance of the DCM the various physical, biological, and chemical factors that had been individually correlated with the occurrence of a DCM were measured in a manner as synoptic as possible, both when a DCM was present and when it was not present in the Slope Water, the Northern Sargasso Sea and Gulf Stream cold core rings.

Included in this chapter are analyses of 0-200 m profiles of chlorophyll, oxygen, ATP, ^{14}C fixation, particulate nitrogen, and plant nutrients. From the distribution of these properties the standing stock and to some degree the production of primary particulate material can be estimated. If these profiles have consistent relationships to the temperature and density structure they define a predictable feeding environment. The following chapter analyzes 0-200 m distributions of zooplankton taxa and biomass to see if these have predictable relationships to the same physical features. Although on any one cruise hydrographic and zooplankton stations were taken as close together as possible, the two sets of

data were not in fact simultaneously collected. Therefore, the attempt is made to interpret all data in light of the best estimate of the hydrography at the time of sampling.

METHODS

The data presented in this paper were collected on seven cruises in the western North Atlantic: R/V KNORR cruise 38 (March 1974; R/V ATLANTIS II cruise 84 (August 1974); R/V ATLANTIS II cruise 85 (September 1974); R/V KNORR cruise 47 (February 1975); R/V CHAIN cruise 125 (August 1975); R/V KNORR cruise 53 (November 1975); and R/V KNORR cruise 58 (August 1976). With the exception of KNORR 47, ATLANTIS II 85, and KNORR 58, hydrostations were made in the Slope Water, the Sargasso Sea, and Gulf Stream cold core rings. Prior to ATLANTIS II 85 the ring previously sampled on ATLANTIS II 84 had coalesced with the Gulf Stream and had become, by the time of sampling, a Gulf Stream meander. On KNORR 47 and KNORR 58 no attempt was made to sample a ring. Station positions are illustrated in Figure 17.

At most stations five-liter Niskin bottles equipped with reversing thermometers were placed on the hydrowire every 25 m from the surface to 200 m. Additional bottles were frequently added near the depth at which a chlorophyll maximum might be anticipated. Measurements made included: temperature; salinity; nutrients (NO_2, NO_3[14], PO_4, NH_3); oxygen; chlorophyll *a*; phaeopigments; ATP; and particulate nitrogen. On KNORR 38, CHAIN 125, and KNORR 53 phytoplankton species counts were made. These data are discussed in Chapter Two. On the same cruises, KNORR 47 and ATLANTIS II 84, zooplankton collections were made. These data are discussed

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[14] On early cruises NO_3 and NO_2 were not analytically separated and combined NO_3 and NO_2 µmol/l are given.

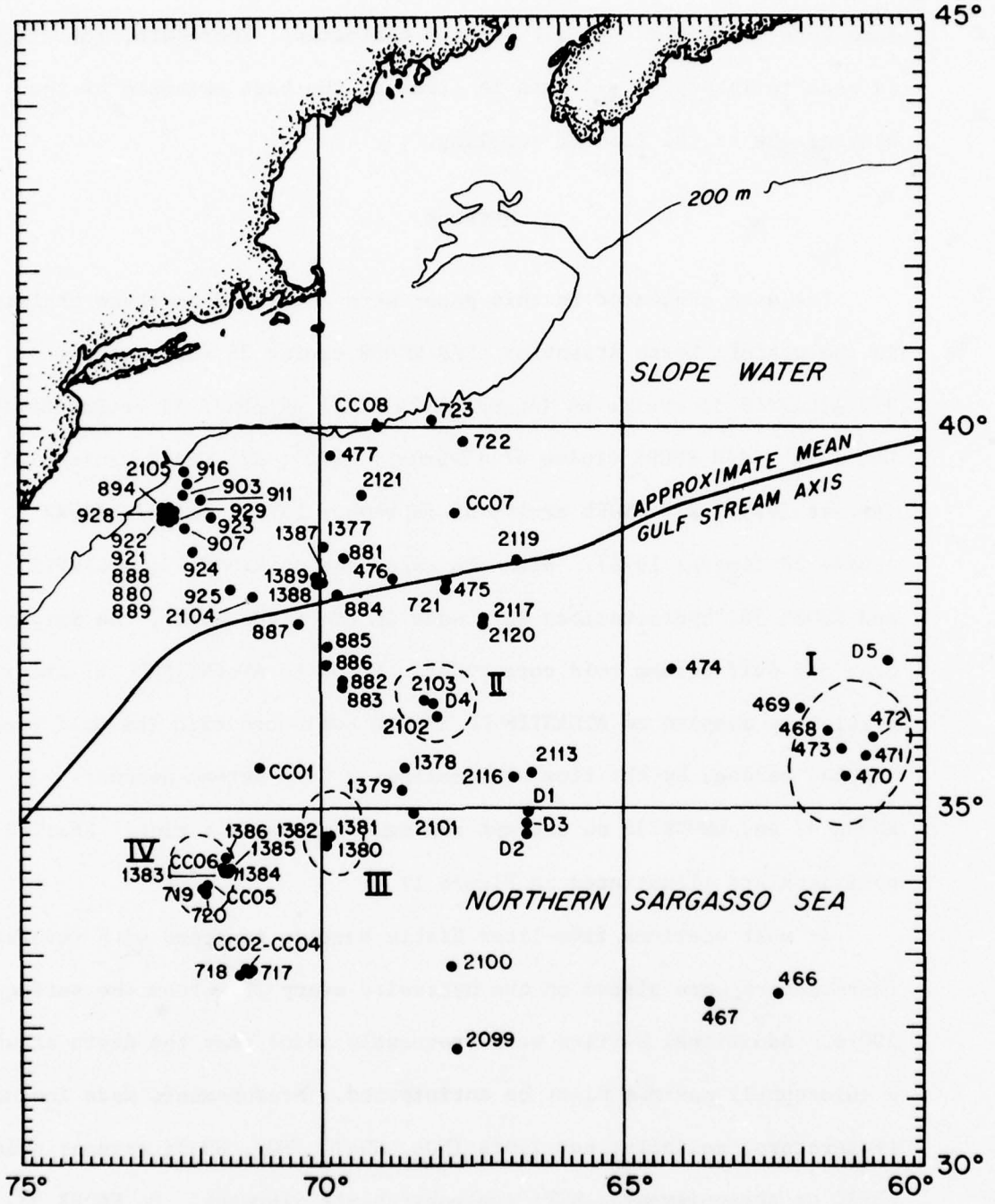


Figure 17. Positions of hydrostations taken on R/V KNORR cruise 38, R/V ATLANTIS II cruise 84, R/V ATLANTIS II cruise 85, R/V KNORR cruise 47, R/V CHAIN cruise 125, R/V KNORR cruise 53, R/V KNORR cruise 58. I, II, III, IV indicate approximate Gulf Stream cold core ring positions on R/V KNORR cruise 38, R/V ATLANTIS II cruise 84, R/V CHAIN cruise 125, and R/V KNORR cruise 53, respectively. Stations 2095, 2096, 2097, 2098 were too far south, and Station 465 too far east, to be included on this chart. Their positions are given in Table 15.

in Chapters One and Four. On KNORR 38, CHAIN 125, KNORR 53, and KNORR 58 a second hydrocast at each station yielded samples used to determine ^{14}C fixation. Not all measurements were made at every station[15]. A list of all stations made, the depths sampled, their positions, and the parameters measured is given in Table 15. On all cruises except ATLANTIS II 84 and KNORR 47 an expendable bathythermograph (XBT) survey was conducted to define the hydrographic characteristics of the regions sampled. On the three most recent cruises CTD profiles were also obtained.

Nutrient and oxygen methods are given in Wiebe *et al.* (1976a). Oxygen saturation values were determined from the temperature and salinity data according to the International Oceanographic tables, Volume Two, Oxygen Solubility in Seawaters. No prefiltration of nutrient samples was performed; this omission could, conceivably, bias some Slope Water samples. Although NH_3 was measured on most cruises, only values from the last leg on KNORR 58 are considered reliable. On that leg all nutrient concentrations, including NH_3,were determined at sea immediately after sample collection. Particulate nitrogen was measured with a Perkin-Elmer elemental analyzer upon a 500-1000 ml sample filtered upon a pre-combusted glass-fiber filter (Gelman A/E).

^{14}C fixation procedures followed on KNORR 38 are given in Wiebe *et al.* (1976a). On CHAIN 125, KNORR 53, and KNORR 59 a different procedure was adopted. Water samples were collected prior to dawn at depths corresponding to 100%, 60%, 30%, 10%, 2%, and .6% of ambient light. Depths were estimated by a Secchi disc measurement the preceding afternoon. On a few occasions the Secchi disc method was checked

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[15] This was a result of the fact that the primary objectives of the various chief scientists on different cruises were often very different.

Table 15 Summary of Hydrographic Stations

Cruise	Station Numbers	Date	Position[a]	Depths Sampled (m)[b]	TEMP[c]	SAL	O_2	ATP	CHLOR	NUTS	^{14}C	PN[d]
KNORR 38	465	3/17/74	32°24',59°57'	STD	X	X	X	*	*	X	*	*
	466	3/21/74	32°24',62°24'	STD	X	X	X	*	*	X	*	*
	467	3/22/74	32°20',63°32'	STD	X	X	X	*	*	X	*	*
	468	3/25/74	36°03',61°42'	STD	X	X	X	*	X	X	*	*
	469	3/26/74	36°24',62°04'	STD	X	X	X	*	X	X	X	*
	470	3/26/74	35°27',61°19'	STD	X	X	X	*	X	X	*	*
	471	3/27/74	35°42',61°00'	STD	X	X	X	*	X	X	X	*
	472	3/28/74	35°59',60°52'	STD	X	X	X	*	X	X	*	*
	473	3/29/74	35°51',61°23'	STD	X	X	X	*	X	*	X	*
	474	3/30/74	36°52',64°35'	STD	X	X	X	*	X	X	X	*
	475	4/2/74	38°07',67°52'	STD	X	X	X	*	X	*	X	*
	476	4/3/74	38°04',68°48'	STD	X	X	X	*	X	X	X	*
	477	4/3/74	39°37',69°50'	STD	X	X	X	*	X	X	*	*
ATLANTIS II 84	2095	8/12/74	20°38',67°46'	115,140	X	X	*	*	X	X	*	*
	2096	8/13/74	23°08',67°42'	115,140	X	X	*	*	X	X	*	*
	2097	8/14/74	25°47',67°47'	115,140	X	X	*	*	X	X	*	*
	2098	8/15/74	28°31',67°38'	115,140	X	X	*	*	X	X	*	*
	2099	8/16/74	31°40',67°43'	115,140	X	X	*	*	X	X	*	*
	2100	8/17/74	32°48',67°48'	115,140	X	X	*	*	X	X	*	*
	2101	8/18/74	34°56',68°25'	115,140	X	X	*	*	X	X	*	*
	2102	8/19/74	36°17',68°01'	115,140	X	X	*	*	X	X	*	*
	2103	8/19/74	36°28',68°14'	115,140	X	X	*	*	X	X	*	*
	2104	8/20/74	37°51',71°03'	STD	X	X	*	*	X	X	*	*
	2105	8/21/74	39°26',72°11'	STD to only 125m	X	X	*	*	X	X	*	*
ATLANTIS II 85	2113	10/13/74	35°28',66°31'	112,140	X	X	X	*	X	X	*	*
	2116	10/16/74	35°24',66°46'	112,140	X	X	X	*	X	X	*	*
	2117	10/17/74	37°32',67°13'	112,140	X	X	X	*	X	X	*	*
	2119	10/18/74	38°19',66°46'	88,112,140	X	X	X	*	*	*	*	*
	2120	10/20/74	37°29',67°18'	88,112,140	X	X	X	*	X	X	*	*
	2121	10/21/74	39°05',69°19'	STD	X	X	X	*	X	X	*	*

Table 15 continued

Cruise	Station Numbers	Date	Position[a]	Depths Sampled (m)[b]	TEMP[c]	SAL	O_2	ATP	CHLOR	NUTS	^{14}C	PN[d]
KNORR 47	D1	2/24/75	34°56',66°30'	STD	X	*	*	*	X	X	*	*
	D2	2/25/75	34°38',66°35'	STD	X	*	*	*	X	X	*	*
	D3	2/27/75	34°46',66°34'	STD	X	*	*	*	X	X	*	*
	D4	2/28/75	36°23',68°06'	STD	X	*	*	*	X	X	*	*
	D5	2/28/75	36°58',68°34'	STD	X	*	*	*	X	X	*	*
CHAIN 125	1377	8/1/75	38°29',69°59'	112,137	X	X	X	*	X	X	X	*
	1378	8/5/75	35°34',68°35'	112,137	X	X	X	X	X	X	X	*
	1379	8/6/75	35°17',68°35'	112,137	X	X	X	*	X	X	X	*
	1380	8/8/75	34°32',69°55'	112,137	X	X	X	X	X	X	X	*
	1381	8/9/75	34°33',69°55'	112,137	X	X	X	*	X	X	X	*
	1382	8/10/75	34°33',69°55'	75-125 (every 5 m)	X	X	X	X	X	X	X	*
	1383	8/11/75	34°10',71°40'	112,140	X	X	X	X	X	X	X	*
	1384	8/12/75	34°09',71°39'	112,140	X	X	X	X	X	X	X	*
	1385	8/13/75	34°10',71°39'	50-125 (every 5 m)	X	X	X	*	X	X	X	*
	1386	8/13/75	34°18',71°32'	50-125 (every 5 m)	X	X	*	*	X	X	*	*
	1387	8/14/75	38°03',70°00'	112,140	X	X	X	X	X	X	*	*
	1388	8/15/75	38°02',70°02'	112,140	X	X	X	*	X	X	X	*
	1389	8/16/75	38°04',70°03'	25-75 (every 5 m)	X	X	X	*	X	X	*	X
KNORR 53	717	11/17/75	32°44',71°10'	STD	X	*	X	X	X	X	X	*
	718	11/18/75	32°43',71°09'	STD	X	X	X	*	X	X	X	*
	719	11/21/75	33°55',71°54'	STD	X	X	X	*	X	X	X	*
	720	11/22/75	33°50',71°50'	STD	X	X	*	*	X	X	X	*
	721	11/27/75	38°57',67°50'	STD	X	X	X	*	X	X	X	*
	722	11/29/75	39°46',67°37'	STD	X	X	X	X	X	X	X	*
	723	11/30/75	40°06',68°07'	STD	X	X	X	*	X	X	X	*
	CC01	11/16/76	35°32',70°57'	STD	*	*	X	*	X	*	*	*
	CC02	11/17/76	32°44',71°10'	STD	X	*	X	X	X	*	*	*
	CC04	11/19/76	32°45',71°09'	50-125 (every 5 m)	X	*	*	X	X	*	*	*
	CC05	11/23/76	33°57',71°53'	50-125 (every 5 m)	X	*	*	X	X	X	X	*
	CC06	11/24/76	34°10',71°34'	50-125 (every 5 m)	X	*	*	*	X	X	X	*

Table 15 continued

Cruise	Station Numbers	Date	Position[a]	Depths Sampled (m)[b]	TEMP[c]	SAL	O_2	ATP	CHLOR	NUTS	^{14}C	PN[d]
KNORR 53	CC07	11/28/76	38°55',67°45'	50-100 (every 5 m)	X	*	*	X	X	X	X	*
	CC08	12/1/76	40°00',69°00'	STD	*	*	X	*	X	X	*	*
KNORR 58	880	8/2/76	38°56',72°25'	40-60 (every 5 m)	X	X	X	*	X	X	X	X
	881	8/4/76	38°19',69°35'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	882	8/5/76	36°41',69°36'	65-85 (every 5 m)	X	X	X	X	X	X	X	X
	883	8/6/76	36°40',69°35'	65-85 (every 5 m)	X	X	X	X	X	X	X	X
	884	8/7/76	37°51',69°41'	65-85 (every 5 m)	X	X	X	X	X	X	X	X
	885	8/8/76	37°12',69°52'	65-85 (every 5 m)	X	X	X	X	X	X	X	X
	886	8/8/76	36°59',69°53'	65-85 (every 5 m)	X	X	X	X	X	X	*	X
	887	8/8/76	37°27',70°20'	65-85 (every 5 m)	X	X	X	X	X	X	*	X
	888	8/11/76	38°56',72°27'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	889	8/12/76	38°57',72°23'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	894	8/20/76	39°01',72°30'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	903	8/22/76	39°06',72°15'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	907	8/23/76	38°45',72°11'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	911	8/24/76	39°05',71°56'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	916	8/25/76	39°21',72°10'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	921	8/29/76	38°57',72°24'	40-60 (every 5 m)	X	X	X	X	X	X	X	X

Table 15 continued

Cruise	Station Numbers	Date	Position[a]	Depths Sampled (m)[b]	TEMP[c]	SAL	O_2	ATP	CHLOR	NUTS	^{14}C	PN[d]
KNORR 58	922	8/30/76	38°56',72°25'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	923	8/31/76	38°49',71°46'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	924	9/1/76	38°24',72°02'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	925	9/2/76	37°58',71°26'	40-60 (every 5 m)	X	X	X	X	X	X	*	X
	928	9/5/76	38°57',72°24'	40-60 (every 5 m)	X	X	X	X	X	X	X	X
	929	9/5/76	38°51',72°21'	40-60 (every 5 m)	X	X	X	X	X	X	X	X

[a] All positions north latitude and west longitude.

[b] Only depths other than standard depths noted. STD (standard) = 0-20 m, 25 m intervals only.

[c] On this and all other measured parameters listed above; X = measurement made and * = no measurement made.

[d] PN = particulate nitrogen.

against an *in situ* light meter and found to be reasonably accurate (3x Secchi disc depth = ± 5-10 m, 1% light level). Samples were prefiltered through 10 μm Nitex nylon gauze and transferred to acid-washed 125 ml glass-stoppered reagent bottles. Two light bottles, one dark bottle, and one time-zero bottle were inoculated by Eppendorf pipette with 1 ml of an HA Millipore-filtered seawater dilution of concentrated ^{14}C sodium bicarbonate stock solution. Considerations of ship time and sea state made regular *in situ* ^{14}C incubations impossible. The following simulation procedure was adopted. Experimental bottles were incubated from dawn until sunset in a seawater cooled incubator that approximates open ocean *in situ* light quality and quantity with $CuSO_4$ solution and gray neutral density screenings. Further, it was not possible to keep each sample at the temperature from which it was obtained which almost certainly biases the results obtained. Time-zero bottles were filtered within minutes of inoculation (Gelman A/E) and the filters placed into scintillation vials containing 15 ml Aquasol (New England Nuclear). Experimental bottles were treated similarly after incubation was complete.

The activity of the ^{14}C inoculation was empirically determined by adding 0.1 ml of the diluted stock solution to a scintillation vial containing 13 ml Aquasol and 2 ml phenethylamine (New England Nuclear). After correction for quenching, carbon fixation (mg C/l/day) = [(cpm of experimental bottle - cpm time-zero bottle)/cpm 1 ml inoculation] x 24.5 mg C/l - i.e., 90 mg dissolved CO_2/l.[16] The last value, given by Saijo

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[16] Essentially the same experimental technique could be used in estuaries or near-shore environments but there dissolved CO_2 would have to be directly measured since even alkalinity would not reliably determine ΣCO_2.

and Ichimura (1961) approximately corresponds with Geosecs measurements of euphotic zone ΣCO_2/l in the North Atlantic[17].

ATP was determined by the luciferin-luciferase method essentially as described in Strickland and Parsons (1972). One liter of sample was filtered immediately after collection, extracted by boiling for five minutes in a scintillation vial containing about 6 ml Tris buffer, and then frozen. Within a few weeks following a cruise the sample volume remaining in each vial was measured and ATP concentration determined by adding .3 ml enzyme (Sigma) to .2 ml sample and measuring the light emitted with a Lab-line integrating photometer.

On cruises prior to and including KNORR 47 chlorophyll a and phaeopigments were measured by the fluorometric method initially described by Yentsch and Menzel (1963) using a Turner Associates model 110 fluorometer[18]. On later cruises the following modified procedure was adopted. A Turner Designs fluorometer was used to measure fluorescence before and after acidification by addition of a few drops of .1 N HCl. Samples were filtered (Gelman A/E), pulverized, and extracted in glass-distilled acetone (90%). Fluorescence was calibrated both against pure chlorophyll a (Sigma) and against a mixture of coccolithophore, dinoflagellate, and diatom cultures. Absorbance of both the weighed

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[17] For example, values given in Geosecs Preliminary Data Reports, Leg II for stations 18, 19, 23 range from 2.047-2.121 ΣCO_2 mmol/kg or 25.1-26 mg C/l. In Slope Water lowered salinities and temperature are often encountered, but biological effects can be predominant and it did not seem appropriate to apply the equilibrium tables given in Strickland and Parsons (1972).

[18] In calculating phaeopigments from early cruise data an acid ratio tau of 2.2 and a 0.0 (90% acetone) blank had to be assumed. Consider the equation: phaeopigments = $F\ (\frac{\gamma}{\gamma-1})(\pi R_A - R_B)$ (extract volume/sample volume), given in Strickland and Parsons (1972). If γ was in fact less than 2.2, apparent phaeopigment concentrations would be found where none were present and maxima would be amplified. A non-zero blank would simply give the former error. In either case, the shape of the depth profile would be unaltered and depths of maximal concentration would remain the same.

chlorophyll *a* standard[19] and the cultures was measured on a Cary 17 recording spectrophotometer. Concentrations in the latter were determined according to the equations of Jeffrey and Humphrey (1975). On all KNORR 47 and some CHAIN 125 and KNORR 53 stations, replicate additional chlorophyll samples were gravity prefiltered through 35 μm and 10 μm Nitex gauze. Throughout KNORR 58 replicate additional chlorophyll samples were prefiltered through 3 μm Nuclepore filters under low (< 0.25 atm) vacuum.

The parameter defining the DCM is chlorophyll concentration. It is important to compare chlorophyll profiles obtained with the cell count data in Chapter Two. To investigate possible systematic errors that could bias interpretation of the above relationship the following experiment was conducted to evaluate the counting method. Cell counts in Chapter Two were made following the concentration procedure of Hulburt and MacKenzie (1970). Their method involves sequential centrifugation and pooling of the concentrates remaining at the bottom of 15 ml centrifuge tubes after the supernatant has been discarded. In the counts earlier described the method was applied to both freshly collected and preserved (2.5% formalin) samples. No substantial difference was found between the two sets of samples (E. Hulburt, personal communication). To test the efficiency of this concentration procedure, the chlorophyll contents of the eventual concentrate and the pooled discarded supernatant were measured on a number of occasions during CHAIN 125. Let efficiency of concentration = (P / P + S) x 100 - where P = the chlorophyll content of the "concentrate" and S = the chlorophyll content of the discarded supernatant. No significant difference was found between Northern Sargasso Sea and Ring D samples. Their pooled mean efficiency equalled

[19] Purported 1 mg chlorophyll *a* standards (Sigma) in fact contained from 1.05-1.45 mg chlorophyll *a*.

20 ± 12 (95% confidence limits). Slope Water sample mean efficiency equalled 46 ± 11 (95% confidence limits). The concentration method employed was more effective in the Slope Water than in either the Northern Sargasso Sea or Ring D. Additional data that bears on the reasons for this systematic bias will be presented in the following section.

THE DCM AND RELATED PHYSICAL-CHEMICAL PROPERTIES

Far too many data points were obtained to present all the individual temperature, salinity, chlorophyll, oxygen, particulate nitrogen, ATP, and nutrient profiles (see Table 15). Individual station profiles will, therefore, be combined into average profiles in an attempt to minimize variability within each set. The criteria for combining station profiles were as follows: a) all stations were sorted according to the cruise on which they were obtained, and b) stations within a cruise were sorted into hydrographic types based upon the similarity of their temperature regimes. The major criteria were the depth of the mixed layer and the depth of the shallow thermocline. The only geographic regions subdivided by this procedure were landward of the Gulf Stream. Of those, Shelf stations had reduced salinities, 34-35‰, from 0-200 m while Shelf/Slope stations had very prominent temperature inversions characterized by reduced salinities within the upper 100 meters.

Station values were averaged within a set for each measured property over as small a depth interval as the field sampling permitted (refer to Table 15). The average values so derived were connected by straight lines to produce 0-200 m average profiles. Note that with such averaging, the distinct peaks and valleys often characteristic of individual station profiles will usually be smoothed since vertical concordance of the same

property at the different stations within a set will rarely be perfect. A few individual profiles more precisely depicting suspected relationships will as well be eventually presented.

Late Winter and Early Spring:

Data from KNORR 47 (February 1975) and KNORR 38 (March 1974) illustrate characteristics of well-mixed upper water columns (see Figure 18 top and Figure 19) which had been unstratified for at least four months. In the Northern Sargasso Sea on both cruises the water columns from 0-200 m were nearly isothermal (Δ T < 1°). On the March cruise (KNORR 38) salinity was measured and a moderately deep (75-100 m) isopycnal mixed layer lay above a very weak pycnocline (Δ $\sigma t/Z$ <.008, 75-200 m, where Z equals defined depth interval in meters).[20] On the same cruise the ring fringe stations and ring center stations were similarly isothermal in the upper 200 m and the pycnocline was even weaker (Δ $\sigma t/Z$ < .0005, 0-200 m). In the remaining hydrographic sets on both cruises relatively isothermal conditions (Δ t < 2°) extended only to about 50 m below which weak pycnoclines were generally noted (average Δ $\sigma t/Z$ < .005, 50-200 m).

Chlorophyll profiles in all hydrographic regimes declined from the surface downwards. Only in the Slope Water (March 1974) were the highest chlorophyll concentrations at depth and at that station 50-100 m were more stratified (Δ $\sigma t/Z$ = .02). The subsurface chlorophyll maximum was at the top of this stratified zone. Significantly at this same station a distinct nutricline was observed. Below the depth of maximal chlorophyll concentration combined nitrite and nitrate concentration sharply increased. This suggests prior biological utilization of nutrients.

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[20] On an earlier leg of KNORR 47 salinity determinations were made and under a temperature regime similar to that observed on the latter leg of KNORR 47, a moderately deep isopycnal layer was underlain by weak stratification as on KNORR 38 (R. Gagosian, personal communication).

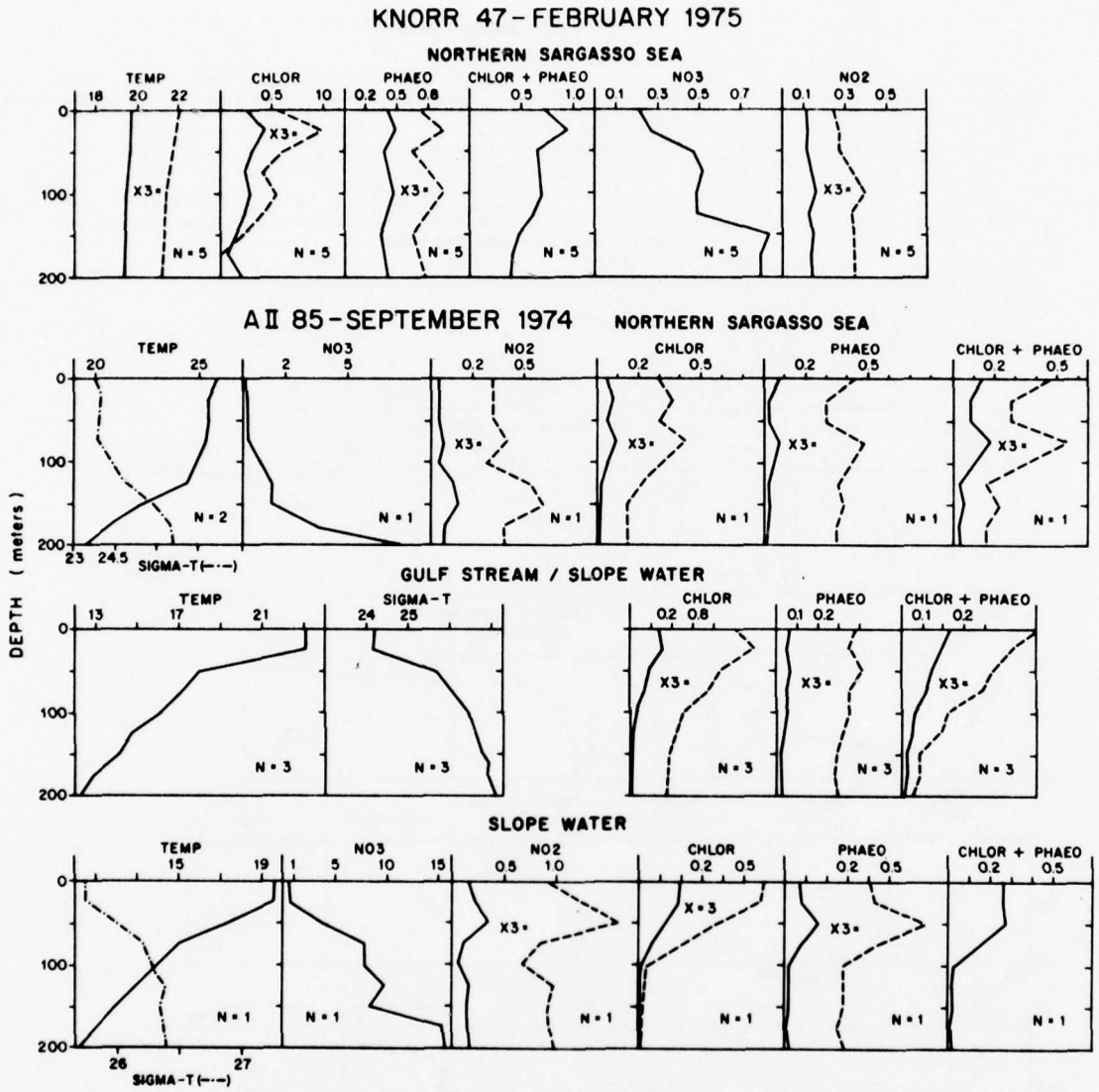


Figure 18. 0-200 m average vertical profiles of temperature (°C), σ_t, chlorophyll (µg/l), phaeopigments (µg/l), nitrate (µ mol/l), and nitrite (µ mol/l). R/V KNORR cruise 47 - February 1975 and R/V ATLANTIS II cruise 85 - September 1974. N equals the number of stations used in calculating average profile. In dashed lines adjacent to a multiplying factor (e.g., - x3), the value of every point is multiplied by the given factor and the position of the line on the horizontal axis is completely arbitrary.

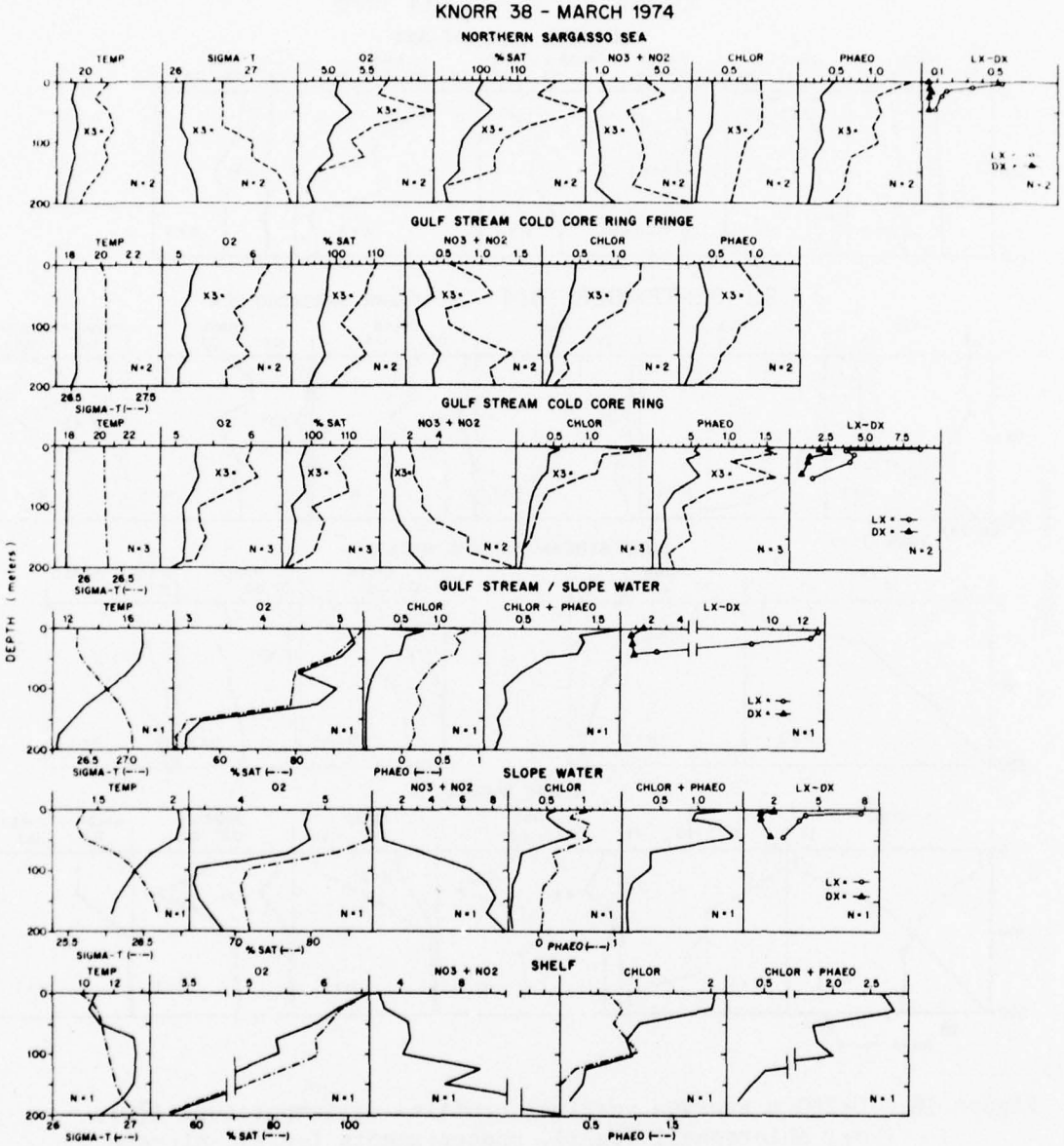


Figure 19. 0-200 m average vertical profiles of temperature (°C), σ_t, dissolved oxygen (ml/l), percent saturation of oxygen (%), nitrate plus nitrite (µmol/l), chlorophyll (µg/l), phaeopigments (µg/l), light fixation of ^{14}C (µg C/l over a dawn to dusk incubation) and dark fixation of ^{14}C (µg C/l over a dawn to dusk incubation). R/V KNORR cruise 38 - March 1974. N equals the number of stations used in calculating the average profile. In dashed lines adjacent to a multiplying factor (e.g., - x3), the value of every point is multiplied by the given factor and the position of the line on the horizontal axis is completely arbitrary.

Where measurements were obtained on KNORR 38 ^{14}C light fixation was highest in the near surface samples and generally declined with depth. It exceeded ^{14}C dark fixation in all samples. Oxygen concentration and supersaturation were generally highest at the surface and declined with depth. Overall the late winter-early spring stations indicated active plant growth (particularly near the surface) and no well developed deep chlorophyll maxima.

Summer:

Data from ATLANTIS II 84 (August 1974), CHAIN 125 (August 1975) and KNORR 58 (August 1976) illustrate characteristics of upper water columns (Figures 20, 21, and 22, respectively) that had been well stratified for several months.

In August 1974 stations were taken in the Southern Sargasso Sea. At those stations stratification began at a depth $\leq$ 25 m and extended to at least 200 m ($\Delta \sigma t/Z = .02$). Temperature profiles in the Northern Sargasso Sea were similar but stratification began at the surface and extended only to about 125 m below which the slope diminished ($\Delta \sigma t/Z$ = .02, 0-125 m). Within a cold core ring the surface to at least 50 m was relatively isothermal ($\Delta T = 1°$) but the gradients in the temperature and density from 50-150 m were steeper than at the Sargasso stations (e.g., $\Delta \sigma t/Z = .03$, 50-100 m) below which their slope diminished. The thermocline and pycnocline were even shoaler and steeper at the shelf/Slope Water stations (i.e., $\Delta \sigma t/Z = .05$, 25-75 m) which had as well a prominant temperature inversion.

In the Southern Sargasso Sea the DCM corresponded with a minimum in the combined nitrate and nitrite profile. Both features occurred in the

middle of an extensive stratified zone extending from at least as close to the surface as 25 m to the lowest depths sampled. In the Northern Sargasso Sea the DCM and a nitrate plus nitrite minimum were also in the middle of the stratified zone. The DCM in the Gulf Stream cold core ring stations - unaccompanied by a nitrate plus nitrite minimum - was shallower than in the Sargasso Sea but this ring was quite new (2 months) and nutrient concentrations at the DCM were over an order of magnitude higher than in the surrounding Northern Sargasso Sea. Although spacing of the samples in the Shelf/Slope Water was not adequate to define the limits of the DCM (Figure 20; Table 15), it appeared to be at the base of the pycnocline. In both the ring and Shelf/Slope stations the DCM occurred in the middle of a nutricline in the combined nitrate and nitrite profile.

In all hydrographic regimes sampled on CHAIN 125 (August 1975) strong stratification began at or near the surface (see Figure 21). The cold core ring sampled, Ring D (see Methods, Chapter One) had a stepped vertical density profile less smoothly varying than that of the ring sampled a year earlier on ATLANTIS 84 (compare to Figure 20). Shelf/Slope Water stations had an instability in the density profile at about 60 m. In all regions a deep chlorophyll maximum was present near the base of the most strongly stratified zone (Northern Sargasso Sea - 25-100 m; Ring D - 25-100 m; Slope Water- 0-70 m; Shelf/Slope Water- 0-40 m). The DCM was particularly acute at the Slope Water and Shelf/Slope Water stations where the density gradients were especially steep (Slope Water - $\Delta \sigma t/Z$ = .06, 0-70 m; shelf/Slope Water - $\Delta \sigma t/Z$ = .10, 0-70 m).

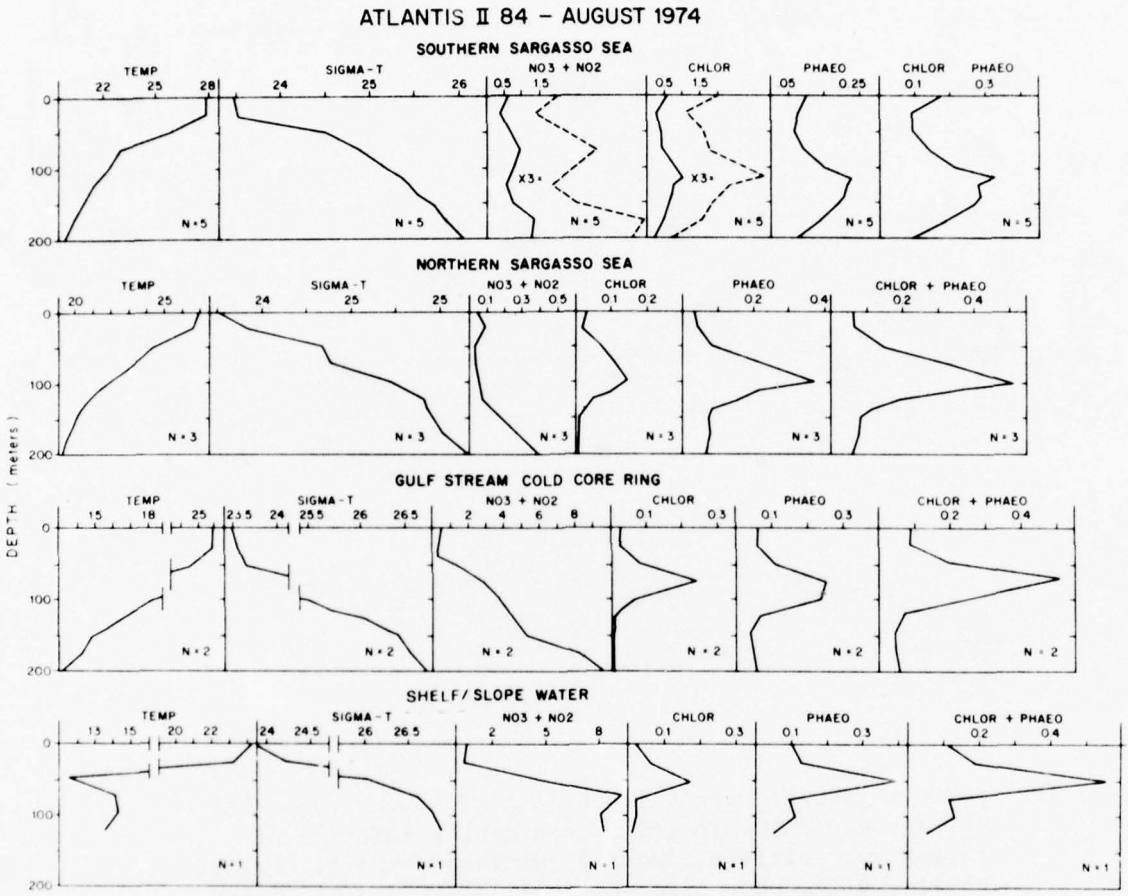


Figure 20. 0-200 m average vertical profiles of temperature (°C), σt, nitrate plus nitrite (µmol/l), chlorophyll (µg/l) and phaeopigments (µg/l). R/V ATLANTIS II cruise 84 - August 1974. N equals the number of stations used in calculating the average profile. In dashed lines adjacent to a multiplying factor (e.g., - x3), the value of every point is multiplied by the given factor and the position of the line on the horizontal axis is completely arbitrary.

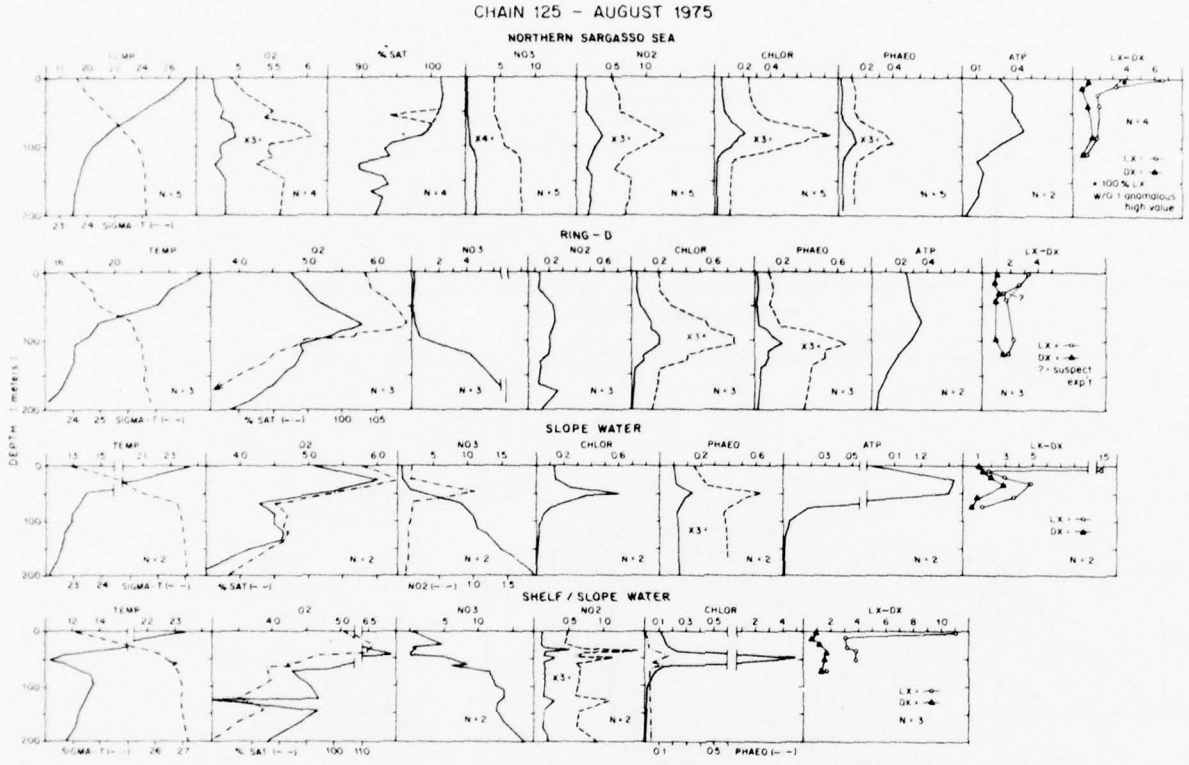


Figure 21. 0-200 m average vertical profiles of temperature (°C), σt, dissolved oxygen (ml/l), percent saturation of oxygen (%), nitrate (μmol/l), nitrite (μmol/l), chlorophyll (μg/l), phaeopigments (μg/l), ATP (μg/l), light fixation of ^{14}C (μg C/l over a dawn to dusk incubation), and dark fixation of ^{14}C (μg C/l over a dawn to dusk incubation). R/V CHAIN cruise 125 - August 1975. N equals the number of stations used in calculating the average profile. In dashed lines adjacent to a multiplying factor (e.g., - x3), the value of every point is multiplied by the given factor and the position of the line on the horizontal axis is completely arbitrary.

In all hydrographic regimes sampled in August 1975 nitrite maxima appeared coincident in depth with chlorophyll maxima but may well have been deeper since the sampling intervals for chlorophyll (5 m) were narrower than for nitrite or nitrate (25 m). Nitrate concentrations increased abruptly in all regions beneath the DCM. In the Shelf/Slope Water stations nitrite maxima corresponded closely in depth with nitrate minima.

In August 1975 Northern Sargasso Sea, Ring D, and Slope Water stations ATP concentrations increased from the surface to the DCM and decreased beneath it. ATP concentration in the Northern Sargasso Sea had a minor minimum at the same depth as a minor nitrite minimum (about 125 m). Like the Slope Water DCM, the sub-surface ATP peak in the Slope Water was particularly prominent. However, determining the precise location of these peaks is impossible since ATP, like nutrients, was measured only at 25 m intervals.

In Ring D both oxygen concentration and percent saturation were maximal in the middle of the stratified zone ($\sim$ 75 m). At roughly the same depths ^{14}C light fixation slightly increased. A similar relationship was observed in Slope Water and Shelf/Slope Water data but not the Northern Sargasso Sea. The Northern Sargasso Sea did not show a distinct subsurface oxygen maximum but was nevertheless supersaturated everywhere above the center of the DCM. The intensity of biological nutrient utilization in Slope Water is shown by a minimum in nitrate concentration at the depth of the upper reaches of the DCM - i.e., the middle of the stratified zone. In Shelf/Slope Water, Slope Water, and the Northern Sargasso Sea ^{14}C dark fixation was maximal at the depth of the nitrite maximum.

On the third consecutive summer cruise, KNORR 58, data were obtained from the Northern Sargasso Sea, the Gulf Stream, and five distinguishable Slope Water hydrographic regimes (see Figure 22).

Temperature and density gradients in the Northern Sargasso Sea were almost identical to August 1975 (CHAIN 125) Northern Sargasso Sea gradients. Chlorophyll concentrations were maximal at the base of the most strongly stratified zone ($\Delta \sigma t/Z = .05$, 50-100 m). Nitrite concentrations were maximal beneath the DCM. Nitrate concentration increased abruptly at the DCM. While not perfectly concordant, both ATP and particulate nitrogen concentration were maximal roughly at the DCM. Although ^{14}C light fixation was low at all depths, declining from rather near the surface, dissolved oxygen concentration and percent saturation were definitely maximal somewhat above the DCM with supersaturations observed at all depths above 100 m. ^{14}C dark fixation was maximal just beneath the DCM and roughly corresponded in depth with the initiation of the nitrate maximum. At all depths below 50 m dark ^{14}C fixation was no different than light ^{14}C fixation within the precision of the measurement.

Although considered separately the hydrography of the station designated Gulf Stream was not very different from that of stations designated Sargasso Sea. Both groups had a subsurface salinity maximum (not shown) greater than 36‰ below 25-50 m. At the Gulf Stream stations the temperature and density distributions were more variable but again, the DCM was present at the base of a stratified zone ($\Delta \sigma t/Z = .05$, 40-100 m). Nitrite, ATP, and particulate nitrogen profiles had multiple peaks at or around the DCM. The shallowest of these peaks were located at about the same depth as the principal peak of the DCM. In fact, a suggestion of multiple peaks can be seen in the total chlorophyll profile and they are clearly expressed in the phaeopigment and $< 3\ \mu$ chlorophyll profiles.

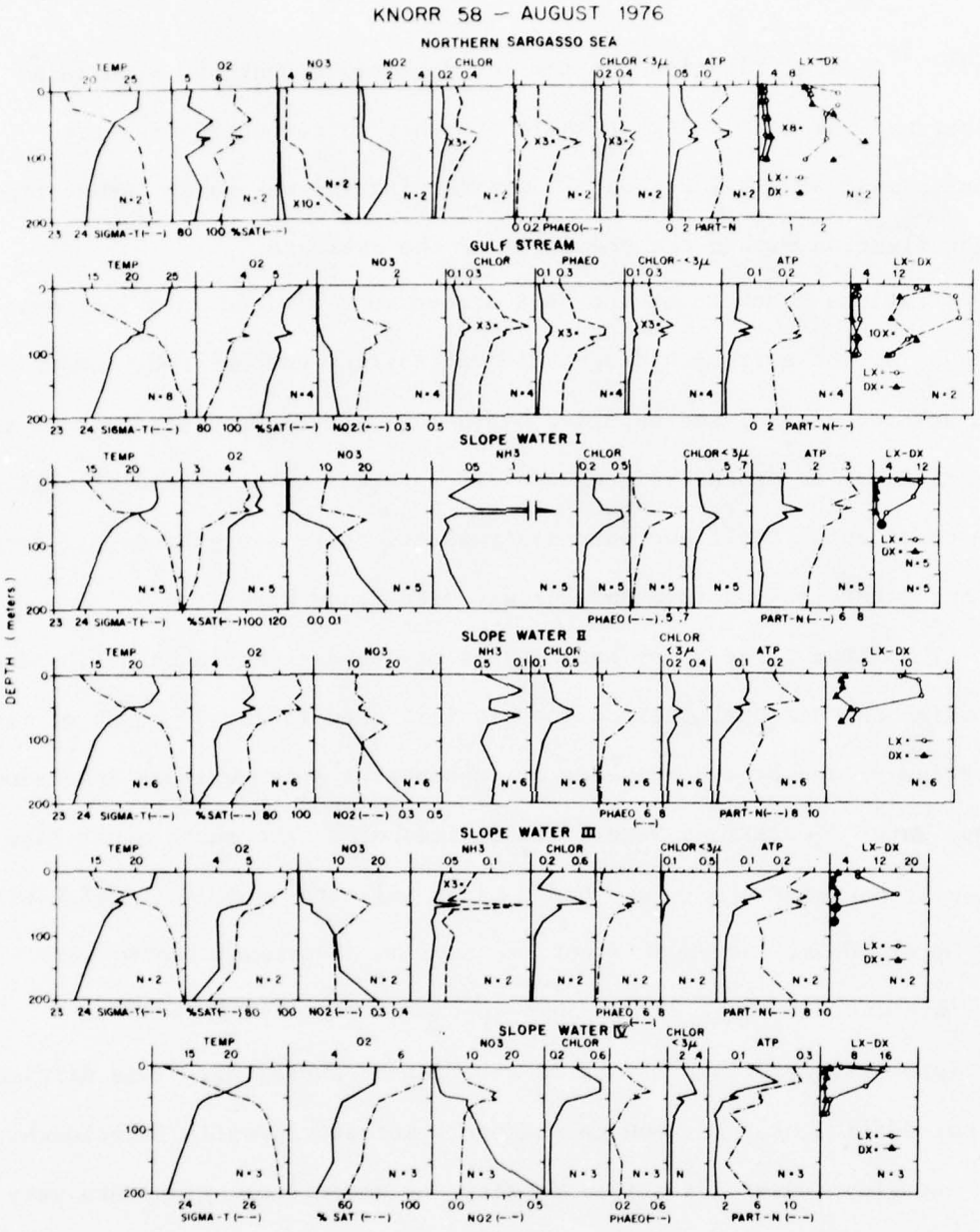


Figure 22. 0-200 m average vertical profiles of temperature (°C), σt, dissolved oxygen (ml/l), percent saturation of oxygen (%), nitrate (μmol/l), nitrite (μmol/l), ammonia (μmol/l), chlorophyll (μg/l), phaeopigments (μmol/l), <3 μm chlorophyll (μg/l), ATP (μg/l), particulate nitrogen (μg/l), light fixation of ^{14}C (μg C/l over a dawn to dusk incubation), and dark fixation of ^{14}C (μg C/l over a dawn to dusk incubation). R/V KNORR cruise 58 - August 1976. N equals the number of stations used in calculating the average profile. In dashed lines adjacent to a multiplying factor (e.g., - x3), the value of every point is multiplied by the given factor and the position of the line on the horizontal axis is completely arbitrary.

Again, ^{14}C light fixation was low and declined beneath 50 m while a deeper maximum in ^{14}C dark fixation roughly corresponded with the nitrite maximum. Below about 75 m dark fixation was no different than light fixation within the precision of the estimate.

Stations landward of the Gulf Stream were divided into four sets because of the extreme hydrographic variability encountered. Experimental Frontal Analyses supplied by the U.S. Naval Oceanographic Office clearly show an extensive tongue of fresh Shelf water extending well off the continental shelf and warm salty water, there designated Gulf Stream water, inter-leaving in a complex way with Slope Water.

The first three Slope Water types may be distinguished by the depth at which the seasonal thermocline was initiated (50 m, 40 m, 25 m, respectively) and by the presence or absence of a temperature inversion. Slope Water IV stations were a little fresher at the surface but like other Slope Water stations had a minor salinity anomaly (> 36‰) within the upper 100 m. At Slope Water IV stations a seasonal thermocline was initiated at about 25 m. Some of the complexity of KNORR 58 Slope Water profiles may be an artifact of averaging. This difficulty is not sufficiently serious to obscure systematic profile relationships.

At Slope Water I stations density and temperature gradients were stepped at about 50 m below which there was a DCM and a nitrite maximum. Again, nitrate concentration increased abruptly beneath the DCM. ATP and particulate nitrogen had subsurface maxima at about the depth of the DCM but in both profiles multiple peaks occurred. In this case none of the pigment profiles had corresponding multiple peaks. ^{14}C light fixation declined from near the surface and was considerably higher than in the Gulf Stream or Sargasso Sea. Light fixation markedly exceeded

dark fixation at all depths except the deepest sampled. At and above the DCM dissolved oxygen was super-saturated. A small maximum occurred just above the DCM. Ammonia concentration was highly variable with a sharp peak at about 50 m coincident both with initiation of the DCM and and nitrite maximum, and with the principal ATP peak.

Slope Water II and Slope Water III profiles were similar to the Slope Water I profile. The DCM was just beneath the principal density and temperature gradients with a nitrite maximum a little deeper. ATP and particulate nitrogen profiles, although more complicated, contained peaks near the DCM and the nitrite maximum. Further, ammonia concentration while quite variable was generally high at DCM depths. ^{14}C light fixation was quite high, particularly at Slope Water III stations, and greatly exceeded ^{14}C dark fixation in the upper 40 m. ^{14}C dark fixation was maximal at depth. Dissolved oxygen was only slightly supersaturated at and above the DCM.

Slope Water IV stations conform to the typical pattern of DCM occurrence; it was at the base of the maximally stratified zone with the nitrite maximum a little deeper. Separate ATP and particulate nitrogen peaks appeared to correspond with both the DCM and the nitrite maximum. Oxygen was well supersaturated above the DCM with ^{14}C light fixation correspondingly high. ^{14}C dark fixation was quite variable with no obvious depth trend.

Summarizing a diverse set of hydrographic regimes sampled during three consecutive summers, the DCM had the following characteristics (not all properties were measured in every case): a) it occurred at or within the pycnocline; b) nitrate levels increased sharply beneath the DCM; c) ^{14}C light fixation exceeded ^{14}C dark fixation at DCM depths; d)

ammonia was high at DCM depths; e) oxygen concentration was super-saturated at DCM depths; and f) ATP and particulate nitrogen profiles roughly paralleled the chlorophyll profile and were relatively high at DCM depths.

Fall:

Data from ATLANTIS II 85 (September 1974), and KNORR 53 (November 1975) illustrate the characteristics of hydrographic regimes where seasonal stratification had either just been erased by mixing or was in the process of being eroded. Data from ATLANTIS II 85 (Figure 18) will be compared with that obtained in the same regions one month earlier on ATLANTIS II 84 (Figure 20). Data from KNORR 53 (Figure 23) will be compared with that obtained in the same regions three months earlier on CHAIN 125 (Figure 21).

Between August 1974 and late September 1974 the Northern Sargasso Sea had mixed to at least 100 m, perhaps 125 m (Δ T = 1.5, 0-125 m). Compare temperature profiles in Figures 20 and 18. The DCM observed in August had been erased. Integration of the average 0-200 m concentration curve, shows that the total amount of chlorophyll was similar. In contrast, the nitrite maximum (which lay deeper than the DCM in August) was still present in September presumably because mixing had not yet erased it.

The Gulf Stream cold core ring sampled during August 1974 had become by September 1974 the meander designated Gulf Stream/Slope Water (Figures 20 and 18, respectively). Intense mixing was apparently associated with the process of reabsorbtion. In September the maximum gradient in density was in general less steep and considerably shallower than in August ($\Delta \sigma$ t/Z = .02, 0-100 m). Atop this gradient was a minor

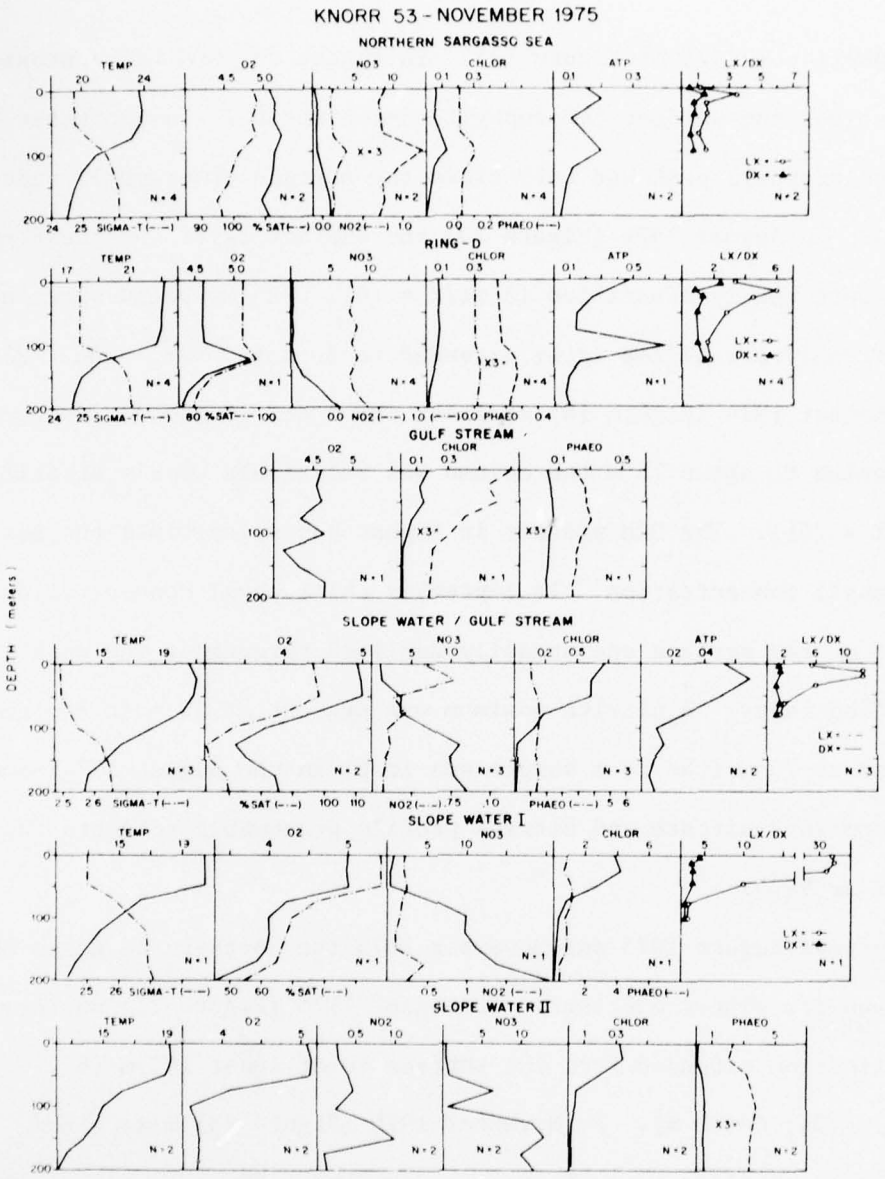


Figure 23. 0-200 m average vertical profiles of temperature (°C) Δt, dissolved oxygen (ml/l), percent saturation of oxygen (%), nitrate (µmol/l), nitrite (µmol/l), chlorophyll (µg/l), phaeopigments (µg/l), ATP (µg/l), light fixation of ^{14}C (µg C/l over a dawn to dusk incubation) and dark fixation of ^{14}C (µg C/l over a dawn to dusk incubation). N equals the number of stations used in calculating the average profile. R/V KNORR cruise 53 - November 1976. In dashed lines adjacent to a multiplying factor (e.g, - x3), the value of every point is multiplied by the given factor and the position of the line on the horizontal axis is completely arbitrary.

chlorophyll peak (25 m; Figure 18). In August the DCM had approximately ten times the surface chlorophyll concentration. In September the minor chlorophyll peak had 1.25 times the surface chlorophyll concentration. In August 1974 (Figure 20) the surface layers of the Slope Waters were weakly stratified ($\Delta \sigma t/Z = .01$, 0-25 m) below which a very strongly stratified layer extended to 50 m ($\Delta \sigma t/Z = .08$), 25-50 m). By September 1974 (Figure 18) at least the upper 25 m were isothermal below which to about 75 m the column was relatively weakly stratified ($\Delta \sigma t/Z = .01$). The DCM present in August had seven times the surface chlorophyll concentration. In September chlorophyll concentrations were highest at the surface and steadily declined throughout the weakly stratified layer. A nitrite maximum was present at 50 m in September. The peak at 75 m (the 50 m sample was lost) in the August 1974 Slope Water combined nitrate and nitrite profile presumably reflects the same feature as 1975.

Between August 1975 and November 1975 the Northern Sargasso Sea had begun its winter overturn. In August 1975 (Figure 21) uniform stratification extended from the surface to at least 100 m (e.g., $\Delta \sigma t/Z = .04$, 0-100 m). By November 1975 (Figure 23) mixing had erased the stratification of at least the upper 50 m ($\Delta \sigma t/Z = .002$, 0-50 m). This mixing was not yet sufficient to effect the DCM which was still within the deeper stratified layer. Nitrate, nitrite, oxygen saturation, ATP, and pigment profiles were all basically similar in August and November 1975. However, mixing had erased the slight 0-100 m dissolved oxygen gradient of increasing concentration observed in August 1975.

Between August and November 1975 Ring D also had begun its winter overturn. Mixing was considerably more advanced in Ring D (Figure 23). Isothermal and isopycnal layers extended from the surface to at least 100 m (e.g., $\Delta \sigma t/Z = .001$, 0-100 m) in contrast to the stratification of August (see Figure 21). In November dissolved oxygen concentration and saturation, nitrite, and chlorophyll were all relatively uniform from 0-100 m. A subsurface dissolved oxygen maximum located just beneath a well stratified layer ($\Delta \sigma t/Z = .05$, 100-125 m) was not supersaturated. ^{14}C light fixation was higher in November than in August. Nitrate concentrations below 125-150 m were also higher in November than in August. In the only profile obtained there was a prominent ATP maximum at about 100 m atop the above-mentioned well stratified layer.

Changes in the Slope Water between August and November 1975 paralleled the changes in Ring D. By November mixing had proceeded sufficiently to produce isothermal and isopycnal conditions from the surface to at least 50 m (e.g., $\Delta \sigma_t/Z = .002$, 0-50 m in Slope Water I). The DCM of August was erased and ^{14}C light fixation much enhanced (only measured in Slope Water I). Nitrate in the upper layers was depleted, but was no different at depth than in August. Dissolved oxygen concentration was uniform within the mixed layer and never supersaturated.

There was no DCM at either the Gulf Stream or the Slope Water/Gulf Stream stations in November 1975. At the latter stations chlorophyll, ^{14}C light fixation, ATP, and nitrite profiles were roughly parallel. Hydrography is complex within the Gulf Stream and it is possible that advective transport processes may be effecting the property distributions observed. Further, this set of stations, like some of those

earlier described from KNORR 58, somewhat arbitrarily pools stations with undesirable hydrographic variability.

INTERPRETATION OF RESULTS

The DCM and Water Column Stratification:

A DCM was consistently observed with persistent stratification of the upper water column in all years sampled. It was absent in the absence of stratification (examples in Figures 18, 19) and if mixing had occurred or was occurring (examples in Figures 18, 23). Mixing to 50-60 m in the Northern Sargasso Sea did not completely eradicate the DCM at 75 m in August 1975 but mixing to 100-112 m in Ring D did completely erase the DCM observed at 100 m in August (Compare Figures 21, 23). The depths of the centers of the DCM on these occasions were determined within 5 m (see Table 15). Secchi disc depths in August 1975 were about 26 m in both Ring D and the Northern Sargasso Sea so mixing had to extend well beneath the 1% light level (3x Secchi depth) to erase a DCM.

Precisely where the DCM might occur relative to the maximum gradient of density was variable. At various times a DCM was located atop well-stratified layers, within them, or at their base (examples in Figures 18, 21, 22). Both the DCM-pycnocline relationship and this variability were discussed by Hobson and Lorenzen (1972) who quite reasonably suggested that different light and nutrient requirements of the dominant phytoplankton might contribute to this variability. In any case, the strength of the DCM/density gradient relationship is undeniable. It was shown by the systematic changes in DCM depth within any one cruise in the different hydrographic regimes sampled (compare chlorophyll and density profiles within the station sets in Figure 21). Further, the amplitude

of the DCM observed was roughly proportional to the steepness of the density gradient with which it was associated (examples in Figures 21, 23). Defining more precisely the DCM/density gradient relationship, however, requires sampling one water mass at frequent intervals throughout the seasonal evolution of a particular DCM. This has been done and the results modeled as reported in Jamart *et al.* (1977) for a DCM off the Washington coast.

The DCM, Shade-Adaptation, and Cell Sinking:

As noted by many authors (most recently Kiefer *et al.*, 1976 and Gunderson *et al.*, 1976) some part of the increase in chlorophyll concentration called the DCM can be attributed to shade-adaptation by phytoplankton, i.e., an increase in individual cell chlorophyll/individual cell biomass. Shade-adaptation is clear, for example, in KNORR 58 data (Figure 22). Consider the Gulf Stream. At the surface chlorophyll divided by ATP (here taken to be proportional to cell biomass) was about 2.0 while at the DCM the ratio was about 3.0. The same calculation for Slope Water I yielded ratios of 2.9 and 3.7, respectively. Within one environment an increase in ratio with depth suggests adaptation. In fact, the ratio at depth is an underestimate in that not all ATP is attributable to phytoplankton (Beers *et al.*, 1975; Venrick *et al.*, 1977) and data in Chapter Four indicate that high microzooplankton concentrations are associated with the DCM. Since ATP samples were not prefiltered (see Venrick *et al.*, 1977) microzooplankton could have significantly contributed to the ATP measured. Microbial biomass may as well contribute to this ATP.

Alternatively, one can calculate an assimilation number (A.N. =

carbon fixed/chlorophyll concentration) for the same data. Using ^{14}C light fixation data for KNORR 58 Gulf Stream stations: A.N. (25 m) = 133 and A.N. (60 m) = 66 while for Slope Water I stations: A.N. (25 m) = 33 and A.N. (50 m) = 7. Decreased assimilation numbers at DCM depths indicate shade-adaptation. Surface measurements were not used in this computation because ^{14}C experiments at 100% light might be effected by photo-inhibition.

However, these data suggest that *in none of the hydrographic regimes* sampled is the increase in chlorophyll concentration at the DCM completely explained by shade-adaptation alone. First, shade-adaptation requires at least a day. A cell has to remain in a constant low light environment to be able to accumulate synthesized chlorophyll at the expense of other cellular metabolites. Therefore stratification, in that it retards mixing, complements shade-adaptation to produce the observed distributions. Second, light intensity declines approximately exponentially with depth. Extremely sharp chlorophyll concentration peaks at the DCM in the averaged profiles of Shelf/Slope and Slope Waters were occasionally observed (Figures 21, 22). Since light levels dropped only a few percentage points over depth intervals in which chlorophyll concentration increases many-fold, simple shade-adaptation must be complemented by a slowdown in cell-sinking rate. Steele and Yentsch(1966) discuss a physiological mechanism which relates shade-adaptation and cell sinking rate. Such a mechanism may operate in conjunction with the density gradient in producing phytoplankton cell accumulations at DCM depths.

But, what about the more oligotrophic Sargasso Sea where the average profiles of pigment concentration did not show such dramatic

average peaks? Consider Figure 24 which depicts two individual (*not averaged*) station profiles taken in the Northern Sargasso Sea. The sum of chlorophyll and phaeopigments is plotted. The two measurements reflect different fractions of plant-derived particulate material. Cowles (1977) argued that this sum was a better indicator of available food than either chlorophyll or phaeopigments alone. In any case, at station 882 between 65 m and 70 m pigment concentration increased nearly 50%. At station CC04 between 75 m and 80 m the pigment concentration nearly doubled. A decline nearly as great can be seen between 110 m and 115 m at the same station. This suggests that also in the Sargasso Sea particle accumulation occurs at the DCM even though the density gradient is very much less steep than in more shoreward environments. Some authors have implied or reached opposite conclusions regarding the DCM in the oligotrophic North Central Pacific gyre (Eppley *et al.*, 1973; Kiefer *et al.*, 1976; Beers *et al.*, 1975).

The DCM as a Significant Food Resource:

At times of the year when plant growth is rapid and the upper water column near isothermal high chlorophyll concentrations of course represent elevated plant biomass. This is evident in Figure 25 which depicts two individual station profiles taken during a leg of KNORR 47 just prior to that earlier discussed (February 1975) and in the same region. Both particulate carbon and particulate nitrogen profiles roughly paralleled the chlorophyll profile (unpublished carbon and nitrogen data, courtesy R. Gagosian). In other words, chlorophyll increases were proportional to increases in total particulate material. But what about seasons when plant growth was more limited, stratification was well established, and a DCM was present? In Northern Sargasso

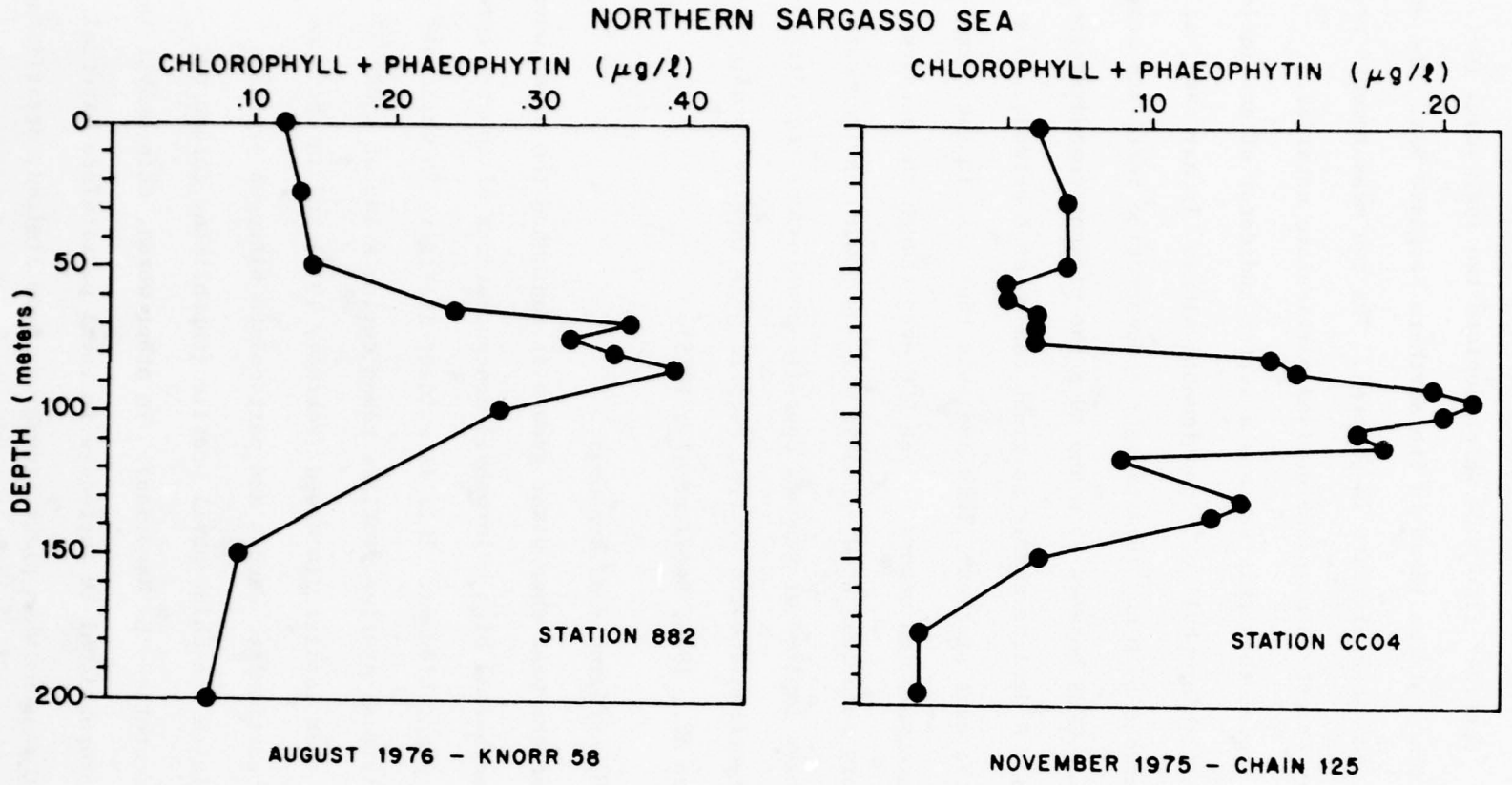


Figure 24. 0-200 m vertical profiles of chlorophyll plus phaeopigment (µg/l) at two stations in the Northern Sargasso Sea.

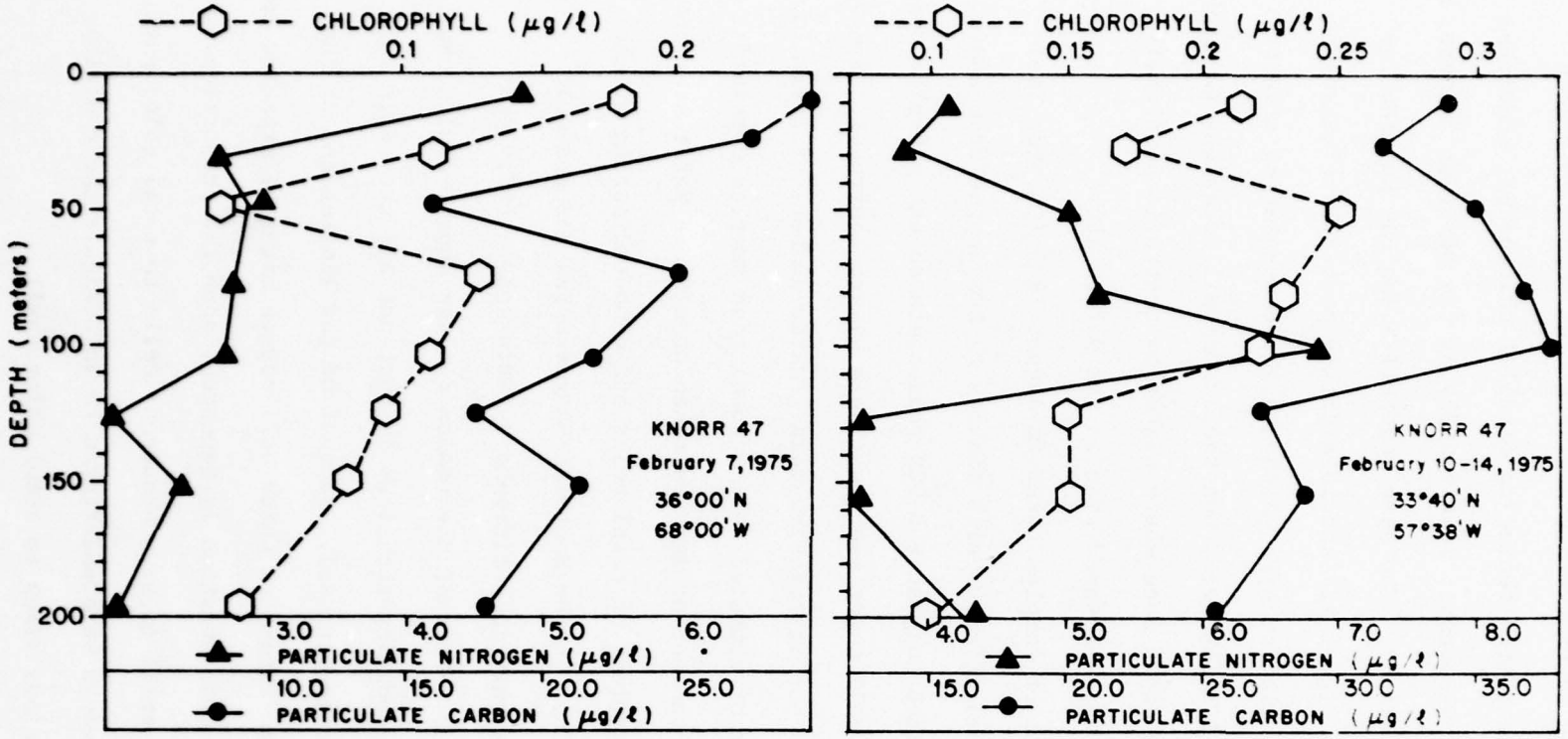


Figure 25. 0-200 m vertical profiles of chlorophyll (µg/l) particulate carbon (µg/l), and particulate nitrogen (µg/l) at two stations in the Northern Sargasso Sea.

Sea, Ring D, and Slope Water average profiles from August 1975 (see Figure 21), ATP concentration tended to parallel chlorophyll concentration, albeit increasing somewhat less rapidly at the DCM (due in part, no doubt, to shade-adaptation). The same generalization can be made for August 1976 data (see Figure 22) and in addition particulate nitrogen followed a pattern similar to ATP. Although shade-adaptation affects the amplitude of the DCM observed, nonetheless on all occasions the DCM invariably signaled a depth zone where higher concentrations of small particulate material were measured than in the waters above.

Do the cell counts of samples taken in August 1975 (Chapter Two) also indicate an accumulation of cells sinking to DCM depths from above, i.e., do the cell counts suggest the DCM represents an exploitable food resource? In brief, cell count results (Table 9) are equivocal. Samples obtained at a DCM did not invariably yield greater numbers of cells (or even a greater amount of computed cell carbon) than samples obtained above the DCM. Only the set of samples taken at a Slope Water station showed large concentrations of total cells and computed carbon at the strongly developed DCM. In the Northern Sargasso Sea and the Gulf Stream cold core ring only coccolithophores were consistently most numerous at DCM depths. Part of the reason for the above results can be attributed to the counting technique in that not all the cells in a sample were counted (see Methods). Because of the limitations of the counting technique the extent to which cell counts might be expected to parallel chlorophyll concentration is dependent upon the proportional contribution of very small (i.e., uncounted) cells to total chlorophyll. Two series of experiments were undertaken to investigate the contributions of cells of various sizes to total chlorophyll.

On all KNORR 47, and some CHAIN 125 and KNORR 53 stations, replicate chlorophyll samples were prefiltered through 35 μm and 10 μm Nitex mesh. At KNORR 47 Northern Sargasso Sea stations an average of 66% of total chlorophyll passed a 35 μm filter while an average of 54% passed a 10 μm filter. The 35 μm fraction is significantly different from the 10 μm fraction and both are significantly different from total chlorophyll ($p < .01$, Sign tests). No significant depth interval differences were measured in relative fraction contributions to total chlorophyll. In short, at all depths large cells significantly contributed to total chlorophyll. The same experiments conducted on CHAIN 125 and KNORR 53 produced very different results. During CHAIN 125 there was no significant average difference between total 10 μm and 35 μm fractions in the Slope Water, the Northern Sargasso Sea, or in Ring D. While the result has no statistical significance, in the three samples obtained at DCM depths total chlorophyll exceeded the < 35 μm fraction which in turn exceeded the < 10 μm fraction. Values observed at the three stations were: 0.80 > 0.60 > 0.55, 0.26 > 0.22 > 0.21, 0.17 > 0.14 > 0.13 respectively for total, > 35 μm, and > 10 μm chlorophyll μg/l. This suggests more large cells were present at DCM depths than above or below. During KNORR 53 total, 10 μm, 35 μm chlorophyll fractions were not significantly different in either the Northern Sargasso Sea or in Ring D. However, in the two KNORR 53 Slope Water profiles at least within the upper 50 m total chlorophyll considerably exceeded both the < 35 μm fraction and the < 10 μm fraction (< .05, Sign tests) indicating relatively more large cells in the Slope Water.

The smallest phytoplankton cells included in the cell counts are estimated to be 4 μm (E. Hulburt, personal communication). To find out how much

chlorophyll was associated with particles smaller than this, throughout KNORR 58 replicate chlorophyll samples were prefiltered through 3 μm Nuclepore filters. Results obtained are shown in Figure 22. In all regions at all depths < 3 μm chlorophyll was a large fraction of total chlorophyll. In the Northern Sargasso Sea and Gulf Stream the contribution of < 3 μm particles was particularly large, often exceeding 50%. In Slope Water II, Slope Water III, and Shelf/Slope Water the contribution of < 3 μm particles was considerably smaller (< 30%). At Slope Water I < 3 μm particle contribution was intermediate (about 45%).

Considering the preceding experiments it appears probable that there was some accumulation of phytoplankton cells at the DCM in all regions sampled despite the ambiguity of the cell count results. Was this entirely the result of cells sinking from above or was there evidence that the phytoplankton cells of the DCM were actively growing? There are three reasons to believe that cell growth had occurred and was occurring at DCM depths despite the low light levels.

First, on a number of occasions (see Figures 21, 22) ^{14}C light fixation of samples from DCM depths exceeded that of samples obtained at shallower depths (Figure 20: Shelf/Slope Water, Slope Water, Ring D; Figure 22: Slope Water III). This was atypical. In any case, interpretation of deck incubation ^{14}C productivity experiment results, particularly in oligotrophic waters, is difficult. Clearly the temperature of samples taken from depth under stratified conditions will be considerably elevated in an incubator cooled by surface seawater. Further, is it meaningful to subtract ^{14}C dark fixation from ^{14}C light fixation or is the latter value, if corrected by subtraction of a time-zero blank, equivalent to photosynthesis (Morris *et al.*, 1971)?

Second, nutrient and dissolved oxygen distribution provide evidence that photosynthetic production had occurred at DCM depths. Most often the DCM was found above a nutricline (Figures 21, 22). If nutrients were depleted at the DCM but increased below it presumably they had been utilized at the DCM. The suggestion of Venrick *et al.* (1973) that under some circumstances the DCM may function as a nutrient barrier by preventing upward diffusion of nutrients into the surface layers seems consistent with the observations here presented. On rare occasions the depth of the DCM was depleted of nutrients relative both to the waters above and below it (Figure 21: Shelf/Slope Water; Figure 20: Northern Sargasso Sea). This, too, is suggestive of prior nutrient uptake and presumably cell growth at the DCM.

Under some circumstances dissolved oxygen profiles can also be considered indications of prior photosynthetic activity. Changes in oxygen concentration can be both physically or biologically produced. Oxygen can be gradually stripped from the surface layers by heating, producing in the summer a subsurface maximum (Pytkowicz, 1964). Oxygen can be added to the upper 20 m or so by storm-induced submergence of air bubbles (Kanwisher, 1963). Air injection is estimated for the Atlantic at less than .5 ml/l (Craig and Weiss, 1971), i.e., only 0.1 ml O_2/l or a possible 2% supersaturation at 5.0 ml O_2/l. Only the latter effect would, in itself, result in a positive saturation anomaly. Biological mechanisms for altering oxygen concentration include microbial oxidation of reduced inorganic ions, respiration, and plant photosynthesis. Only photosynthesis would produce supersaturation. Regardless of their cause, saturation anomalies within the mixed layer should last no longer than a month (Broecker and Peng, 1974), but could be persistent

if re-equilibrium were slowed by water column stratification. As noted by Kester (1975), rigorous interpretation of the distribution of a reactive gas like oxygen requires knowledge of the distribution at the same location of a non-reactive gas like helium or argon. Unfortunately, such data

In results earlier presented, it was common to observe supersaturations at and above the DCM but rarely below the DCM. The definition and amplitude of observed oxygen concentration peaks appeared to be dependent, presumably for the reasons just discussed, on the steepness of the density gradient with which the DCM was associated. In August 1975 a subsurface dissolved oxygen maximum was noted in the Northern Sargasso Sea, but it was not supersaturated. One mechanism contributing to the subsurface maximum was probably stripping of surface oxygen due to gradual heating of the water column (Figure 21). On the other hand at Ring D on the same cruise supersaturations as great as 15% were observed (Figure 21), and when revisited in November 1975 the Northern Sargasso Sea was also supersaturated (Figure 23). Numerous examples of supersaturation were noted in August 1976 in all regions sampled (Figure 22). Maximum supersaturation rarely occurred at the DCM but secondary peaks were occasionally observed at the DCM. Since on most occasions DCM depths were partially isolated by the density gradient from oxygen evolution in the surface layers, at least part of the observed supersaturation can be attributed to *in situ* processes. Oxygen profiles in regions dominated by advective processes (Figure 22: Slope Water II and III) are suggestive of *in situ* growth but require cautious interpretation because of the extremely complex hydrography in the Slope Water in August 1976.

Possible Microbial Processes at the DCM:

The cumulative weight of the evidence so far discussed suggests that the DCM gained phytoplankton cells both by sinking from above and by *in situ* growth. There is another possible source which may contribute particulate material to the DCM.

It is reasonable to expect particle accumulation at a density gradient beneath a particle source. Organic particles sinking out of the euphotic zone probably slow down at the pycnocline. Such particles would accumulate and themselves represent a heterotrophic food resource. In addition, both inorganic and organic particles are physical substrates. Suspended particles have been shown to enhance the growth of marine bacteria (Wirsen and Jannasch, 1975). However, "it is by no means proven that the majority of bacteria are associated with aggregates or other particles" (Wiebe and Pomeroy, 1972). It has been suggested that one way particles might enhance growth is by concentrating dissolved organic material (Jannasch and Pritchard, 1972). The fact that in November 1975 (Figure 23) ATP concentrations were found at the maximal density gradient, although mixing had erased the DCM, suggests that enhanced microbial populations may as well have been present at the more shallow density gradients with which the DCM was associated. Subsurface ^{14}C dark fixation maxima at DCM depths may indicate microbial activity (Figures 21, 22), but the problem of incubator temperature, mentioned earlier, complicates interpretation of these results.

Heterotrophic microbial processes may not have been the only ones occurring about the DCM. Data presented in Chapter Four indicate that macrozooplankton and microzooplankton biomass was often higher in the vicinity of the DCM. Consider, for example, data for the Northern

Sargasso Sea in August 1975. Averaging all tows, about 88 mg C macrozooplankton biomass, or about 41% of 0-200 m total biomass was found both night and day between 50 and 100 m (data in Figure 29). Copepod nauplii and small post-naupliar stages contributed an additional 9.5 mg C (data in Figure 33). Other microzooplankton were also concentrated in the same depth intervals (data in Figure 30). The smallest mesh size employed, however, was comparatively coarse (67 μm). Therefore, we have no good estimate of total protozoan biomass and, in fact, many naupliar forms would have passed through the net mesh (Beers and Stewart, 1969). In the computations to follow, therefore, naupliar and post-naupliar biomass will be underestimated. Assuming nauplii and post-nauplii represented a similar fraction to that reported by Beers and Stewart (1969) protozoan biomass in the same depth interval would have been a minimum of 2.4 mg C. If dry weight were 40% carbon then in the 50-100 m interval macrozooplankton dry weight would have been 220 mg, naupliar and post naupliar pooled biomass would have been about 23.8 and protozoan biomass would have been about 5 mg. All values are converted to dry weight to utilize the excretion equation of Jawed (1973).

We can estimate the excretion of these zooplankton fractions as follows: 23.8 mg naupliar and post naupliar copepods have an ingestion rate equal to about 142 mg adult copepods (Paffenhöffer, 1971). If we assume that adult copepod assimilation efficiency represents that of the total MOCNESS catch and assume copepod excretion is approximately proportional to ingestion (Takahashi and Ikdea, 1975), then 23.8 mg naupliar and post naupliar copepods have an excretion rate equivalent to 142 mg macrozooplankton (MOCNESS catch). Following Jawed (1973) macrozooplankton excretion is about .38 μmol NH_3/mg dry weight/day; therefore,

from 50-100 m metazoan excretion would have been 142 mg + 220 mg = 362 mg, 362 mg x .38 μmol NH_3/mg = 138 μmol NH_3/m^2/day. Protozoan dry weight of 5 mg/m^2 would similarly yield 1.9 μmol NH_3/m^2/day. However, Johannes (1965) data indicate that the metabolic rate of protozoa can be twenty times that of animals the size of macrozooplankton which would indicate that 38 μmol NH_3/m^2/day would be a more reasonable estimate of protozoan excretion. Total zooplankton excretion would have been, therefore 138 + 38 = 176 μmol NH_3/n^2/day (50-100 m). Although the multiplying factor taken from Johannes (1965) data may introduce error, overall the NH_3 excretion rate calculated is a certain underestimate since both juvenile copepod and protozoan biomass were underestimated.

The above nitrogen flux can be compared to that required to support observed levels of ^{14}C fixation. In the Northern Sargasso Sea in August 1975 ^{14}C light fixation (50-100 m) for one daylight period = 1 μg C/l, while ^{14}C dark fixation = .7 μg C/l. Assuming a C:N ratio = 7 then this amount of nitrogen would be about 30% of that required for light fixation, but close to 100% of that required for the difference between light and dark fixation. Further, the only form of "regenerated nitrogen" here discussed is NH_3 but urea is also excreted and it, too, can be a source of nitrogen for phytoplankton (Eppley *et al.*, 1977).

The fraction of ammonia excreted at depths where light is sufficient to support active plant growth should be preferentially utilized by phytoplankton (Bates, 1977; MacIsaac and Dugdale, 1972). Although dark ammonia uptake has been shown (Bhovichitra and Swift, 1977) considering the possibility of an upward flux of nitrate due to the proximity of the DCM to the nutricline, the total dissolved nitrogen concentration at

the DCM, and the fact that nitrate and ammonia uptake are not incompatible (McCarthy *et al.*, 1977), it is likely that both nitrate and ammonia contribute significantly in supplying phytoplankton nitrogen requirements at the DCM. The possibility should not be dismissed that at least part of the ammonia excretion just calculated was oxidized to nitrite by bacteria.

Limited data support this speculation. High ammonia concentrations at Slope Water DCM depths were found during August 1976. In some average profiles there were distinct ammonia peaks (Figure 22). But, no ammonia determinations were made in the Northern Sargasso Sea. There is evidence that enhanced concentrations and presumed microbial activity may have occurred under the more oligotrophic conditions of the Northern Sargasso Sea. Figure 26 contains two individual nutrient profiles taken in August 1976: one in the Northern Sargasso Sea and the other in Shelf/Slope Water. In the Northern Sargasso Sea profile a minor peak on the phosphate nutricline corresponded to the nitrite maxima (see Pomeroy *et al.*, 1963). In the Shelf/Slope Water profile the same relationship was found and, in addition, a large ammonia peak was located adjacent to the former peaks. This concordance is strong circumstantial evidence that animal release and microbial mineralization of wastes may have been taking place in both regions.

Kiefer *et al.* (1976) argued that the secondary nitrite maximum can be completely accounted for if DCM phytoplankton are reducing nitrate as initially suggested by Vaccaro and Ryther (1960), although they admitted that recent experimental work (Wada and Hattori, 1971; Miyazaki *et al.*, 1973) did not support this view. The principal argument they raised

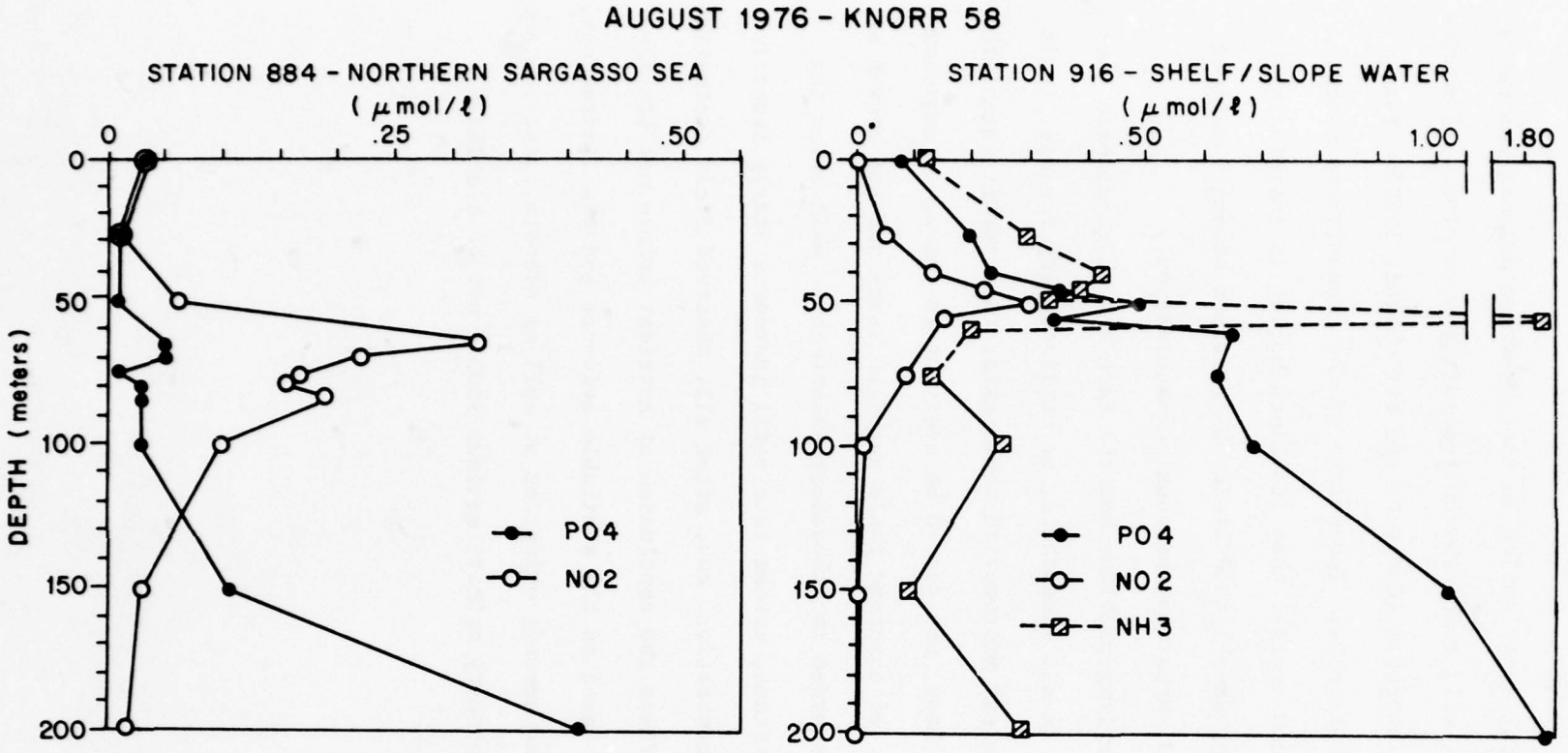


Figure 26. 0-200 m vertical profiles of nitrite (μmol/l) and phosphate (μmol/l) at one station in the Northern Sargasso Sea, and 0-200 m vertical profiles of nitrite (μmol/l), phosphate (μmol/l), and ammonia (μmol/l) at one station near the Continental Shelf.

against any microbial contribution is that measured ammonia concentrations are typically well below the half-saturation constants of marine, ammonia-oxidizing, bacteria (Carlucci and Strickland, 1968). This argument is not irrefutable. The nature of the mechanism by which ammonia is introduced implies that its distribution is inordinately patchy. Preliminary unpublished field observations strongly suggest this is the case (J. McCarthy, personal communication).

Considering sampling problems and the fact that high ammonia concentrations would, in all likelihood, be utilized very rapidly, it is possible that transient microenvironments exist that permit chemolithotrophic activity. Last, one should be hesitant in basing an argument upon comparison of observed field nutrient loads and the growth or uptake constants recorded in laboratory experiments. Well below the half-saturation constant, uptake rate still increases nearly linearly with substrate concentration; and, after all, observed field concentrations generally reflect the conclusion of nutrient uptake not its initial conditions. Based on the available evidence and its limitations, the possibility that ammonia oxidation as well as nitrate reduction contributes to the secondary nitrite maximum should not be dismissed.

SUMMARY AND CONCLUSIONS

1. In order to assess the standing stock and the production of primary particulate material at the DCM, 0-200 m profiles of chlorophyll, phaeophytin, ATP, particulate nitrogen, ^{14}C fixation, and plant nutrients were analyzed in relation to 0-200 m profiles of temperature.

2. Previous studies were too limited in scope and duration to define the range of circumstances under which a DCM occurs. Environments investigated in the present study ranged from the oligotrophic Sargasso Sea to nearly eutrophic Shelf Water; further, sampling was done both when a DCM was present and when it was not present.

3. The properties associated with, and presumably the factors controlling, the occurrence of a DCM appeared to be essentially similar in the oligotrophic open ocean and in more nearshore environments.

4. Corroborating previous observations a DCM occurred only after the formation of a stable shallow density gradient, typically marked by a seasonal thermocline. DCM depth was apparently dependent upon thermocline depth and is relatively predictable (within about 10 m) given knowledge of the evolution of the observed hydrographic regime. Minor apparent regional differences in the relationships between 0-200 m profiles investigated could frequently be explained as sampling artifacts.

5. Increasing chlorophyll concentration at the DCM did not *per se* indicate a proportional accumulation of plant biomass. This result corroborates many previous studies in documenting shade-adaptation. Nonetheless, in the oligotrophic open ocean as well as more coastal

environments, evidence suggests that the depth interval signalled by the DCM constituted a significant food resource. Specifically, oxygen profiles, nutrient profiles, and ^{14}C fixation experiments imply phytoplankton growth had occurred or was occurring at DCM depths. In addition, ATP profiles, dark ^{14}C fixation experiments and nutrient profiles imply microbial activity was enhanced at DCM depths relative to the waters above. Both the correlation between the DCM and the seasonal thermocline and the shape of the pigment profiles obtained imply that DCM depths accumulated particulate materials sinking from above.

6. The evidence presented in this chapter together with the zooplankton data given in Chapter Four indicate that the depth zone signalled by the DCM was a locus of particularly intense trophic activity in the Slope Water, in some Gulf Stream cold core rings, and in the Northern Sargasso Sea. Further, computations based upon the concentrations of zooplankton biomass associated with the DCM indicated that zooplankton excretion could have been significantly contributing nutrients for phytoplankton growth at DCM depths in all regions investigated.

CHAPTER FOUR. THE RELATIONSHIP OF THE VERTICAL DISTRIBUTIONS OF ZOOPLANKTON BIOMASS AND FUNCTIONAL GROUPS TO VERTICAL TEMPERATURE STRUCTURE AND THE DEEP CHLOROPHYLL MAXIMUM - DCM

INTRODUCTION

It has become increasingly clear that there are major discrepancies between experimental zooplankton feeding studies and field studies of plankton distributions. First, many plankton herbivores appear to obtain adequate food rations only at "unnaturally" elevated phytoplankton densities (Frost, 1974) and may be undernourished at many depths in the water column for a part of the year (Mullin and Brooks, 1977). Second, although some models of plankton production (Steele, 1974) required a "threshold" feeding response for system stability — that is, a cessation of feeding activity at low food concentrations — laboratory determination of this concentration had indicated that it was well above the average food level obtaining in much of the world oceans (Parsons *et al.*, 1969; Adams and Steele, 1966). More recently the model requirement has been disputed (Landry, 19766; Steele; 1976), and data have suggested that some early laboratory results may have been experimental artifacts (Frost, 1975). In any case, we have comparatively little information concerning the relationship between inhomogeneous phytoplankton distribution and the growth and feeding of gracing animals (Frost, 1974). A first step in assessing the possible significance of this relationship is to determine the degree to which zooplankton and phytoplankton are co-distributed in the pelagic environment with particular emphasis on

habitats potentially representating an augmented local food resource.

Seasonal accumulations of chlorophyll at the bottom of the euphotic zone have been shown to be characteristic features of three distinct hydrographic regimes in the western North Atlantic Ocean: the Slope Water, the Northern Sargasso Sea, and Gulf Stream cold core rings — whenever the upper water column remained reasonably well-stratified for an extended period of time (Chapter Three). This phenomenon has been called the Deep Chlorophyll Maximum - DCM (Venrick *et al.*, 1973). A number of investigators have reported zooplankton species suggestively associated with the depth of a DCM (Anderson *et al.*, 1972; Mullin and Brooks, 1972; Hobson and Lorenzen, 1972; Chester, 1975; Beers and Stewart, 1967; Youngbluth, 1975; Gunderson *et al.*, 1976; Haury, 1976). However, in no case were detailed vertically stratified samples concurrently obtained of both macrozooplankton and microzooplankton. On the other hand, Venrick *et al.* (1973) and Longhurst (1976) report no such association in oligotrophic areas in the Pacific Ocean.

The work of Boyd (1973), Harder (1968) and others has indicated that zooplankton can exhibit considerable sensitivity to temperature gradients. In light of the predictable relationship between the DCM and the vertical temperature distribution (Chapter Three), the comparative paucity of euphotic zone phytoplankton biomass when the seasonal thermocline is well-developed (Chapter Two), and the significant food resource represented by the DCM (Chapter Three), it would be reasonable to anticipate that in the western North Atlantic the distribution of euphotic zone zooplankton might be related to the stage of development of the DCM. Such an association would be of particular interest in that zooplankton grazing is a major parameter in a recent model of DCM

development off the Washington coast (Jamart *et al.*, 1977).

Chapter Three analyzed a series of 0-200 m vertical profiles of chlorophyll, oxygen, ATP, ^{14}C fixation, and plant nutrients and related these to 0-200 m temperature and density distributions to see if, and to what extent, the DCM represents a significant food resource.

This, the second of two chapters directly concerning the DCM in the western North Atlantic, relates 0-200 m vertical distributions of various zooplankton taxa and zooplankton biomass to 0-200 m temperature and density distributions to ascertain if zooplankton biomass peaks at and about the DCM and to see if the structure of the zooplankton assemblage at those depths is identifiably different from the assemblage above and below.

METHODS

Most of the data presented in this paper were collected on R/V CHAIN cruise 125 (August 1975) and on R/V KNORR cruise 53 (November 1975). On both of these cruises the same ring (Ring D) was sampled. It had formed in February 1975 and was therefore about six months old in August and nine months old in November. A smaller numer of samples were collected on R/V ATLANTIS II cruise 84 (August 1974). The positions of sample collection are shown in Figure 27.

Collections were made with three different types of sampling gear: on R/V ATLANTIS II 84 opening/closing modified Bongo nets (McGowan and Brown, 1966) with a mouth area of 0.38 m^2; on the two more recent cruises both a multiple opening/closing net and environmental sensing system - MOCNESS (Wiebe *et al.*, 1976b) - with a mouth area of 1 m x 1.4 m (effective area is 1 m^2) and Clarke-Bumpus samplers with a mouth area of .012 m^2.

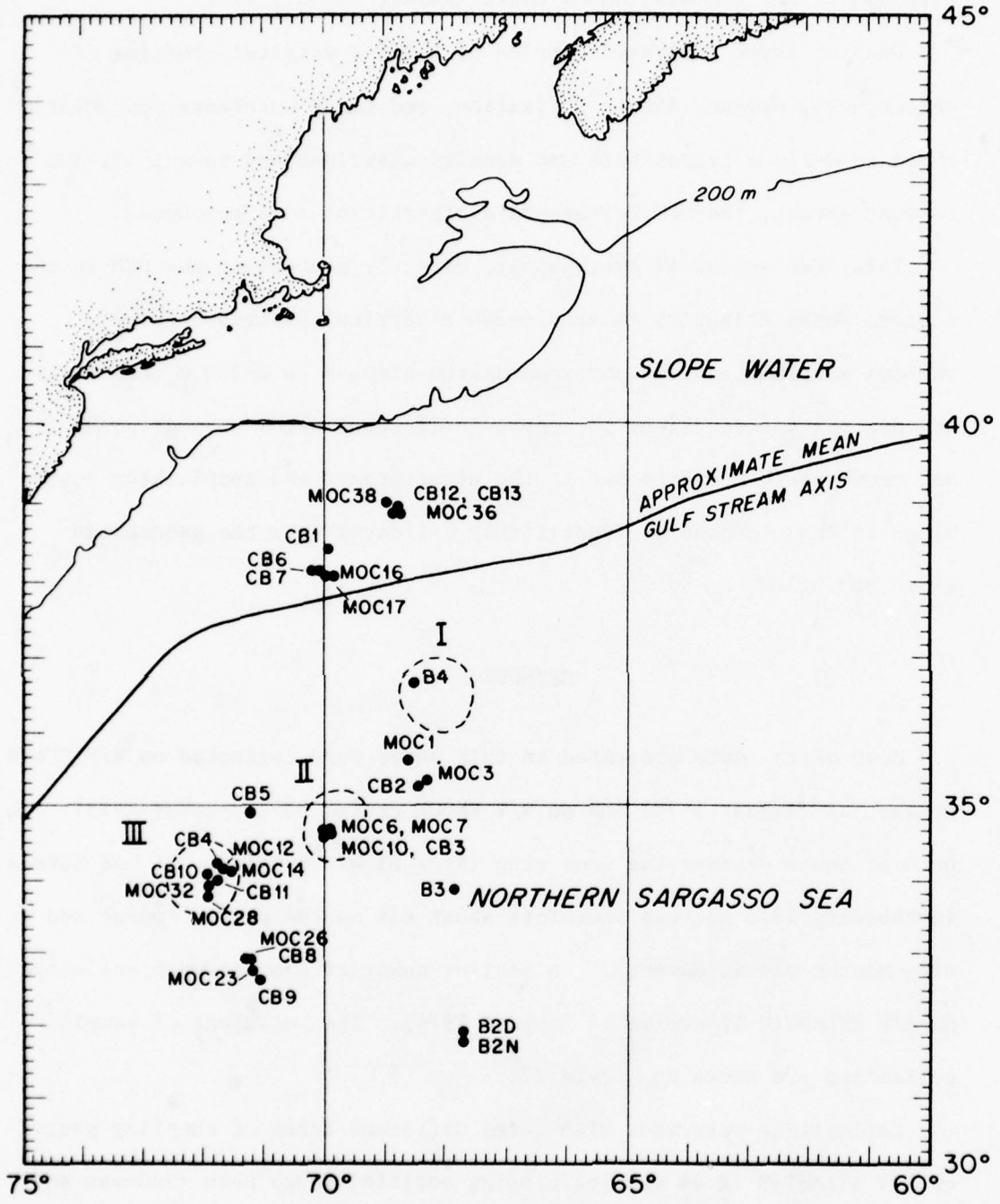


Figure 27. Positions of zooplankton tows. The position of B 1 (ATLANTIS II 84) is given in Table 16. I, II, III, indicate approximate Gulf Stream cold core ring positions on ATLANTIS II 84, CHAIN 125, and KNORR 53, respectively. Note stations CB 4, MOC 12, and MOC 14 were not taken in a ring because at that time ring D was at position II.

Both the Bongo nets and the MOCNESS nets were constructed with .335 μm Nitex nylon gauze, while Clark-Bumpus nets were made of 67 μm nylon gauze: depth recorders and flow meters were used on all tows.

Towing procedure varied with the sampling gear employed. Three Bongo nets were placed on the wire at equal intervals, the topmost net submerged, and all nets opened by dropping a messenger weight. The nets were then hauled obliquely to a predetermined depth. When the topmost net had resurfaced a second messenger was dropped closing all three nets. The intervals sampled were chosen so that the DCM at that station would be located in the middle of the interval sampled by the second net. Bongo net sampling was done at night. If both nets of each paired Bongo net functioned properly, two estimates of the zooplankton in each depth interval would be obtained at every station.

MOCNESS sampled obliquely from 200 m to the surface in 25 m intervals.[21] MOCNESS collections were made both during the day and at night. Clarke-Bumpus sampling was also conducted both during the day and at night according to the following procedure. Five Clarke-Bumpus samplers were placed on the hydrowire at 36 m intervals, i.e., 25 m sampling intervals assuming a constant 45° wire angle, and opened by dropping a messenger when the topmost net had either submerged (the first cast: 0-125 m) or had reached sampling depth (the second cast: 75-200 m). The nets were towed obliquely and closed by dropping a second messenger when the topmost net had reached its starting depth. If all nets functioned properly the central 75-100 m and 100-125 m depth intervals would be sampled twice at every station.

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[21] 0-800 m MOCNESS tows taken on the same cruises are discussed in Chapter One.

Ship speed for all tows was closely monitored and kept at approximately two knots. The types of tows obtained, the dates and times of sampling, and the latitude and longitude at which each tow was initiated are given in Table 16. All samples were presented in 5-10% formalin buffered to pH 8.0 with sodium tetraborate.

Zooplankton biomass in MOCNESS and Bongo samples was measured by the displacement volume method of Ahlstrom and Thrailkill (1963) as described in Chapter One[22] and usually converted to mg C/m^3 according to an equation given in Wiebe *et al.* (1975). Salp-rich samples were converted to biomass by assuming salps constitute 100% of the sample, salps are 99% H_2O (Madin, personal communication), and salp tissue when dried averages 23% carbon (Silver, 1971). Such samples are noted in the text.[23] One effect of this computation is to alter the day/night biomass ratio earlier determined from displacement ratios (compare MOC 16 and MOC 17 in Figures 29 and 1). The salp-dominant biomass calculation used here when applied to the same data resulted in biomass estimates close to those obtained by measuring each individual salp in a sample, applying an experimentally determined species-specific length to carbon regression, and then summing the individual contributions. Zooplankton biomass in Clarke-Bumpus samples was measured after taxonomic enumeration and subdivision of the sample with a Folsom plankton splitter (McEwen *et al.*, 1954). An aliquot of each Clarke-Bumpus sample was

[22] After biomass determination some of the samples were sorted for species identification.

[23] That method and the resulting biomass estimates are described in Wiebe, P. H., L. P. Madin, G. R. Harbison, L. R. Haury, and M. L. Philbin. Diel vertical migration by *Salpa aspera*: potential for large-scale particulate organic matter transport to the deep-sea. Submitted to Science.

Table 16. Summary of zooplankton sample stations (chronological order).

Cruise	Date	Station Code[a]	Position[b]	Time	Actual Stratum Sampled	Sampling Interval	N[c]
ATLANTIS II 84	8/13/74	B1	24°07',67°39'	2100	0-200 m	66 m	6
	8/16/74	B2D	31°42',67°41'	1500	0-205 m	70 m	5
	8/16/74	B2N	31°43',67°41'	2200	0-205 m	70 m	6
	8/17/74	B3	33°52',67°48'	2100	0-225 m	75 m	5
	8/19/74	B4	36°40',68°30'	2100	0-150 m	50 m	4
CHAIN 125	8/1/75	CB1	38°24',69°58'	1800	100-200 m	25 m	4
	8/4/75	MOC1	35°37',68°31'	2030	0-195 m	25 m	8
	8/5/75	MOC3	35°22',68°17'	1100	0-195 m	25 m	8
	8/5/75	CB2	35°18',68°21'	1930	0-125 m	25 m	6
	8/7/75	MOC6	34°34',69°52'	2300	0-195 m	25 m	8
	8/8/75	MOC7	34°33',69°51'	1300	0-195 m	25 m	8
	8/9/75	MOC10	34°33',69°53'	2345	0-195 m	25 m	8
	8/10/75	CB3	34°31',69°53'	1430	0-200 m	25 m	10
	8/11/75	MOC12	34°11',71°40'	0930	0-195 m	25 m	8
	8/11/75	MOC14	34°10',71°34'	2020	0-195 m	25 m	8
	8/12/75	CB4	34°10',71°37'	1400	0-200 m	25 m	9
	8/13/75	CB5	34°06',71°22'	0400	0-200 m	25 m	10
	8/14/75	MOC16	38°02',69°59'	2020	0-195 m	25 m	8
	8/15/75	MOC17	38°04',69°58'	1030	0-195 m	25 m	7
	8/15/75	CB6	38°08',70°07'	2300	0-200 m	25 m	9
	8/16/75	CB7	38°04',70°03'	0630	0-150 m	25 m	6
KNORR 53	11/17/75	MOC23	32°44',71°10'	0900	0-195 m	25 m	8
	11/18/75	CB8	32°50',71°09'	2000	0-200 m	25 m	8
	11/18/75	MOC26	32°52',71°08'	2240	0-195 m	25 m	8
	11/19/75	CB9	32°48',71°06'	0730	0-200 m	25 m	8
	11/21/75	MOC28	33°49',71°54'	1430	0-195 m	25 m	8
	11/22/75	MOC32	33°56',71°54'	1900	0-195 m	25 m	7
	11/23/75	CB10	34°03',71°54'	1130	0-200 m	25 m	8
	11/23/75	CB11	34°00',71°48'	2200	0-200 m	25 m	8
	11/27/75	CB12	38°55',67°46'	1500	0-100 m	25 m	4
	11/27/75	MOC36	38°56',67°47'	2230	0-195 m	25 m	7
	11/28/75	MOC38	38°55',67°54'	1530	0-195 m	25 m	7
	11/28/75	CB13	38°55',67°49'	1800	0-100 m	25 m	4

[a] B = Bongo net; MOC = MOCNESS; CB = Clarke-Bumpus sample.

[b] All positions north latitude and west longitude.

[c] N = number of samples obtained.

filtered upon pre-weighed glass fiber filters (Whatman GF/D, dried at 60° in a drying oven, and its weight determined by difference after water loss was complete. This value was converted to mgC/m^3 by an equation given in Wiebe *et al.* (1975).[24] In addition, counts of individual categories were converted to mgC/m^3 by multiplying $numbers/m^3$ by the appropriate values in Table 17.

Larger organisms in the Clarke-Bumpus samples, i.e., large copepods (> 1 mm); medium copepods (.5-1 mm); large ostracods (>.5 mm); euphausids; coelenterates; chaetognaths; larvaceans (largely appendicularians); amphipods; polychaetes; mysids, decapods, and molluscs (largely pteropods but occasionally heteropod larvae and benthic mollusc veligers as well) - were counted at low magnification (25x) in the entire sample. Smaller and more abundant organisms in the Clarke-Bumpus tows, i.e., nauplii; small copepods and copepodites (< .5 mm); dinoflagellates (largely *Ceratium* spp.); foraminiferans; and tintinnids - were counted after staining with Rose Bengal at moderate magnification (50x) in an aliquot of the entire sample.

The procedure was as follows: first a subsample was obtained using a Stempel pipette; then this subsample was dispersed with a detergent (Alconox) and transferred to a lucite counting tray with four separate rows. Rows were counted in random order until at least one hundred, but never more than one thousand, individuals were counted. To obtain a rough estimate of the errors involved in this procedure nine replicate trial counts were made on the nauplii in a representative sample. At an initial density of approximately 400 individuals per row the average

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[24] Note that the effect of these conversions is nonlinear since in Wiebe *et al.* (1975) equations operate on log transformed data. Thus, conversion defines the type of statistical analyses that are reasonable, i.e., ones insensitive to non-linearity.

Table 17. Functional Group Carbon Contents (mg/individual).

Group	∿ Length or Diameter (mm)	∿ Volume (μ^3)	∿ Wet Weight (mg)	∿ mg C/individual
Large copepods	1-4[a]	-	1.4[d]	1.1×10^{-1}
Ostracods	1.5[a]	-	2.9×10^{-1}[d]	2.3×10^{-2}
Larvaceans	1-5[a]	-	7.5×10^{-2}[d]	6.0×10^{-3}
Molluscs	.15-.25	1.22×10^{6}[g]	-	9.7×10^{-5}
Nauplii	.08-1.5[a]	2.36×10^{5}[c]	-	1.9×10^{-5}
Small or juvenile copepods	.2-.4[a]	1.57×10^{6}[c]	-	1.3×10^{-4}
Medium copepods	.75[a]	-	1.7×10^{-1}[d]	1.4×10^{-2}
Dinoflagellates	.045[b]	5.9×10^{4}[e]	-	2.2×10^{-6}
Foraminiferans	.08-2.0[b]	4.2×10^{4}[c]	-	3.3×10^{-6}
Tintinnids	.08[a]	1.1×10^{5}[f,g]	-	8.8×10^{-6}
Chaetognaths	3-9	-	2.6×10^{-1}[d]	2.1×10^{-2}

[a] Length

[b] Diameter

[c] Volume from Beers et al. (1975), then 1 μ^3 = 8×10^{-11} mg C, i.e., tissue density ≈ 1.0, dry weight ≈ 20% wet weight, and carbon ≈ 40% dry weight.

[d] Wet weight obtained directly or (extrapolated) from Isaacs et al. (1969) then calculated with the same assumptions as above.

[e] Appendix A, Ceratium trichoceros.

[f] Calculated with the assumption that protoplast volume = 1/2 lorica volume (Beers, 1975) and a tintinnid lorica is one-half of an oblate spheroid.

[g] By geometric approximation.

error (± two standard deviations/overall mean) between pipette subsamples was ± 6% and that between rows was ± 9%. Decreasing the density of individuals approximately by a factor of ten increased the average errors attributed to pipette subsampling and inter-row differences to ± 10% and ± 18% respectively. Although the exact errors associated with individual sample counts would be difficult to estimate, the two major sources of error (inter-row and inter-pipette differences) are small relative to the differences observed between samples.

In the following results, total biomass refers to the complete catch of a net whether it is a MOCNESS or Clarke-Bumpus net. Macrozooplankton and microplankton specifically refer to the catch of a .333 μm mesh net (MOCNESS or Bongo) and to that fraction of the .67 μm catch (Clarke-Bumpus) that was not sampled by the larger nets. The relative contribution of microplankton biomass to total Clarke-Bumpus net biomass is small, therefore, the term total biomass is used for the complete catch of any of the nets.

Temperature and salinity profiles accompany each tow with MOCNESS since it is equipped with a CTD. For Bongo or Clarke-Bumpus tows the temperature structure had to be estimated from the nearest XBT, CTD, or hydrocast. Most often these profiles were taken within an hour of the tow. In the results that follow biomass and functional group abundance data are interpreted in relation to temperature profiles because water bottle casts and net tows could not be taken simultaneously. Inter-station variability should be reduced by this procedure.

RESULTS

In the following sections the vertical distributions of zooplankton biomass, copepod naupliar and post-naupliar pooled biomass, and various zooplankton taxa or functional groups will be related to prevailing hydrography in the Northern Sargasso Sea, in a Gulf Stream cold core ring, Ring D, and the Slope Water. In Chapter Three depth intervals at and about a seasonal thermocline were shown to often represent a significant food resource, therefore our particular concern will be to analyze the above distributions with respect to the strength and position of the seasonal thermocline.

Total Biomass, August 1975

Zooplankton biomass data were obtained from both MOCNESS tows and Clarke-Bumpus sampler tows in the Northern Sargasso Sea, Ring D, and the Slope Water in August 1975 (Figure 28). Day and night average 0-200 m biomass values (mgC/m^2) in MOCNESS and Clarke-Bumpus tows in each region sampled were:

	Northern Sargasso Sea	Ring D	Slope Water
CB-Day	132	100	480
CB-Night	174	-	1478*
MOC-Day	163	95	581
MOC-Night	350	216	1550*

Starred samples, at least at some depths, were overwhelmingly dominated by salps. The biomass at those depths was calculated differently than that of the other samples (see Methods).

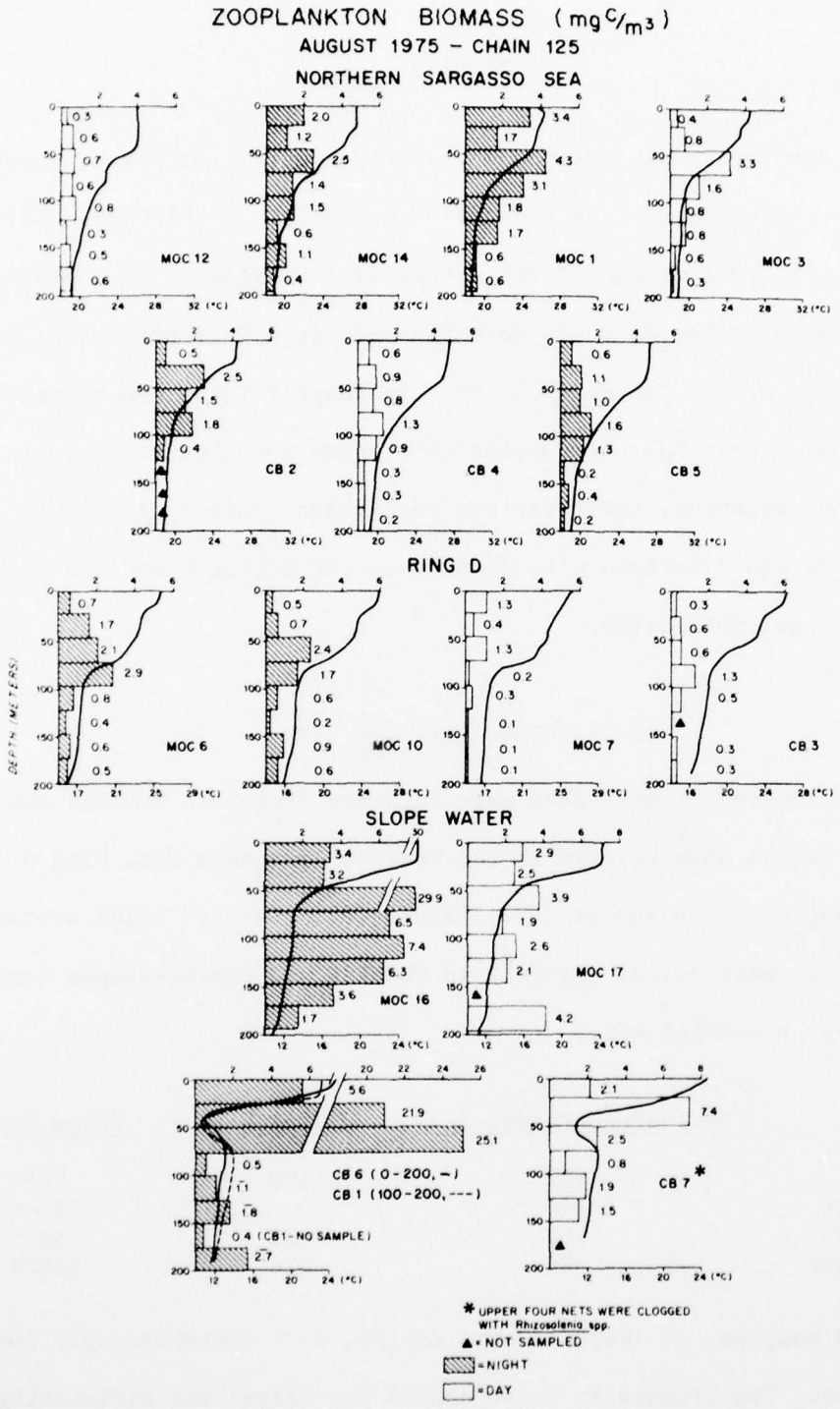


Figure 28. Zooplankton biomass (mg C/m^3). August 1975 - R/V CHAIN cruise 125 in the Northern Sargasso Sea, Ring D, and the Slope Water. MOCNESS and Clarke-Bumpus net tows. Values given are mg C/m^3 over adjacent depth intervals. The 0-200 m temperature structure at the station or stations is superimposed on the biomass profile.

Differences between Samplers:

Biomass in Clarke-Bumpus day tows was not significantly different from biomass in MOCNESS day tows in the three regions sampled. For the Northern Sargasso Sea there are day and night biomass estimates, calculated by the same method, for both types of gear. In that data the night/day 0-200 m biomass ratio as determined by MOCNESS was 2.15 — not very different from either the ratio of 2.73 earlier determined for August 1974 or the August 1975 Ring D MOCNESS ratio of 2.27.[25] In contrast, the night/day 0-200 m biomass ratio was only 1.32 for Northern Sargasso Sea Clarke-Bumpus tows. In spite of this difference there appears to be no systematic difference in vertical distribution in Clarke-Bumpus and MOCNESS tows. To obtain a sufficient number of samples to statistically test some of the patterns observed, the Clarke-Bumpus and MOCNESS data have been considered to represent one data set.

Differences between Regions:

Systematic regional differences in 0-800 m zooplankton biomass have earlier been shown (see Table 2). Data here given corroborate that observation. In all three possible pair-wise comparisons 0-200 m average biomass in the Northern Sargasso Sea exceeded that in Ring D. In all three possible comparisons, 0-200 m average biomass in the Slope Water also exceeded that in Ring D. (Data for both comparisons given above.) If estimates of 0-200 m biomass derived from 0-800 m MOCNESS tows (data

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[25]Night/day biomass ratios based on displacement volume in both 0-200 m and 0-800 m MOCNESS tows are given in Table 6. In that data as well as the Ring D ratio exceeded the Northern Sargasso Sea ratio.

in Figure 1) are added to this data, the number of comparisons becomes sufficiently large (N = 10) to justify testing. The above differences between Ring D average 0-200 m biomass and that of the two other regions is clearly significant ($p < .05$, Sign test).

Differences in Vertical Distribution:

In most of the biomass profiles a subsurface peak occurred in the vicinity of the pycnocline and the DCM. The objective of the analysis which follows is to determine the statistical significance of these peaks. The null hypothesis is that biomass values within a profile are not significantly different.

Seven 0-200 m tows were taken in the Northern Sargasso Sea with MOCNESS and Clarke-Bumpus samplers (Figure 28). Omitting CB2 because of its numerous missing values and ranking the 25 m interval biomass estimates in the remaining six tows, the significance of individual depth interval differences can be calculated by the method of Nemenyi (1963) without multiple-testing. A ranking procedure prevents tows with higher overall biomass from dominating the analysis. The most significant differences were as follows: 50-75 m biomass >125-150 m, >150-175 m, and >175-200 m biomass; 75-100 m biomass >125-150 m, >150-175 m, and >175-200 m biomass; 100-125 m biomass >175-200 m biomass ($p < .05$). That is, 50-100 m was significantly greater than that above and below. The temperature profiles accompanying the biomass histograms indicate that 50-100 m enclosed the base of the seasonal thermocline in the Northern Sargasso Sea. It is suggestive that at CB2 the top of the thermocline was shallower than at any of the other stations and at that station anomalously high 25-50 m biomass was observed.

Four 0-200 m MOCNESS and Clarke-Bumpus tows were taken in Ring D (Figure 28). After interpolating to generate the single missing value in CB3, the significance of individual depth interval differences can be calculated as above. The most significant differences were as follows: 50-75 m biomass >125-150 m, >150-175 m, and >175-200 m biomass; 75-100 m biomass >175-200 m biomass ($p < .05$). This statistical approach is extremely conservative when the number of comparisons is small (here N = only 4). If the level of significance is relaxed then: 75-100 m biomass >125-150 m and >150-175 m biomass ($p < .10$). In Ring D, as in the Northern Sargasso Sea, 50-100 m biomass exceeds that above and below. Accompanying temperature profiles again indicate that 50-100 m enclosed the base of the seasonal thermocline.

Four 0-200 m MOCNESS and Clarke-Bumpus tows were taken in the Slope Water (Figure 28). The statistical approach that has been used requires a balanced experimental design. Truncating 150-200 m seems preferable to generating three missing values, two of which would have to be extrapolated. Treating the combined profile as an entity, and considering only 0-150 m, the significance of individual depth interval differences can be calculated as above. The most significant biomass difference was 50-75 m biomass >75-100 m biomass ($p < .05$). Again relaxing the level of significance: 50-75 m biomass >100-125 m and >125-150 m biomass; 0-25 m biomass >75-100 m biomass ($p < .10$). Once again the subsurface peak is significant. In the Slope Water the 50-75 m interval usually enclosed the base of the seasonal thermocline. Total biomass clearly shows significant subsurface peaks centered at the seasonal thermocline. It is of interest to see if the microplankton fraction of total biomass (see Methods) does likewise.

Corroborating Biomass Data, August 1974

Data from an earlier cruise, August 1974, partially corroborate some of the observations made during August 1975 (Figure 29). Samples were obtained with Bongo nets. The number of samples is too few to attach statistical significance to the results obtained, but for comparisons sake the following observations can be made. On a mg C/m^2 basis zooplankton biomass increased with latitude in the Sargasso Sea - i.e., B3 > B2N > B1. In the single day/night station the ratio of mg C/m^2 biomass to mg C/m^2 day biomass was 2.73 (0-200 m). Zooplankton biomass inthe Gulf Stream cold core ring station was considerably larger than that at any of the Sargasso Sea stations. For example, B4 mg C/m^2 ÷ B3 mg C/m^2 = 3.9 (0-150 m only). The middle interval at each station encompassed the deep chlorophyll maximum. Biomass in the middle interval was largest in three of five tows. It greatly exceeded the adjacent intervals only at the ring station. That particular biomass peak coincided with the steepest temperature gradient measured at any of the five stations.

Microplankton Biomass, August 1975

Naupliar and post-naupliar copepods were numerically dominant in the microplankton fractions of all Clarke-Bumpus samples since their carbon content per individual is very much greater than that of the other microplankton groups (see Table 17) their contribution typically represented close to 99% of microplankton carbon. Naupliar and post-naupliar pooled biomass (mg C/m^3) in the Northern Sargasso Sea, Ring D, and the

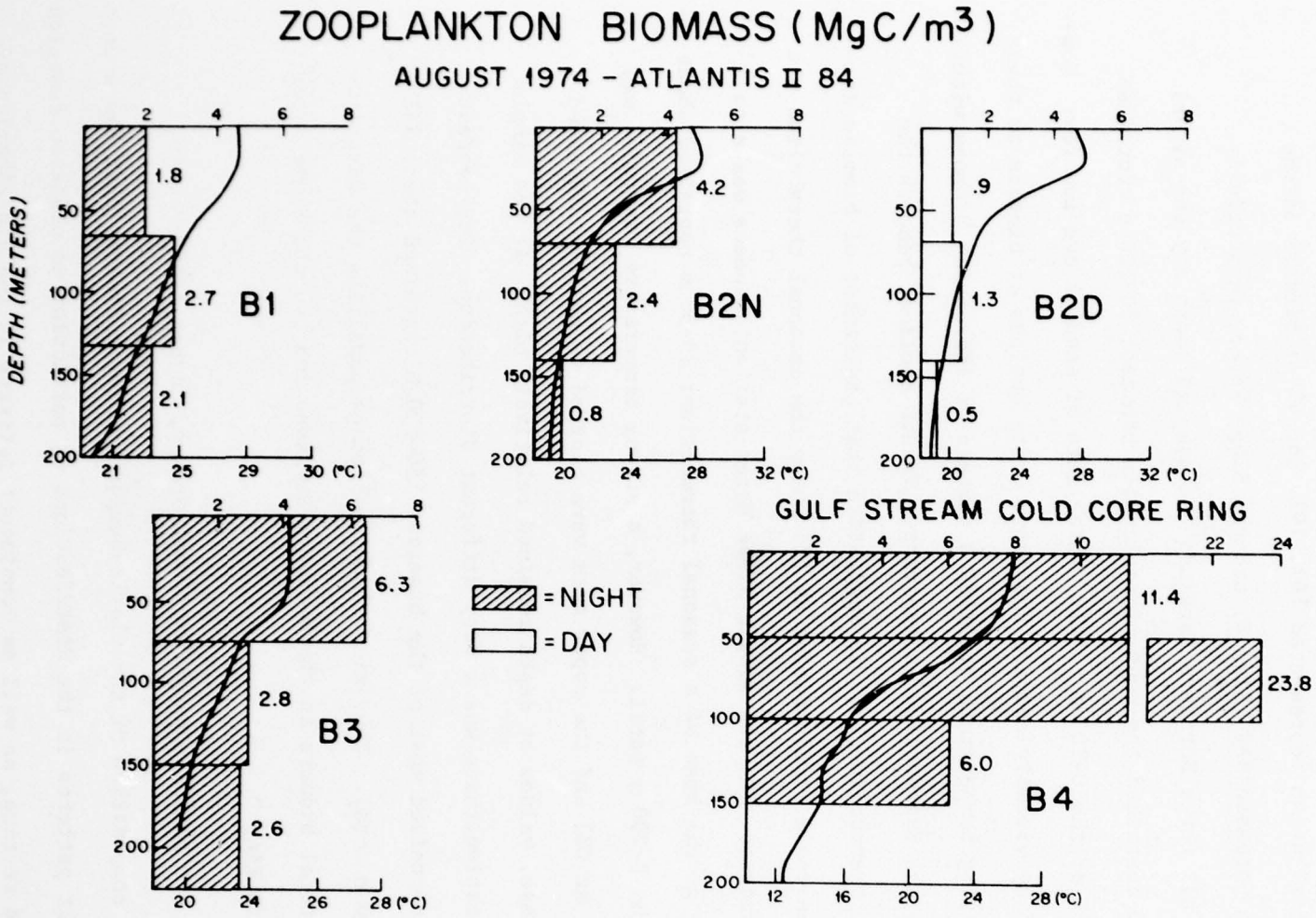


Figure 29. Zooplankton biomass (mg C/m^3) in the Sargasso Sea and a Gulf Stream ring, August 1974 - R/V ATLANTIS II cruise 84. Bongo net tows. Values given are mg C/m^3 over adjacent depth interval.

Slope Water is shown in Figure 30. In the Clarke-Bumpus tows depicted, this contribution represented 16%, 19%, and 4% of biomass in the Northern Sargasso Sea, Ring D, and the Slope Water, respectively.

In all three Northern Sargasso Sea samples (both day and night) 75-100 m contained the most microplankton biomass; 50-100 m contained about 43% of the 0-200 m total. Three sets of samples are too few. However, if we visually compare the above distributions of biomass to their accompanying temperature profiles a pattern of increasing biomass within the seasonal thermocline is apparent. Values declined beneath the seasonal thermocline. It is suggestive that the center of biomass distribution was a little deeper at CB5 where the seasonal thermocline was also depressed. At the single Slope Water station, biomass was also greatest at the base of a seasonal thermocline; 25-50 m contained about 29% of the 0-200 m total. However, a strong temperature inversion was observed at CB7 and the upper nets were clogged as earlier discussed. In any case, values at depth remained relatively high. At the single Ring D station,there was a very different distribution. The deepest samples contained most of the biomass: 150-500 m contained about 35% of the 0-200 m total. Thus microplankton biomass parallels the distribution of total biomass in the Northern Sargasso Sea and the Slope Water, but not in Ring D.

Distribution of Functional Groups, August 1975

The composition of the Clarke-Bumpus samples indicates that there were consistent patterns in the distributions of particular zooplankton functional groups or taxa, as well as consistent patterns in the distribution of zooplankton biomass, in the three areas investigated in August 1975.

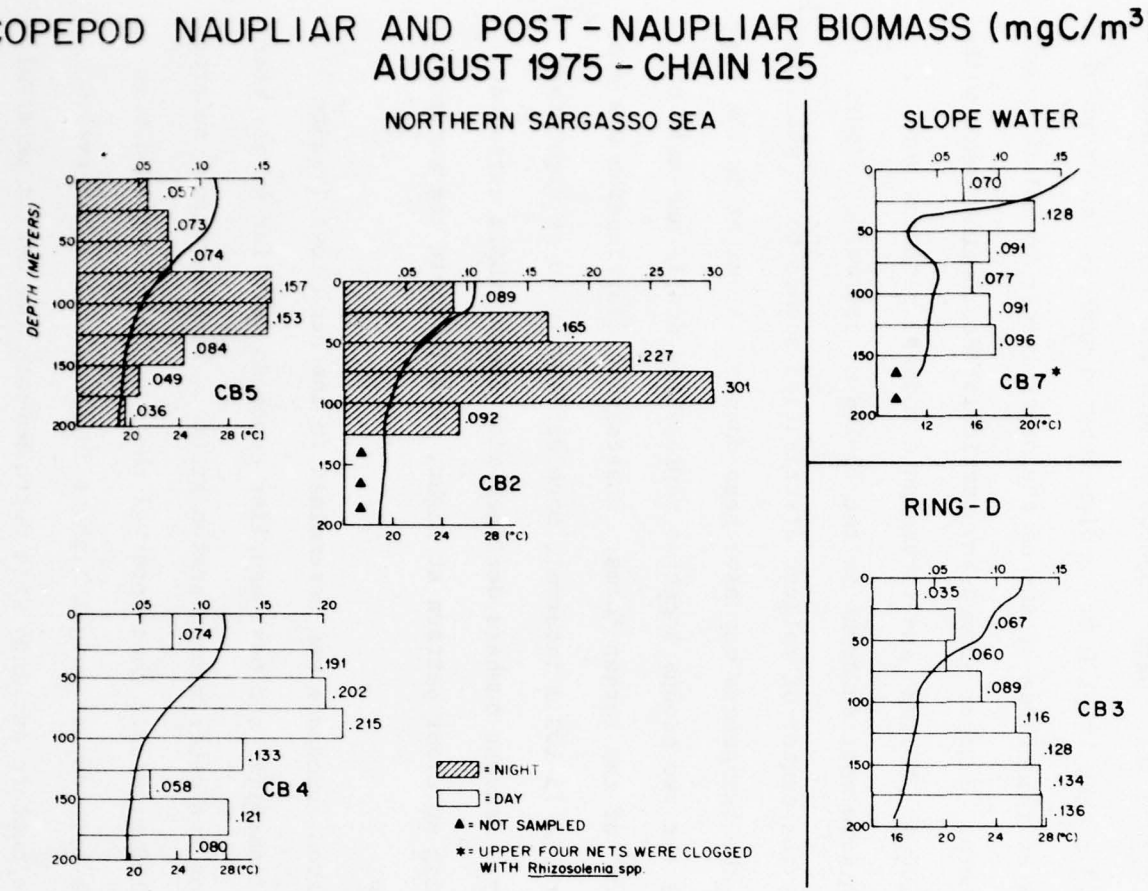


Figure 30. Histograms of pooled copepod naupliar and post-naupliar calculated biomass plotted versus depth - August 1975 - R/V CHAIN 125 - in the Northern Sargasso Sea, Ring D and the Slope Water. 0-200 m temperature structure at each station is superimposed on the biomass profiles.

Average zooplankton functional group or taxa abundance day and night in Northern Sargasso Sea was determined from Clarke-Bumpus tows: CB4, CB2, and CB5 (Figure 31). Large copepod numbers were higher both day and night 0-100 m than 100-200 m. Medium copepod numbers (an order of magnitude greater than those of any of the other larger forms) followed a similar pattern. Neither showed any particular depth preference within the upper 100 m. Mollusc and larvacean abundance patterns were similar. Both were most numerous in the 75-100 m interval at night. During the day the center of mollusc distribution seemed to be shallower, while that of the larvaceans may have been deeper. At night in the 75-100 m interval the two groups together represented nearly one-half of total numbers/m^3 of the larger forms. Chaetognath distribution was also centered about the 75-100 m interval, more definitely so at night than during the day. Medusae numbers declined with depth, while ostracod numbers, showing no clear pattern at night, were low near the surface during the day.

Microplankton abundance was determined in the same tows (Figure 3). The numbers of naupliar and post-naupliar copepods were far larger than those of any of the other microplankton groups. Both were most numerous in the upper 100 m; within that interval their numbers increased with depth and were both day and night highest in the 75-100 m interval. Dinoflagellate numbers declined with depth beneath the 0-25 m interval showing no day/night difference in depth preference. Tintinnid numbers may have been a little greater 100-200 m than 0-100 m. At night tintinnid distribution was centered about the 75-100 m depth interval. Foraminiferan numbers were low and generally declined with depth.

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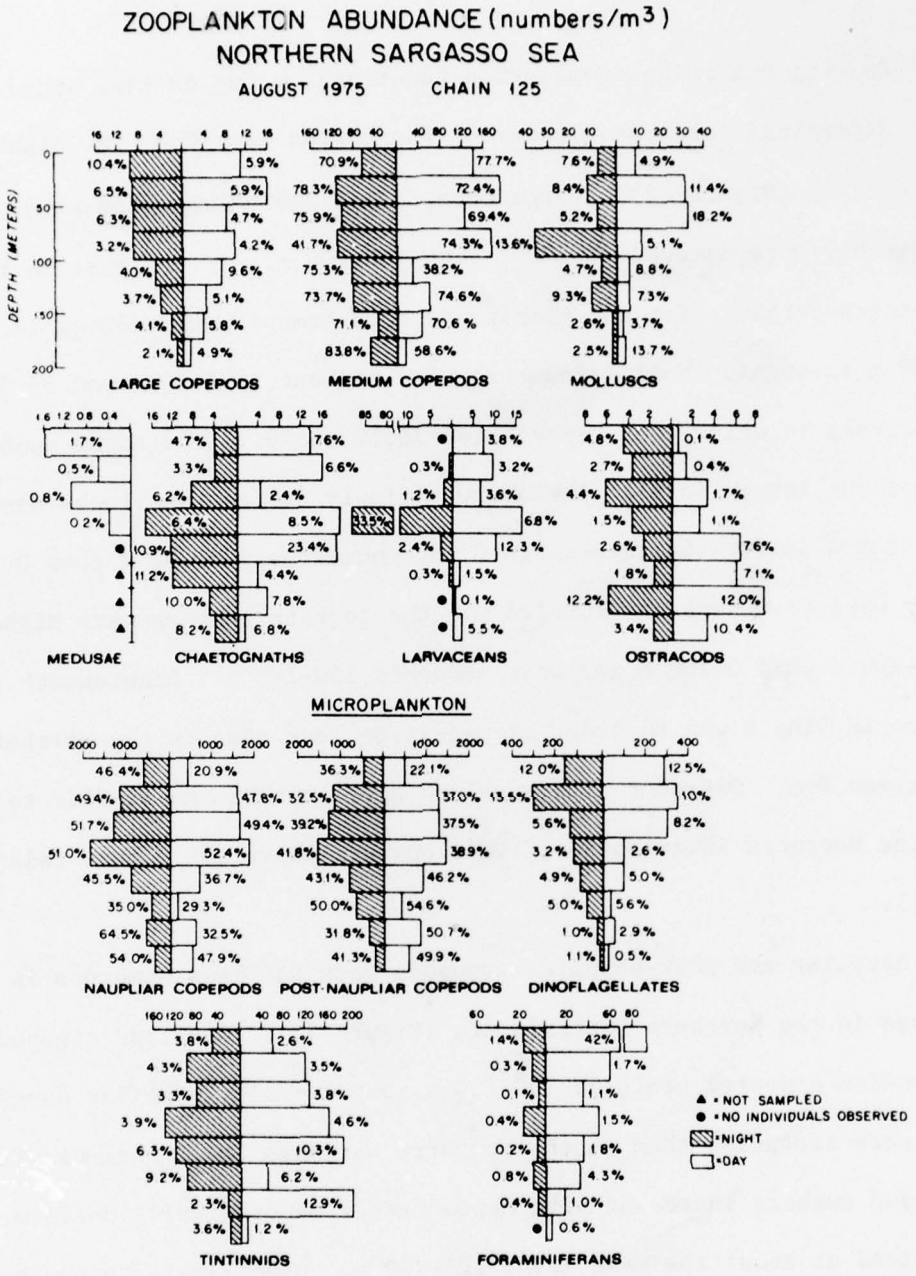


Figure 31. Vertical distribution of Northern Sargasso Sea zooplankton taxa and functional groups. August 1975 - R/V CHAIN cruise 125. Data from CB 4 (day), and both CB 2 and CB 5 (averaged for night value). Values given are the percentage contribution of the particular group to the total number of individuals sampled in the particular depth stratum. Note that day and night tows do not necessarily represent a single sampling station.

In Ring D average zooplankton functional group or taxa abundance was determined for a single day Clarke-Bumpus tow: CB3 - no night tows were taken (Figure 32). Large copepod and medium copepods were considerably more numerous 0-100 m than 100-200 m. In contrast to the Northern Sargasso Sea the numbers of both groups were reduced in the 0-25 m interval. Mollusc numbers were highest in 0-25 m and 25-50 m intervals in which they represented 76.1% and 91.1% of total numbers/ m^3 of the larger forms. The overwhelmingly dominant molluscs were heteropod larvae. Larvaceans were more numerous 100-200 m than 0-100 m; they were most numerous 100-125 m. Chaetognath numbers were higher 100-200 m than 0-100 m and most numerous 150-175 m. Chaetognath abundance in Ring D was an order of magnitude less than in the Northern Sargasso Sea. Ostracod abundance and distribution were similar to that in the Northern Sargasso Sea, i.e., numbers above 100 m were relatively small.

Naupliar and post-naupliar copepods were far less numerous in Ring D than in the Northern Sargasso Sea (Figure 32). Naupliar copepod distribution appeared centered 100-125 m, but overall, naupliar abundance was more irregular than in the Northern Sargasso Sea. Post-naupliar copepod numbers increased with depth nearly monotonically 0-125 m, but remained at about the same level 125-200 m. Dinoflagellate numbers declined with depth from the surface. Tintinnid numbers were low 0-50 m and irregularly higher elsewhere. Again, foraminiferan numbers were low and generally declined with depth. The pattern in Ring D is substantially different from that found in the Northern Sargasso Sea.

Average zooplankton taxa or functional group day abundance was determined in a single day Slope Water Clarke-Bumpus tow (CB7: no night

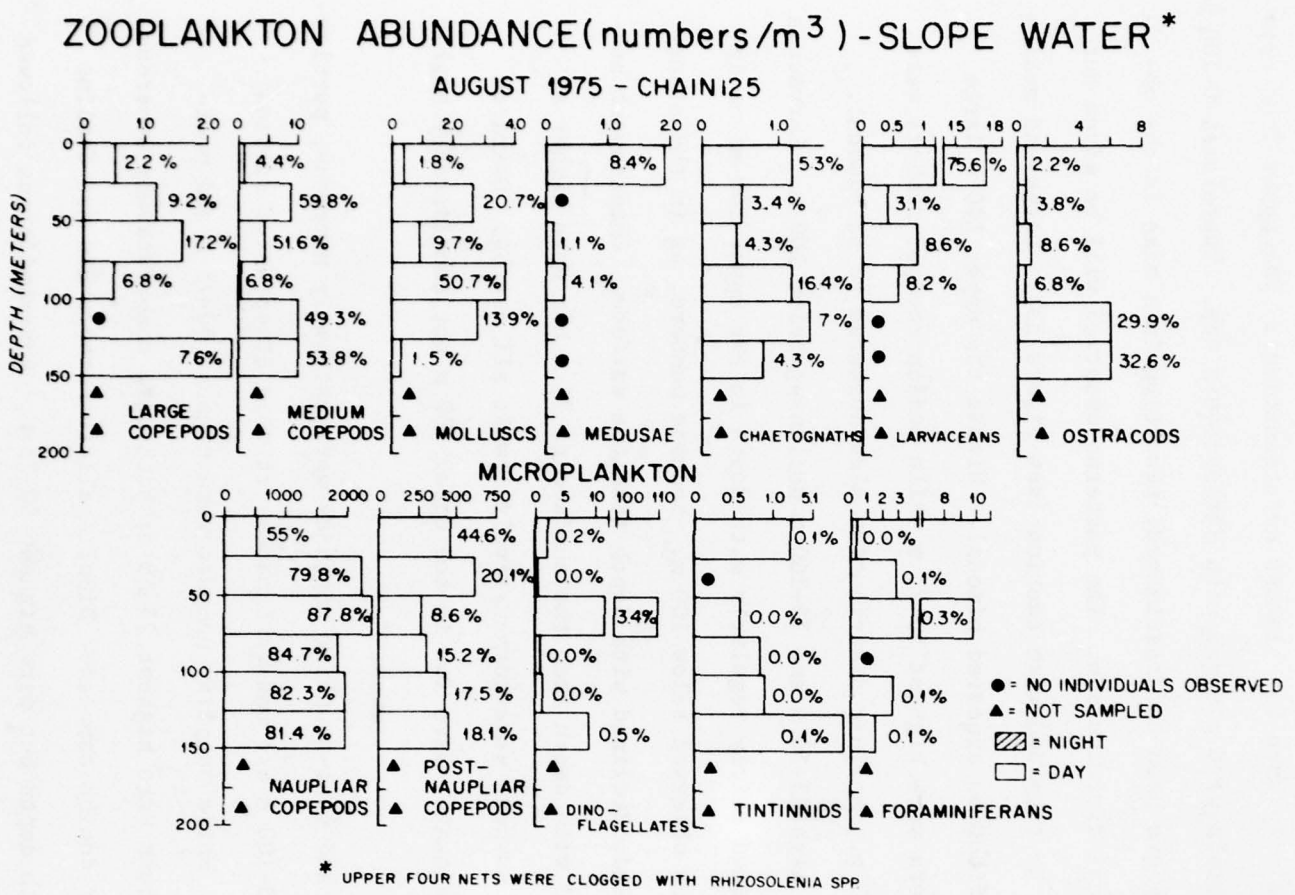


Figure 32. Vertical distribution of Ring D zooplankton taxa and functional groups. August 1975 - R/V CHAIN cruise 125. Data from CB 3 (day). Values given are the percentage contribution of the particular group to the total number of individuals sampled in the particular depth stratum.

samples were enumerated because the samples were so dominated by salps they could be only used for biomass determination). The upper four nets in the day sample were clogged with *Rhizosolenia* spp. Therefore, 0-100 m abundance mayhave been underestimated, resulting in a bias in the observed vertical distribution. The patterns observed will be given but they have to be regarded with caution (see Figure 33). Large and medium copepod distribution appeared bimodal. Within the upper 100 m large copepod numbers were highest 50-75 m while medium copepod numbers were highest 25-50 m. Mollusc distribution also appeared to be bimodal. Numbers were high 25-50 m and 75-100 m declining below 100 m. Larvacean numbers declined fairly regularly with depth in the upper 100 m; no individuals were observed below 100 m. Medusae numbers, as in the other regions sampled, declined with depth from the surface. Chaetognath numbers declined with depth from the surface to 75 m but were higher at depth; their numbers were comparatively low at all depths. Ostracod numbers, once again, were low in the upper 100 m but considerably higher below 100 m.

Naupliar and post-naupliar copepods were extremely numerous, particularly so if 0-100 m are underestimates, at this Slope Water station (Figure 33). While naupliar numbers were highest 50-75 m and post-naupliar numbers were highest 25-50 m; both were comparatively numerous in the deeper depths sampled. Dinoflagellate numbers did not decline uniformly with depth but were highest 50-75 m. Foraminiferans followed a similar pattern. Tintinnid numbers, low relative to other regions, were highest in the deeper samples.

Functional group abundance patterns differed between the three regions. Patterns in the Northern Sargasso Sea microplankton most closely

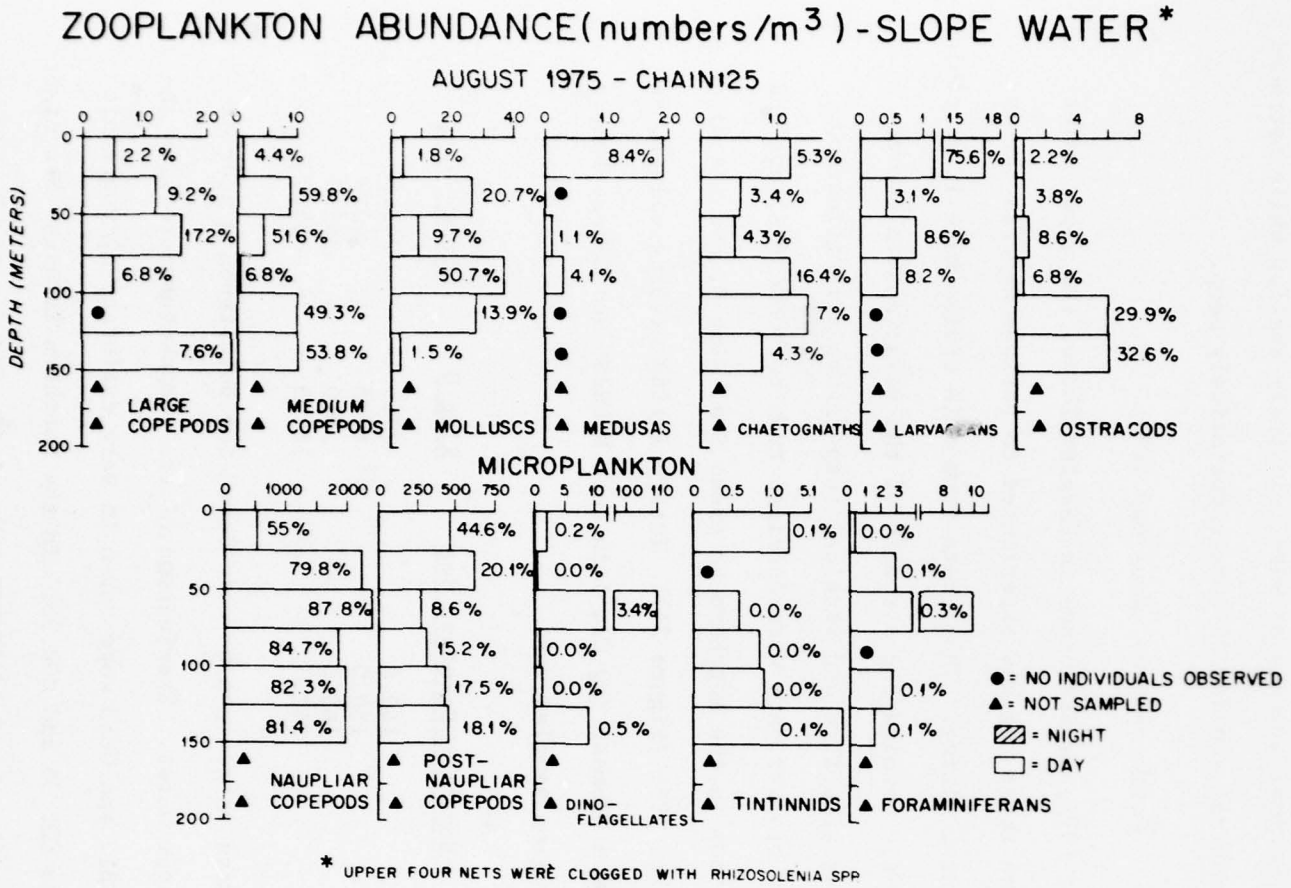


Figure 33. Vertical distribution of Slope Water zooplankton taxa and functional groups. August 1975 - R/V CHAIN cruise 125. Data from CB7 (day). Values given are the percentage contribution of the particular group to the total number of individuals sampled in the particular depth stratum.

paralleled the total biomass pattern of a peak at the depth of the approximate seasonal thermocline. In all regions foraminiferan and dinoflagellate maximal abundances were relatively shallow while ostracod and tintinnid maximal abundances were comparatively deep.

Total Biomass, November 1975

In November 1975, as discussed in Chapter Three, the upper water columns in these three regions experienced to various degrees the initiation of winter mixing. Thus, data from this cruise make it possible to more rigorously examine the strength of the relationship between vertical biomass structure and vertical temperature stratification.

Zooplankton biomass data were obtained from both MOCNESS tows and Clarke-Bumpus tows in the Northern Sargasso Sea, Ring D, and the Slope Water in November 1975 (Figure 34). Interpolating missing values, day and night 0-200 m biomass (mg C/m^2) in both MOCNESS and Clarke-Bumpus tows in each region sampled was:

	Northern Sargasso Sea	Ring D	Slope Water[26]
CB Day	140.0	77.5	242.5
CB Night	160.0	62.5	40.5
MOC Day	165.0	55.0	365.0
MOC Night	242.5	162.5	858.0

Night/day biomass ratios can be calculated for both types of gear except in the Slope Water. Examination of the temperature profiles indicates that CB12 and CB13 were taken in very different hydrographic regimes as were MOC 36 and MOC 38. In the Northern Sargasso Sea night/day biomass ratios were for MOCNESS tows, 1.47, and for Clarke-Bumpus

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26 Slope Water Clarke-Bumpus biomass values 0-100 m only.

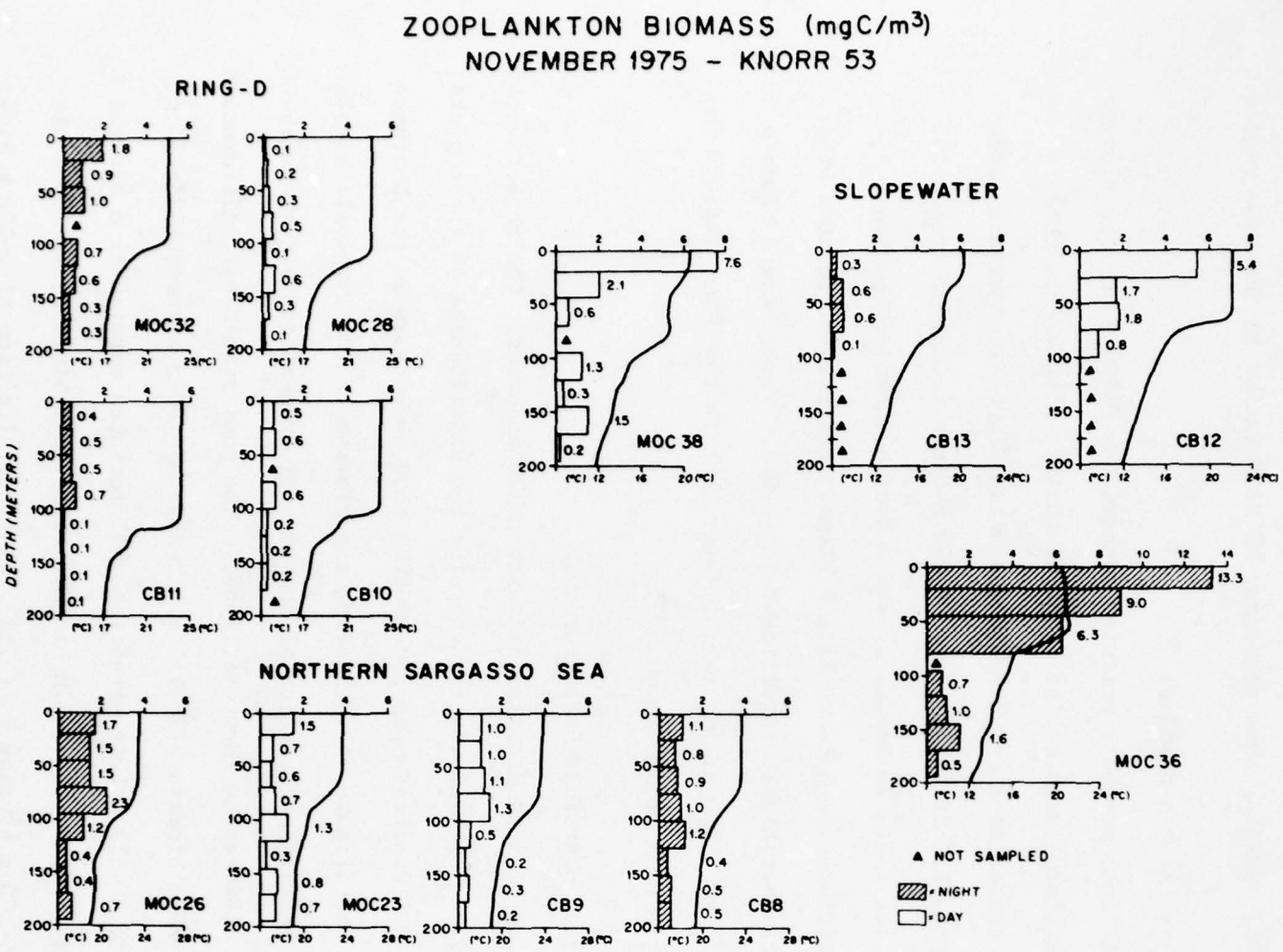


Figure 34. Zooplankton biomass (mg C/m^3). November 1975 - R/V KNORR cruise 53. MOCNESS and Clarke-Bumpus net tows. Values given are mg C/m^3 over adjacent depth intervals. The temperature structure at the particular station is superimposed on the biomass profile.

tows, 0.81.[27] As in August 1975, Clarke-Bumpus night/day ratios were consistently smaller than night/day MOCNESS ratios in the same region.

Differences between Regions:

In all four possible pairwise comparisons 0-200 m average biomass in the Northern Sargasso Sea exceeded that in Ring D. In three of four possible comparisons 0-200 m biomass in the Slope Water also exceeded that in Ring D. If estimates of 0-200 m biomass derived from 0-800 m MOCNESS tows (data in Figure 2) are added to these data; then N = 12, and the differences between Ring D biomass and that of the two other regions becomes highly significant ($p < .01$). Thus, Ring D biomass in the upper 200 m was significantly lower than in the other regions in November as well as in August 1975.

Differences in Vertical Distribution:

In some biomass profiles definite peaks occurred. The objective of the following analysis is to determine the significance of these peaks. Four 0-200 m Clarke-Bumpus and MOCNESS tows were taken in the Northern Sargasso Sea (Figure 34). Ranking the biomass of the intervals within each tow permits calculation of the significance of individual depth interval differences (Nemenyi, 1963). The most significant differences were: 0-25 m biomass >125-150 m biomass; 75-100 m biomass >125-150 m biomass ($p < .05$). Less significant differences were: 0-25 m biomass > 175-200 m biomass; 100-125 m biomass >175-200 m biomass; 75-100 m biomass >175-200 m biomass ($p < .10$). A larger fraction of 0-200 m biomass was found near the surface in November 1975 than in August 1975.

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[27] Biomass ratios based on displacement volume in both 0-200 m and 0-800 m MOCNESS tows are given in Table 6. In that data as well the Ring D ratio exceeded both Northern Sargasso Sea and the Slope Water ratio.

Despite this, there still appeared to be a small, but definite, enhancement of biomass about the base of the seasonal thermocline.

Four 0-200 m Clarke-Bumpus and MOCNESS tows were taken in Ring D (Figure 34). Averaging these to obtain a composite profile (after interpolating or extrapolating to generate the missing values), depth intervals containing the highest percentages of 0-200 m biomass were 0-25 (20%), 25-50 m (15%), 50-75 m (17%), and 75-100 m (19%). The significance of individual depth interval differences can be calculated as above (Nemenyi, 1963). The most significant difference was 75-100 m biomass >175-200 m biomass ($p < .05$). Less significant differences were: 75-100 m biomass >100-125 m, >125-150 m, and >150-175 m biomass; 0-25 m biomass >175-200 m biomass, and 50-75 m biomass >175-200 m biomass ($p < .10$). As in the Northern Sargasso Sea near surface biomass was greater in November 1975 than in August 1975. Overall, 0-200 m biomass declined between August and November 1975. Despite these changes a minor concentration of biomass was noted at approximately the same depth as in August, but just above a seasonal thermocline in the process of erosion.

Four tows were taken in the Slope Water — two 0-200 m MOCNESS tows and two 0-100 m Clarke-Bumpus tows (Figure 34). The significance of individual depth interval differences can be calculated as above if we consider only 0-100 m with $N = 4$. Under these conditions the method we have used (Nemenyi, 1963) will be overly conservative. The most significant interval differences were 0-25 m biomass >75-100 m biomass ($p < .05$) and 25-50 m biomass >75-100 m biomass ($p < .10$). As in both the Northern Sargasso Sea and Ring D, the relative contribution of near surface biomass was greater in November 1975 than in August 1975. On the average, biomass

in November declined with depth and there was no trace of subsurface biomass maximum. Biomass declined sharply beneath an isothermal 0-50 m layer.

Microplankton Biomass, November 1975

Naupliar and post-naupliar copepods were numerically dominant in the microplankton fraction of all Clarke-Bumpus samples. As earlier discussed, their contribution typically represented close to 99% of microplankton carbon. Naupliar and post-naupliar pooled biomass (mg C/m^3) in the Northern Sargasso Sea, Ring D, and the Slope Water represented on the average 22%, 23% and 10% of average total biomass[28] in the Northern Sargasso Sea, Ring D, and the Slope Water, respectively (Figure 35).

In the Northern Sargasso Sea the relationship between microplankton biomass and temperature differed at night and during the day. At night biomass was highest 100-125 m near the bottom of the maximal temperature gradient. During the day biomass was highest 75-100 m at the top of the maximal temperature gradient. In Ring D both day and night biomass was high in the 0-100 m isothermal layer and low beneath it. In the Slope Water both day and night there appeared to be a minor enhancement of biomass at a steep temperature gradient, nonetheless during the day the highest biomass concentration was 0-25 m. Unlike August, only in the Northern Sargasso Sea was there a microplankton biomass peak associated with the seasonal thermocline.

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[28] 0-200 m mg C/m^2 in the Northern Sargasso Sea and Ring D, but 0-100 m mg C/m^2 in the Slope Water.

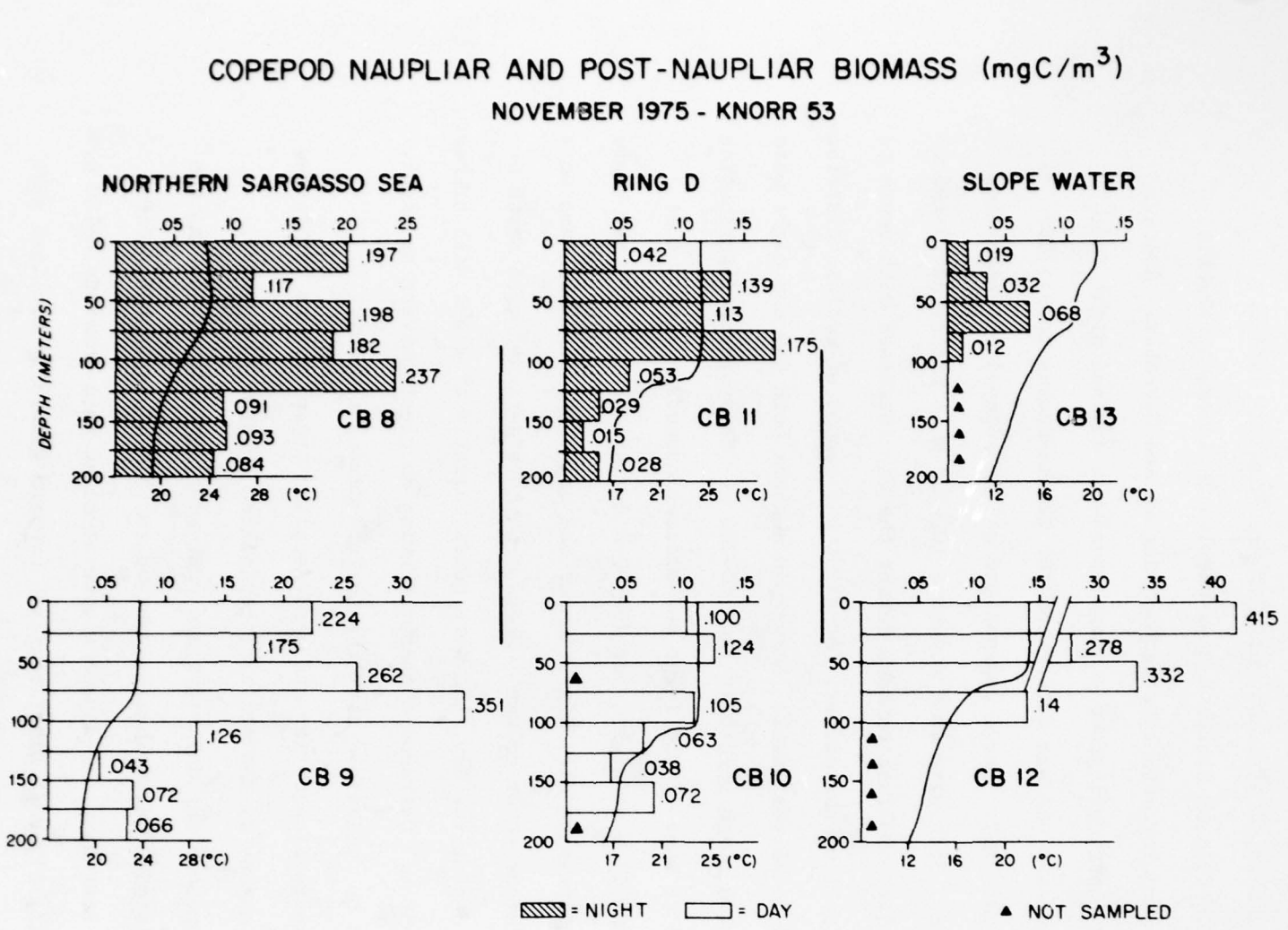


Figure 35. Histograms of pooled copepod naupliar and post-naupliar calculated biomass plotted versus depth - November 1975 - R/V KNORR 53 - in the Northern Sargasso Sea, Ring D, and the Slope Water. The temperature structure at the particular station is superimposed on the biomass profile.

Distribution of Functional Groups, November 1975

The composition of Clarke-Bumpus samples indicates substantial change in community structure between August and November. Average zooplankton functional group of taxa abundance day and night in Northern Sargasso Sea was determined for Clarke-Bumpus tows: CB8 and CB9 (Figure 36). Large copepod and medium copepod distributions were similar. Both were most numerous 100-125 m at night but 75-100 m during the day. Mollusc numbers during the day increased with depth to 100 m and declined thereafter. At night the center of mollusc distribution seemed to be shallower. Larvacean numbers both day and night were highest 75-100 m and generally low 100-200 m. Chaetognath distribution was similar to that of the large and medium copepods — i.e., most numerous 100-125 m at night, but 75-100 m during the day. Either there was a slight reverse diel migration or the night and day tows sampled a rather different water column. Medusae numbers declined with depth beneath 25 m during the day, but were quite variable at night with highest numbers 25-50 m. Ostracod numbers, showing no clear pattern at night, appeared to be diminished near the surface during the day.

The numbers of naupliar and post-naupliar copepods were far larger than those of any of the other microplankton groups (Figure 36). Naupliar copepods day and night and post-naupliar copepods during the day, had a similar distribution pattern to that of large and medium copepods. Post-naupliar copepods were at night most numerous 0-100 m, but only slightly so. Dinoflagellate numbers generally declined with depth, but at night the decline was quite irregular. Day and night tintinnid distribution seemed centered in the 75-100 m interval. Foraminiferan distribution was highly irregular but numbers were always low

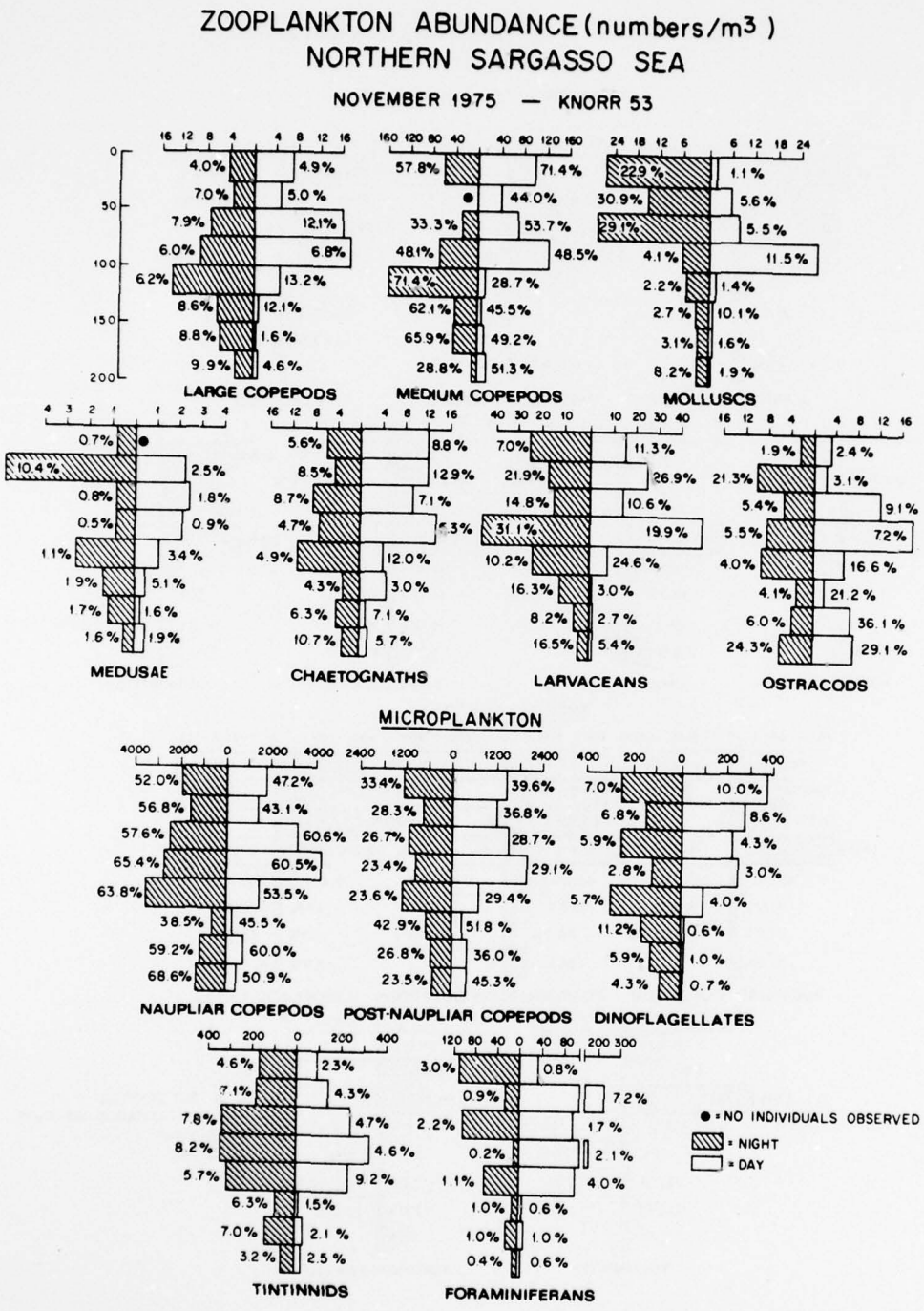


Figure 36. Vertical distribution of Northern Sargasso Sea zooplankton taxa and functional groups. November 1975 - R/V KNORR cruise 53. Data from CB 9 (day) and CB8 (night). Values given are the percentage contributon of the particular groups to the total number of individuals sampled in the particular depth stratum. Note that day and night tows do not necessarily represent a single sampling station.

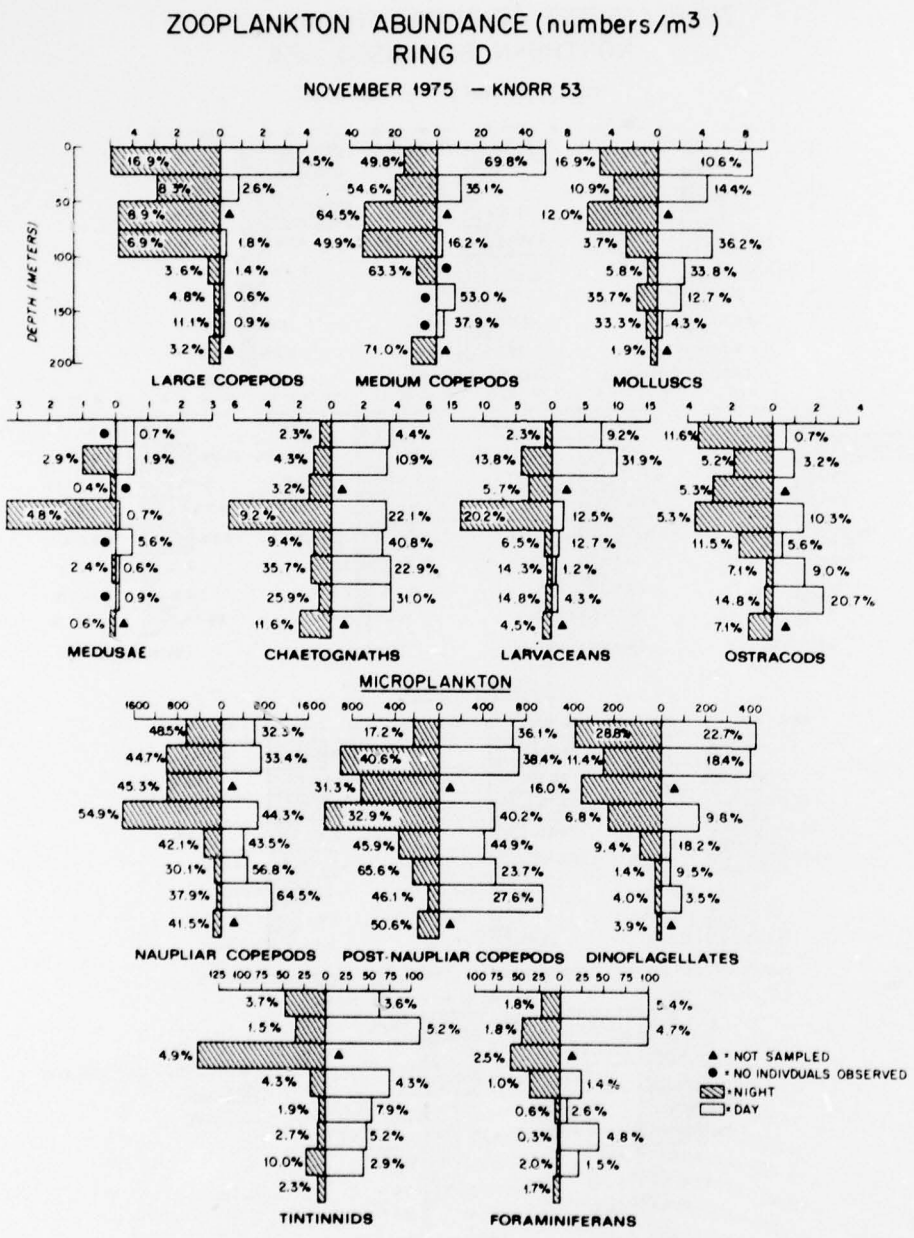


Figure 37. Vertical distribution of Ring D zooplankton taxa and functional groups. November 1975 - R/V KNORR cruise 53. Data from CB 10 (day) and CB 11 (night). Values given are the percentage contribution of the particular group to the total number of individuals sampled in the particular depth stratum. Note that day and night tows do not necessarily represent a single sampling station.

below 125 m. In contrast to August the distribution of the larger copepods seemed to be centered at the thermocline.

Average functional group of taxa abundance day and Night in Ring D was determined for Clarke-Bumpus tows: C10 and CB11 (Figure 37). Large copepods and medium copepods in Ring D, as in the Northern Sargasso Sea, had similar distribution patterns. During the day both were numerous near the surface and virtually absent below 25 m. At night both were numerous 0-100 m, and comparatively sparse 100-200 m. Once again the data indicate a possible case of reverse diel migration. Medium copepod abundance increased slightly with depth from 0-100 m. Mollusc numbers both day and night declined with depth from the surface. Larvacean numbers at night were highest 75-100 m, and low both night and day 100-200 m. Chaetognath numbers were high at night 75-100 m but very uniform during the day. Medusae numbers were generally low with the exception of a 75-100 m concentration at night. Ostracod numbers were highest at night 0-100 m, but were most abundant 100-200 m during the day.

Naupliar and post-naupliar copepods were less numerically dominant than in the Northern Sargasso Sea (Figure 36). They had basically similar distribution patterns, i.e., uniform during the day but increasing from 0-100 m at night with comparative low numbers 100-200 m. Dinoflagellate numbers decreased with depth from the surface. At night tintinnid numbers were high 50-75 m but during the day declined uniformly beneath 25-50 m. Foraminiferan distribution was irregular, but again numbers were low at depth. Only at night was the abundance of any of the functional groups highest at the depth of the thermocline.

Average functional group or taxa abundance day and night in the Slope Water was determined from Clarke-Bumpus tows: CB12 and CB13.

Large copepod numbers during the day declined with depth from the surface, but at night their numbers increased from 0-75 m declining abruptly thereafter. Medium copepods had a more or less reverse distribution declining with depth from the surface at night, but most numerous 50-75 m during the day. Mollusc numbers declined with depth during the day but were more uniform, perhaps increasing slightly with depth, at night. Both day and night numbers were low 75-100 m. Larvacean distribution was similar to mollusc distribution both day and night, as was chaetognath distribution. Both declined with depth during the day and were most numerous 50-75 m at night; day and night numbers were low 75-100 m. Medusae numbers increased with depth but were always low 75-100 m. Ostracod distribution, showing no clear pattern at night, appeared to be diminished near the surface during the day.

Microplankton abundance in the Slope Water is also represented in Figure 37. Again, naupliar and post-naupliar copepods were numerically dominant. Both day and night naupliar numbers increased with depth from 0-75 m, but were low 75-100 m. Post-naupliar copepods had a distribution similar to naupliar copepods at night, but during the day were most numerous 0-25 m. Both day and night numbers were low 75-100 m. Dinoflagellate numbers declined steadily from 25-100 m, but were low 0-25 m both day and night. Tintinnids were most numerous 50-75 m during the day but their distribution showed no clear pattern at night. Foraminiferans were most numerous 0-25 m at night but 25-50 m during the day.

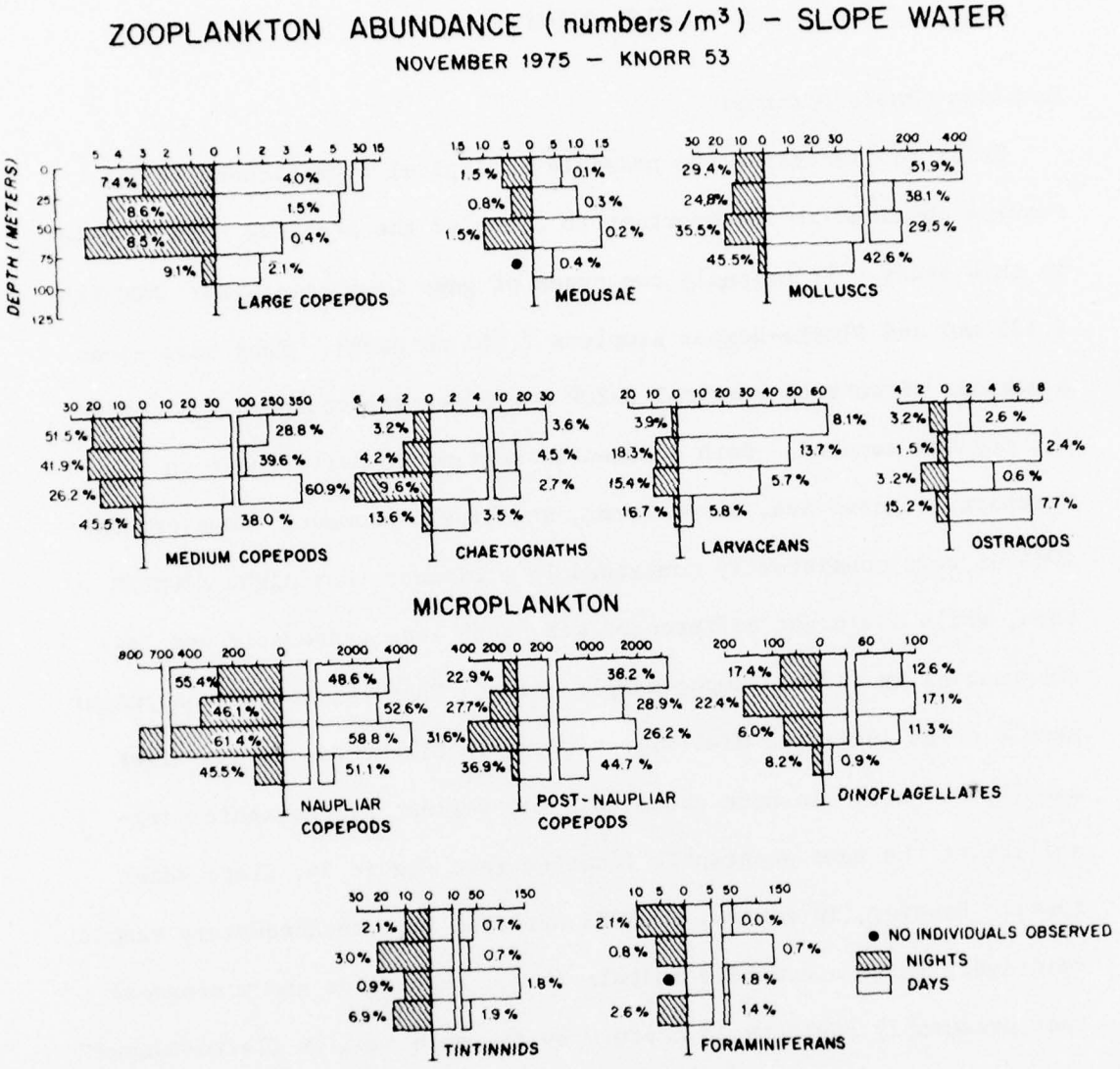


Figure 38. Vertical distribution of Slope Water zooplankton taxa and functional groups. November 1975 - KNORR cruise 53. Data from CB12 (day) and CB13 (night). Values given are the percentage contribution of the particular group to the total number of individuals sampled in the particular depth stratum. Note that day and night tows do not necessarily represent a single sampling station.

DISCUSSION

Sampling Considerations:

Prior to discussing the possible ecological significance of the results obtained it is important to consider the sampling methods used in this study. Principally two types of gear have been used: MOCNESS (.333 mm) and Clarke-Bumpus samplers (.067 mm mesh). They have given a similar picture of vertical 0-200 m biomass structure in the different regions sampled. Both documented systematic differences in Northern Sargasso Sea, Slope Water, and Ring D biomass. However, day MOCNESS tows consistently contained less biomass than night MOCNESS tows, while day/night differences were both less systematic and less substantial in Clarke-Bumpus sample pairs. That is, MOCNESS day/night sample pairs indicated diel migration while Clarke-Bumpus day/night samples did not. In some cases this may reflect hydrographic variability at the same geographic location (see Figure 34: Slope Water tows). However, in general MOCNESS appeared to more adequately sample relatively large and mobile animals (e.g., euphausids and pteropods) that presumably could avoid capture by the much smaller Clarke-Bumpus samplers. Since members of these groups are known to be strong vertical migrators, their nightly presence (and that of other such species) contributed to day/night differences in MOCNESS sample pairs but not to day/night differences in Clarke-Bumpus sample pairs. In contrast, Clarke-Bumpus samples (whose biomass was dominated by larger forms) contained a large number of small zooplankton either underrepresented, or not represented, in MOCNESS samples. In short, the two types of gear sampled partially different components of the zooplankton community.

The "microplankton", that part of the Clarke-Bumpus catch that almost certainly passed through the .33 μm mesh of MOCNESS, included naupliar copepods, post-naupliar copepods, dinoflagellates, tintinnids, and foraminiferans. Of these groups naupliar and post-naupliar copepods dominated both microplankton numbers and biomass. This does not imply that the proportions of the microplankton in the Clarke-Bumpus samples represent their actual relative abundance. For example, one need only compare the numbers/m^3 of Northern Sargasso microplankton groups (Figure 31) with the numbers/m^3 of North Pacific microplankton groups in Beers *et al.* (1975a) to realize that with .67 μm mesh only the very largest individuals of various microplankton groups have been sampled. With the assumption that the size frequency distribution of these groups does not systematically vary with depth it is possible to argue that, despite the mesh problem, conclusions can still be drawn as to the vertical distribution of microplankton. In fact, no such systematic variation was reported by Beers *et al.* (1975b), for their six North Pacific stations. A further indication that the above assumption may be warranted is that microzooplankton contribution to total zooplankton biomass was greater in Northern Sargasso Sea and Ring D samples than in Slope Water samples - a direction of difference which accords with similar observations made by Beers and Stewart (1969) and Lebrasseur and Kennedy (1972).

The Relationship of Zooplankton Biomass to the Vertical Temperature Gradient:

Overall zooplankton biomass in August 1975 has been shown to be significantly higher in 25 m depth intervals adjacent to, or

encompassing, the seasonal thermocline —
(see Figure 28). The same generalizations apply to microzooplankton biomass in Slope Water and Northern Sargasso Sea Clarke-Bumpus tows (see Figure 29). It is suggestive that in the night Northern Sargasso Sea tow in which the mixed layer was deeper (compare CB5 and CB2 in Figure 29) the naupliar and post-naupliar copepod biomass maximum was also deeper. On the other hand, naupliar and post-naupliar copepod pooled biomass in Ring D was high everywhere below the mixed layer. Note that in both the Slope Water and Ring D (Figure 29) biomass increased at approximately 20°. Although we have not examined the taxonomic composition of this population beyond that of functional groups, this suggests that the juvenile copepod population of Ring D (which accounted for most of the pooled biomass) may have been composed of Slope Water species entrained during ring formation in that both Slope Water and Ring D populations appear to prefer temperatures <20°C. In the Slope Water this strategy places them in the maximum temperature gradient where food has been shown to be relatively abundant (Chapter Three). In Ring D the same strategy is less appropriate in that it removes the population from a significant food resource.

In November 1975 the hydrographic situation was quite different. The seasonal thermoclines in the Northern Sargasso Sea, Ring D, and the Slope Water had either been erased, or were in the process of being eroded, by the onset of winter mixing (Figure 34). Zooplankton biomass in the Northern Sargasso Sea still exhibited a small but definite enhancement of biomass about the base of a deeper but more sharply defined seasonal thermocline. The Northern Sargasso Sea mixed layer was nearly isothermal unlike August and in addition to the subsurface biomass

maximum there was also a substantial surface, or near surface, biomass concentration. In Ring D where mixing was more advanced a similar deep maximum was present but the near-surface maximum was less definite. In the Slope Water where mixing was the most advanced, no trace of a subsurface biomass maximum remained, surface concentrations were very high and biomass was reasonably high everywhere above the remnant seasonal thermocline. In November naupliar and post-naupliar copepod pooled biomass had very different distributions than in August. Surface values were relatively high in all regions and subsurface maxima were noted in all regions at approximately the same depths as in August. Although, as noted earlier, we have not examined the taxonomic composition of these samples, similarity of Ring D and Northern Sargasso Sea profiles (in contrast to August 1975) suggests that the juvenile copepod population of Ring D may in November 1975 have been composed of Northern Sargasso Sea immigrants. This speculation and that based on the August Ring D naupliar and post-naupliar pooled biomass distribution are in accord with a hypothesis offered in Chapter One. Based upon 0-800 m biomass profiles taken in August and November 1975 it was proposed that, relative to carnivores, ring herbivores are replaced by Northern Sargasso Sea immigrants early in ring evolution.

Community Structure at Subsurface Biomass Maxima:

Data discussed in Chapter Three have led to the conclusion that the same depth intervals here shown to have enhanced zooplanton biomass can be a potentially exploitable food resource. Augmentation of available food at these depths may result both from *in situ* phytoplankton and microbial growth and from the sinking to depth of detrital and cellular

particulate material produced at shallower depths. On a number of occasions the zooplankton assemblage present in the subsurface biomass maximal appeared to be particularly well-suited to utilize efficiently the food items available there.

Data in Chapters Two and Three indicated that the most abundant phytoplankton cells in the Northern Sargasso Sea were quite small. The medium and large copepod distributions in the Northern Sargasso Sea August 1975 appear unrelated to the DCM (Figure 31). Grice and Hart (1962) have commented upon the fact that in the Northern Sargasso Sea purely herbivorous groups are relatively rare, while there appears to have been a radiation of more carnivorous types. The adult copepods here sampled did not appear to be utilizing the DCM as a major food resource. It is possible that inter-setal spaces within the feeding appendages of many of these forms may be too large to efficiently filter small particles. In contrast, larvaceans, molluscs, and microplankton appeared at the same time to be concentrated about the DCM. Due to their mode of feeding, these should be able to capture very small particles (Hamner *et al.*, 1975; Beers and Stewart, 1969). Chaetognaths, a purely carnivorous group relatively abundant in the Northern Sargasso Sea, were also concentrated about the same depths. Their primary food may have been one of the above small particle-feeding zooplankton groups.

In Slope Water, August 1975, larvaceans, molluscs, and copepods of all sizes had enhanced numbers at DCM depths (Figure 33). This suggests that all may be able to utilize food available there. In fact, data in Chapters Two and Three indicated that although small cells were still abundant, in the Slope Water larger cells were considerably more abundant than in the Northern Sargasso Sea at the same season.

Differences between the Slope Water and the Northern Sargasso Sea as herbivore habitats have been discussed in Chapter Two. It is possible that a minimum density of phytoplankton is required for an adequate ration to be obtained by the larger copepods. The data of Dagg (1977) and Mullin and Brooks (1977) suggests this may be the case. It has also been suggested that the mucous and ciliary feeding of some of the same forms found at the Northern Sargasso Sea DCM may be a more efficient form of feeding than filter-feeding (Hamner *et al.*, 1975).

In general Ring D abundance patterns in August 1975 appeared similar to those of the Slope Water except for the fact, earlier commented upon, that post-naupliar copepod numbers increased gradually with depth from the surface to 200 m (Figure 32). However, in Chapter Two the phytoplankton of Ring D in August were shown to be rather more similar in composition to the surrounding Northern Sargasso Sea than to the Slope Water. Further overall biomass, presumably dominated by groups not depicted here, had a subsurface maxima at depths similar to the Northern Sargasso Sea. For example, unpublished data show dramatic concentrations of migratory thecosomatous pteropods from 50-75 m (including the upper DCM) both at night and during the day (J. Wormuth, personal communication). Euphausids are thought to concentrate particularly at night, at DCM depths (Youngbluth, 1975), but in that study sampling intervals were comparatively coarse.

Nearly all Northern Sargasso Sea groups in November 1975 had distributions centered about the DCM including medium and large copepods (Figure 36). Yet, in November 1975 the Northern Sargasso Sea had only just begun its winter mixing and the DCM was essentially unaffected (Chapter Three). We have no explanation for the addition of larger

copepods to the DCM assemblage. It is possible that the distribution of the larger copepods changed because food within the mixed layer had become insufficient after so many months of stratification.

In contrast to August 0-100 m November 1975 Ring D numbers greatly exceeded 100-200 m numbers in all groups except ostracods (Figure 37). These same groups nearly always increased in number at a seasonal thermocline considerably sharpened because above it the water column was nearly isothermal. A DCM was no longer present but an ATP maximum was still observed approximately at the seasonal thermocline (Chapter Three). Further, with the onset of winter mixing, diatom numbers had increased relative to August (Chapter Two and ^{14}C fixation rates were higher. These changes may indicate that prior to and during our sampling more food was available throughout the mixed layer than in August 1975.

All traces of DCM structure had been erased in the Slope Water by November 1975 (Chapter Three). Diatom abundance had markedly increased (Chapter Two). Zooplankton day abundances reflect these changes (Figure 38). Numbers in nearly all groups increased relative to August. Yet some groups still showed enhanced numbers in conjunction with the thermocline structure remaining beneath August DCM depths. These included tintinnids, nauplii, and medium copepods.

In contrast, the night abundance patterns of nearly all groups show definite subsurface maxima at thermocline depths (Figure 38). However, the water column sampled during the night tow was very different from that observed during the day (Figure 23). Vertical mixing had been far less thorough, and temperature structure was more similar to earlier August Slope Water profiles than to the "paired" November day tow.

Causal Mechanisms for DCM/Zooplankton Association:

For reasons earlier discussed, our interpretation of community structure is certainly biased because only the Clarke-Bumpus samples have been sorted. Further, sampling intervals of 25 m are clearly too broad, especially in the Slope Water. That is, all that has really been established is the general co-occurrence of the DCM and zooplankton aggregation within the 25 m depth interval that brackets the seasonal thermocline. It does appear that on some occasions a distinguishable zooplankton assemblage was associated with the DCM and that the composition of this assemblage could be interpreted in light of the food available at those depths. Furthermore, MOCNESS biomass profiles indicated that a similar generalization might obtain for zooplankton groups inadequately sampled by the Clarke-Bumpus samplers. But, what are the causal mechanisms that produce these distributions? There appear to be two major alternatives: relative availability of food and physical structure in the upper water column. In a series of experiments apparently not repeated since, Bainbridge (1953) demonstrated that some herbivorous zooplankton species behave as if they perceive gradients in phytoplankton concentration and are in fact attracted to concentrations of particular species. On the other hand, the experiments of Harder (1968) and the field data of Boyd (1973) suggest that zooplankton are capable of sensing temperature gradients and may aggregate at those gradients in the absence of any other behavioral stimulus.

Data presented here do not resolve this difficult issue but do shed some light on its complexity and suggests an approach which might resolve it. Clearly in the summer — or when the DCM is well developed and stratification is most intense — food availability and physical

structure are more or less coincident and cannot be separated. The fall data, however, suggests that such a separation may be possible. Although in some cases the DCM had been erased by mixing, the subsurface zooplankton biomass maxima was still observed. The herbivorous species at that time could not have been behaving as in Bainbridge's experiments. Either they were following an instinctive habit perhaps conditioned by prior biological interactions or they were responding to the physical environmental gradient still present. When herbivorous plankton have a vertical distribution apparently related to temperature structure it is difficult to interpret unambiguously the co-distribution of carnivorous species who might be responding either to the temperature gradient or to the distribution of their prey. In some cases it did appear, however, that chaetognath distribution was rather precisely regulated by temperature in the absence of a parallel distribution of their possible prey. A further complication is that an unknown fraction of the nauplii enumerated may not feed (Paffenhöffer, 1971). Were samples to be obtained at weekly intervals, from the time the DCM and seasonal thermocline were well-established to the time when both had been completely erased by winter mixing, the alternative hypotheses discussed above might be better evaluated. Unfortunately, sampling periods in this study were far apart in time, and in November winter mixing, even in the Slope Water, had probably only recently occurred and was certainly not complete.

Historical Context:

To what extent do the results reported herein corroborate those of earlier investigators? Associations between zooplankton and seasonal deep chlorophyll maxima in near coastal environments

have been documented by Mullin and Brooks (1972), Haury (1976), Anderson *et al.* (1972) and Chester (1975). In more oceanic environments microplankton/DCM associations have been reported by Beers and Stewart (1971), Hobson and Lorenzen (1972), and Gunderson *et al.* (1976). It is possible that the zooplankton microdistributions reported by Timonin (1976) in the tropical Pacific reflect a DCM/zooplankton association although the phytoplankton of the depth intervals sampled were not assessed. It has been argued that the Central North Pacific may be dominated by *in situ* rather than advective processes and can for much of the year be considered to be in steady-state (McGowan, 1977). In these respects the Central North Pacific appears to be analogous to the Northern Sargasso Sea. Beers *et al.* (1975a) presented data for six Central North Pacific bottle casts in late June and observed that the numbers and biomass of micro-metazoans increased from 0-120 m. They observed no accumulation of phytoplankton cells at the DCM as had been previously reported for the same region by Venrick *et al.* (1973). On the other hand the latter authors found no concentration of zooplankton biomass (> .035 mm as sampled by a pump) and argued that the DCM could be accentuated by grazing pressure on the cell populations above. This argument had earlier been made by Lorenzen (1967). No evidence for macrozooplankton associations with the Central North Pacific DCM has been reported. Examination of ZETES Expedition, data reports (S.I.O. Reference 70-5) reveals no indicationof such an association. In fact, there have been few documented cases of oceanic macrozooplankton/DCM associations (Longhurst, 1967; Youngbluth, 1975; perhaps Vinogradov *et al.*, 1970 and Timonin (1977). The set of observations reported here represents the only systematic documentation of substantial

oceanic zooplankton biomass/DCM association. It is not unlikely that the reasons for this are methodological. It is suggestive that the biomass distribution pattern clear in MOCNESS profiles was absent or nearly indiscernible in stratified Bongo net tows (see Figure 30).

There are two accounts of open-ocean vertical zooplankton distribution that appear to explicitly contradict the results reported here: Angel (1968) and Longhurst (1976). Angel towed nets above, in, and below a seasonal thermocline in the eastern Atlantic Ocean. The method was similar to that used with Bongo nets on ATLANTIS II 84. He reported only upon euphausid, ostracod, and fish enumerated in the samples. Unfortunately, the cod end of the middle net had .500 μm mesh while those of the nets above and below had .333 μm mesh. Of these groups only fish aggregated at the thermocline while the two other groups appeared to specifically avoid the thermocline. In the results earlier described ostracod distribution did appear to differ on most occasions from that of the other groups and rarely was centered about the thermocline. Yet, Youngbluth (1975) and Longhurst (1967) reported euphausid/DCM associations. In any case, the weight of the evidence here presented suggests that the seasonal thermocline may be an "ecological boundary" but in a very different sense to that proposed by Angel.

Longhurst (1976) presents extensive data obtained during EASTROPAC. His conclusion is that of Lorenzen (1967), that zooplankton biomass and presumed grazing pressure is concentrated above the DCM at about the depth where primary productivity is maximal. It is difficult to determine the exact reason for the discrepancy between our results. They may differ for purely methodological reasons.

All EASTROPAC data on chlorophyll, phytoplankton cell numbers, and ^{14}C uptake were obtained from bottle casts sampling at depths defined by percentages of ambient light and were, therefore, so widely spaced that below about 50 m it is impossible to precisely define the locations of maximal primary production, cell numbers, or chlorophyll concentration. This was the case as well for the ^{14}C data presented in Chapter Three. But this is a comparatively minor problem. More important considerations concern zooplankton sampling. Longhurst concludes avoidance was not a problem because "no consistent day/night ratio could be detected in numbers of organisms per cubic meter". It is precisely this observation that suggests avoidance may be a problem since such a ratio is nearly always observed with many different kinds of sampling gear. Even more significant are probably biases in the biomass profiles generated by the LHPR. Haury *et al.* (1976) document a number of sourcesof bias in LHPR results most of which result in variable time lags between introduction into the filtering cone and appearance on the recording gauze. During EASTROPAC only upward oblique hauls were taken. Since these sources of error result in time lags this means that they would systematically shift peaks in biomass, or numbers, upward to shallower depths. These problems cannot occur with either MOCNESS or Clarke-Bumpus samplers because the entire filtering cone is opened and closed at specific depths. In any case given the conditions described by Longhurst — i.e., recorder box design, gauze advance time, length of tow, direction of tow, etc., a systematic upward bias is quite likely to have been introduced into EASTROPAC LHPR tows. While the rejection criteria used by Longhurst are valid and rightfully eliminate some spurious tows, they would not have been able to detect this bias.

On theoretical grounds Longhurst's conclusions are unsatisfying. While behavioral cues abound to account for zooplankton aggregation about the DCM, it is difficult to say how an individual zooplankton animal would perceive the depth where ^{14}C uptake rate was maximal — unless, and this cannot be discounted, more actively dividing cells "taste better". Oddly, in the microzooplankton study (Beers and Stewart, 1971) which Longhurst cites as supporting his results the positive correlation between chlorophyll concentration and microzooplankton biomass was no less significant than the positive correlation between microzooplankton biomass and primary productivity. In short, it is impossible to determine if Longhurst's (1976) data are contradictory to those here reported and indicative of a fundamental difference in the structure of the plankton communities of the eastern Tropical Pacific and the western North Atlantic.

SUMMARY AND CONCLUSIONS

1. As determined by two different sampling systems total zooplankton biomass was significantly enhanced within depth intervals including, or adjacent to, the seasonal thermocline in the Northern Sargasso Sea, a Gulf Stream cold core ring, and the Slope Water. Since, it has been shown that the DCM was predictably associated with the seasonal thermocline (Chapter Three), these data indicate zooplankton biomass was enhanced about the DCM.

2. The zooplankton assemblage at the DCM was distinguishable from those at both shallower and deeper depths. The functional groups that predominate at the DCM could be related to the size of the phytoplankton cells at DCM depths in different environments.

3. Data given in Chapter Three, in conjunction with those here presented, imply that in the western North Atlantic in environments ranging from moderately rich nearshore Slope Waters to the highly oligotrophic open-ocean Sargasso Sea, the DCM signalled a depth zone of particularly intense trophic activity. Not only herbivorous zooplankton but also, a purely carnivorous group, the chaetognaths, aggregated on occasion at DCM depths.

MAJOR FINDINGS

1. Total zooplankton biomass in the upper 800 m of the Gulf Stream cold core rings sampled significantly exceeded that in the Northern Sargasso Sea and the center of its distribution was very much deeper than in the Northern Sargasso Sea. Such a distribution may result in reduced ecological efficiency and increased flux of organic matter to the deep sea.

2. Although no common species was unique to rings the phytoplankton assemblage in Gulf Stream cold core rings was significantly different from that of both the Slope Water and the Northern Sargasso Sea many months after ring formation. The flora was distinguishable both because certain species appeared to capitalize on the unique ring environment and were more numerous in rings than in either the Northern Sargasso Sea or the Slope Water, and because some taxa were underrepresented in rings.

3. Due to the composition, distribution, and variability of its characteristic phytoplankton the Slope Water represented a herbivore habitat very different from that in either the Northern Sargasso Sea or a six-month-old core core ring. Under highly stratified conditions the preceding contrasts were maximal.

4. Phytoplankton species sorted into groups according to their abundance in different samples constituted ecological types with different apparent responsiveness to nutrient concentration variation.

5. The DCM in diverse environments appeared to be an essentially identical phenomenon. The DCM accumulated phytoplankton cells (and possibly other organic particulates) sinking from above. Additionally, phytoplankton growth occurred at DCM depths despite low light levels. As a consequence the DCM signalled a depth zone which, under stratified conditions, was a significant food resource, especially since mixed-layer food was scarce.

6. Concentrations of zooplankton biomass at the DCM and the vertical distributions of zooplankton functional groups indicate the DCM in the western North Atlantic was a locus of particularly intense trophic activity. The depth interval of the DCM had more total biomass and more microplankton biomass than above and below. Further, at DCM depths, the abundance of particular zooplankton functional groups appeared to reflect the size of the resident phytoplankton. Not only presumed herbivores but a purely carnivorous group, the chaetognaths, on some occasions aggregated at DCM depths.

SUGGESTIONS FOR FUTURE RESEARCH

The results of this thesis adumbrate a number of promising avenues for future research. These include:

1. The mechanism determining the vertical distribution of cold core ring biomass needs to be more completely explored. Identification to the species level of all samples already collected is only the beginning. Experimental determination of the physiological requirements and feeding strategies of the dominant Slope Water and Northern Sargasso Sea zooplankton species will have to be made.

2. In order to understand the mechanisms responsible for the distributional patterns that defined the phytoplankton species ecotypes, the physiological ecology of the various species will have to be investigated. It is not unlikely that much more than simple nutrient uptake capabilities are involved. Oceanic forms may differ from nearshore forms more subtly. Gracing pressure and the availability of trace metals may contribute to the distributions observed.

3. For both of the above purposes it will be essential to more thoroughly investigate the Gulf Stream flora and fauna. They have been given comparatively little attention in this and earlier studies. Many observations have had to be qualified because the contribution of these communities to Gulf Stream rings is unknown.

4. The dynamics and quantitative trophic significance of the DCM will have to be investigated by very closely spaced sampling at frequent intervals throughout the seasonal formation and evolution of a particular DCM. Then these static measures (crudely begun in this

thesis) will have to be supplemented by field rate measurements of such parameters as the relative productivity of different size fractions of the phytoplankton, zooplankton community respiration, regenerated nitrogen flux, inputs of particulate materials sinking from above to DCM depths (sediment traps), and zooplankton grazing pressure.

With respect to grazing pressure, one can envisage a series of *in-situ* experiments in which a natural phytoplankton community, gently filtered to remove most grazers) is resuspended at an appropriate depth in an ion-permeable transparent dialysis bag. With suitable controls it may be possible to infer the actual impact of zooplankton grazing on the phytoplankton.

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APPENDIX A

TABLE OF STATIONS

STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT DEPTH	SURF. TEMP	ZOOM TEMP	GEAR	CODE
GSR1005	KN	53	33 57N	71 53W	75• XI •23		1•	•0	•0	CC•5	ACC
GSR1006	KN	53	34 10N	71 34W	75• XI •24		1•	•0	•0	CC•6	ACC
GSR1007	KN	53	38 55N	57 45W	75• XI •28		1•	•0	•0	CC•7	ASW
GSR1355	KN	35	39 45N	70 35W	73• XI •23		1•	12.7	9.2	0355	TSW
GSR1356	KN	35	38 19N	70 20W	73• XI •24		1•	18.0	8.1	0356	TSW
GSR1357	KN	35	35 55N	71 43W	73• XI •27		1•	21.0	11.1	0357	ACC
GSR1359	KN	35	35 54N	71 38W	73• XI •28		1•	21.1	10.8	0359	DCC
GSR1360	KN	35	36 17N	72 4W	73• XI •28		1•	21.5	16.4	0360	NCC
GSR1361	KN	35	37 5N	68 7W	73• XI •30		1•	20.8	18.0	0361	DNS
GSR1362	KN	35	38 33N	68 22W	73•XII • 1		1•	17.9	7.8	0362	NSW
GSR1377	CN	125	38 29N	69 59W	75•VIII• 1		1•	22.9	9.4	1377	ASW
GSR1378	CN	125	35 34N	68 35W	75•VIII• 5		1•	27.7	18.2	1378	ACC
GSR1380	CN	125	34 32N	69 55W	75•VIII• 8		1•	25.6	12.4	1380	ACC
GSR1382	CN	125	34 33N	69 55W	75•VIII•10		1•	27.3	12.8	1382	ACC
GSR1384	CN	125	34 9N	71 39W	75•VIII•12		1•	27.1	18.7	1384	ANS
GSR1468	KN	380	36 3N	61 42W	74•III •25		1•	16.5	•0		NS
GSR1469	KN	380	36 23N	62 4W	74•III •26		1•	18.7	•0		NS
GSR1470	KN	380	35 27N	61 19W	74•III •26		1•	17.9	•0		CC
GSR1471	KN	380	35 42N	61 0W	74•III •27		1•	17.9	•0		CC
GSR1472	KN	380	35 59N	60 52W	74•III •28		1•	17.9	•0		RF
GSR1473	KN	380	35 51N	61 23W	74•III •29		1•	17.7	•0		CC
GSR1474	KN	380	36 52N	64 74W	74•III •30		1•	19.0	•0		NS

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STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT. TIME	COLLECT DEPTH	SURF. TEMP	200M TEMP	GEAR	CODE
GSR1675	KN	380	38 7N	67 52W	74- IV - 2			1-	16.9	.0		WC
GSR1676	KN	380	38 4N	68 48W	74- IV - 3			1-	20.3	.0		WC
GSR1677	KN	380	39 37N	69 50W	74- IV - 3			1-	10.7	.0		SW
GSR1717	KN	53	32 44N	71 10W	75- XI -17			1-	17.7	18.4	0717	ANS
GSR1719	KN	53	33 55N	71 54W	75- XI -21			1-	23.2	14.2	0719	ACC
GSR1723	KN	53	40 6N	68 7W	75- XI -30			1-	20.2	11.7	0723	AWC
GSR2005	KN	53	33 57N	71 53W	75- XI -23			24-	23.2	.0	CC-5	ACC
GSR2006	KN	53	34 10N	71 34W	75- XI -24			25-	22.9	.0	CC-6	ACC
GSR2007	KN	53	38 55N	57 45W	75- XI -28			25-	21.9	.0	CC-7	ASW
GSR2355	KN	35	39 45N	70 35W	73- XI -23			25-	13.4	9.2	0355	TSW
GSR2356	KN	35	38 19N	70 20W	73- XI -24			25-	17.9	8.1	0356	TSW
GSR2357	KN	35	35 55N	71 43W	73- XI -27			25-	21.0	11.1	0357	ACC
GSR2359	KN	35	35 54N	71 38W	73- XI -28			25-	21.1	10.8	0359	DCC
GSR2360	KN	35	36 17N	72 4W	73- XI -28			25-	.0	16.4	0360	NCC
GSR2361	KN	35	37 5N	68 7W	73- XI -30			25-	20.8	18.0	0361	DNS
GSR2362	KN	35	38 33N	68 22W	73-XII - 1			25-	.0	7.8	0362	NSW
GSR2377	CN	125	38 29N	69 59W	75-VIII- 1			24-	16.1	9.4	1377	ASW
GSR2378	CN	125	35 34N	68 35W	75-VIII- 5			24-	25.9	18.2	1378	ACC
GSR2380	CN	125	34 32N	69 55W	75-VIII- 8			24-	24.1	12.4	1380	ACC
GSR2382	CN	125	34 33N	69 55W	75-VIII-10			24-	24.0	12.8	1382	ACC
GSR2384	CN	125	34 9N	71 39W	75-VIII-12			21-	27.0	18.7	1384	ANS
GSR2468	KN	380	36 3N	61 42W	74-III -25			25-	18.7	.0		NS

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STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT. TIME	COLLECT DEPTH	SURF. TEMP	200M TEMP	GEAR	CODE
GSR2469	KN	380	36 23N	62 4W	74-III-26			25-	19.4	.0		NS
GSR2470	KN	380	35 27N	61 19W	74-III-26			25-	17.9	.0		CC
GSR2471	KN	380	35 42N	61 0W	74-III-27			25-	17.9	.0		CC
GSR2472	KN	380	35 59N	60 52W	74-III-28			25-	17.9	.0		RF
GSR2473	KN	380	35 51N	61 23W	74-III-29			25-	17.6	.0		CC
GSR2474	KN	380	36 52N	64 74W	74-III-30			25-	18.9	.0		NS
GSR2475	KN	380	38 7N	67 52W	74- IV - 2			25-	16.9	.0		WC
GSR2476	KN	380	38 4N	68 48W	74- IV - 3			25-	20.4	.0		WC
GSR2477	KN	380	39 37N	69 50W	74- IV - 3			25-	10.4	.0		SW
GSR2717	KN	53	32 44N	71 10W	75- XI -17			25-	23.9	18.4	0717	ANS
GSR2719	KN	53	33 55N	71 54W	75- XI -21			25-	23.2	14.2	0719	ACC
GSR2723	KN	53	40 6N	68 7W	75- XI -30			25-	20.1	11.7	0723	AWC
GSR3005	KN	53	33 57N	71 53W	75- XI -23			48-	23.1	.0	CC-5	ACC
GSR3006	KN	53	34 10N	71 34W	75- XI -24			50-	22.9	.0	CC-6	ACC
GSR3007	KN	53	38 55N	57 45W	75- XI -28			50-	21.1	.0	CC-7	ASW
GSR3355	KN	35	39 45N	70 35W	73- XI -23			50-	16.5	9.2	0355	TSW
GSR3356	KN	35	38 19N	70 20W	73- XI -24			50-	18.0	8.1	0356	TSW
GSR3357	KN	35	35 55N	71 43W	73- XI -27			50-	21.2	11.1	0357	ACC
GSR3359	KN	35	35 54N	71 38W	73- XI -28			50-	21.2	10.8	0359	DCC
GSR3360	KN	35	36 17N	72 4W	73- XI -28			50-	21.5	16.4	0360	NCC
GSR3361	KN	35	37 5N	68 7W	73- XI -30			50-	20.8	18.0	0361	DNS
GSR3362	KN	35	38 33N	68 22W	73-XII - 1			50-	17.9	7.8	0362	NSW

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STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT. TIME	COLLECT DEPTH	SURF. TEMP	200M TEMP	GEAR	CODE
GSR3377	CN	125	38 29N	69 59W	75•VIII• 1			49•	10•5	9•4	1377	ASW
GSR3378	CN	125	35 34N	68 35W	75•VIII• 5			48•	25•3	18•2	1378	ACC
GSR3380	CN	125	34 32N	69 55W	75•VIII• 8			47•	•0	12•4	1380	ACC
GSR3382	CN	125	34 33N	69 55W	75•VIII•10			49•	23•3	12•8	1382	ACC
GSR3384	CN	125	34 9N	71 39W	75•VIII•12			42•	24•6	18•7	1384	ANS
GSR3468	KN	380	36 3N	61 42W	74•III •25			50•	18•7	•0		NS
GSR3469	KN	380	36 23N	62 4W	74•III •26			50•	19•4	•0		NS
GSR3470	KN	380	35 27N	61 19W	74•III •26			50•	18•0	•0		CC
GSR3471	KN	380	35 42N	61 0W	74•III •27			50•	17•9	•0		CC
GSR3472	KN	380	35 59N	60 52W	74•III •28			50•	17•9	•0		RF
GSR3473	KN	380	35 51N	61 23W	74•III •29			50•	17•7	•0		CC
GSR3474	KN	380	36 52N	64 74W	74•III •30			50•	19•0	•0		NS
GSR3475	KN	380	38 7N	67 52W	74• IV • 2			50•	16•7	•0		WC
GSR3476	KN	380	38 4N	68 48W	74• IV • 3			50•	20•1	•0		WC
GSR3477	KN	380	39 37N	69 50W	74• IV • 3			50•	11•0	•0		SW
GSR3717	KN	53	32 44N	71 10W	75• XI •17			50•	23•9	18•4	0717	ANS
GSR3719	KN	53	33 55N	71 54W	75• XI •21			50•	23•2	14•2	0719	ACC
GSR3723	KN	53	40 6N	68 7W	75• XI •30			50•	20•1	11•7	0723	AWC
GSR4005	KN	53	33 57N	71 53W	75• XI •23			75•	23•1	•0	CC-5	ACC
GSR4006	KN	53	34 10N	71 34W	75• XI •24			75•	22•9	•0	CC-6	ACC
GSR4007	KN	53	38 55N	57 45W	75• XI •28			75•	18•6	•0	CC•7	ASW
GSR4355	KN	35	39 45N	70 35W	73• XI •23			75•	17•3	9•2	0355	TSW

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STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT DEPTH	SURF. TEMP	ZOOM TEMP	GEAR	CODE
GSR4356	KN	35	38 19N	70 20W	73• XI •24		75•	18•2	8•1	0356	TSW
GSR4357	KN	35	35 55N	71 43W	73• XI •27		75•	21•3	11•1	0357	ACC
GSR4359	KN	35	35 54N	71 38W	73• XI •28		75•	21•3	10•8	0359	DCC
GSR4360	KN	35	36 17N	72 4W	73• XI •28		75•	21•5	16•4	0360	NCC
GSR4361	KN	35	37 5N	68 7W	73• XI •30		75•	20•8	18•0	0361	DNS
GSR4362	KN	35	38 33N	68 22W	73•XII • 1		75•	16•8	7•8	0362	NSW
GSR4377	CN	125	38 29N	69 59W	75•VIII• 1		73•	•0	9•4	1377	ASW
GSR4378	CN	125	35 34N	68 35W	75•VIII• 5		70•	23•9	18•2	1378	ACC
GSR4380	CN	125	34 32N	69 55W	75•VIII• 8		71•	20•1	12•4	1380	ACC
GSR4382	CN	125	34 33N	69 55W	75•VIII•10		73•	18•2	12•8	1382	ACC
GSR4384	CN	125	34 9N	71 39W	75•VIII•12		63•	•0	18•7	1384	ANS
GSR4468	KN	380	36 3N	61 42W	74•III •25		75•	18•7	•0		NS
GSR4469	KN	380	36 23N	62 4W	74•III •26		75•	19•4	•0		NS
GSR4470	KN	380	35 27N	61 19W	74•III •26		75•	18•0	•0		CC
GSR4471	KN	380	35 42N	61 0W	74•III •27		75•	17•9	•0		CC
GSR4472	KN	380	35 59N	60 52W	74•III •28		75•	17•9	•0		RF
GSR4473	KN	380	35 51N	61 23W	74•III •29		75•	17•7	•0		CC
GSR4474	KN	380	36 52N	64 74W	74•III •30		75•	19•0	•0		NS
GSR4475	KN	380	38 7N	67 52W	74• IV • 2		75•	15•9	•0		WC
GSR4476	KN	380	38 4N	68 48W	74• IV • 3		75•	18•5	•0		WC
GSR4477	KN	380	39 37N	69 50W	74• IV • 3		75•	13•3	•0		SW
GSR4717	KN	53	32 44N	71 10W	75• XI •17		75•	23•8	18•4	0717	ANS

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STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT DEPTH	SURF. TEMP	200M TEMP	GEAR	CODE
GSR4719	KN	53	33 55N	71 54W	75• XI •21		75•	23.3	14.2	0719	ACC
GSR4723	KN	53	40 6N	68 7W	75• XI •30		75•	20.2	11.7	0723	AWC
GSR5005	KN	53	33 57N	71 53W	75• XI •23		100•	21.3	.0	CC-5	ACC
GSR5006	KN	53	34 10N	71 34W	75• XI •24		100•	22.9	.0	CC-6	ACC
GSR5007	KN	53	38 55N	57 45W	75• XI •28		100•	18.0	.0	CC-7	ASW
GSR5355	KN	35	39 45N	70 35W	73• XI •23		100•	14.4	9.2	0355	TSW
GSR5356	KN	35	38 19N	70 20W	73• XI •24		100•	15.7	8.1	0356	TSW
GSR5357	KN	35	35 55N	71 43W	73• XI •27		100•	18.3	11.1	0357	ACC
GSR5359	KN	35	35 54N	71 38W	73• XI •28		100•	21.3	10.8	0359	DCC
GSR5360	KN	35	36 17N	72 4W	73• XI •28		100•	21.5	16.4	0360	NCC
GSR5361	KN	35	37 5N	68 7W	73• XI •30		100•	20.8	18.0	0361	DNS
GSR5362	KN	35	38 33N	68 22W	73•XII • 1		100•	15.2	7.8	0362	NSW
GSR5377	CN	125	38 29N	69 59W	75•VIII• 1		97•	13.9	9.4	1377	ASW
GSR5378	CN	125	35 34N	68 35W	75•VIII• 5		90•	.0	18.2	1378	ACC
GSR5380	CN	125	34 32N	69 55W	75•VIII• 8		94•	19.5	12.4	1380	ACC
GSR5382	CN	125	34 33N	69 55W	75•VIII•10		97•	17.3	12.8	1382	ACC
GSR5384	CN	125	34 9N	71 39W	75•VIII•12		84•	21.6	18.7	1384	ANS
GSR5468	KN	380	36 3N	61 42W	74•III •25		100•	.0	.0		NS
GSR5469	KN	380	36 23N	62 4W	74•III •26		100•	19.3	.0		NS
GSR5470	KN	380	35 27N	61 19W	74•III •26		100•	17.8	.0		CC
GSR5471	KN	380	35 42N	61 0W	74•III •27		100•	17.9	.0		CC
GSR5472	KN	380	35 59N	60 52W	74•III •28		100•	17.9	.0		RF

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STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT. DEPTH	SURF. TEMP	200M TEMP	GEAR	CODE
GSR5473	KN	380	35 51N	61 23W	74-III	•29	100-	17.7	•0		CC
GSR5474	KN	380	36 52N	64 74W	74-III	•30	100-	•0	•0		NS
GSR5475	KN	380	38 7N	67 52W	74- IV	• 2	100-	•0	•0		WC
GSR5476	KN	380	38 4N	68 48W	74- IV	• 3	100-	17.5	•0		WC
GSR5477	KN	380	39 37N	69 50W	74- IV	• 3	100-	13.5	•0		SW
GSR5717	KN	53	32 44N	71 10W	75- XI	•17	100-	21.0	18.4	0717	ANS
GSR5719	KN	53	33 55N	71 54W	75- XI	•21	100-	23.2	14.2	0719	ACC
GSR5723	KN	53	40 6N	68 7W	75- XI	•30	100-	19.1	11.7	0723	AWC
GSR6005	KN	53	33 57N	71 53W	75- XI	•23	125-	18.6	•0	CC-5	ACC
GSR6006	KN	53	34 10N	71 34W	75- XI	•24	125-	20.2	•0	CC-6	ACC
GSR6007	KN	53	38 55N	57 45W	75- XI	•28	125-	14.3	•0	CC-7	ASW
GSR6355	KN	35	39 45N	70 35W	73- XI	•23	125-	13.8	9.2	0355	TSW
GSR6356	KN	35	38 19N	70 20W	73- XI	•24	125-	14.4	8.1	0356	TSW
GSR6357	KN	35	35 55N	71 43W	73- XI	•27	125-	16.8	11.1	0357	ACC
GSR6359	KN	35	35 54N	71 38W	73- XI	•28	125-	17.1	10.8	0359	DCC
GSR6360	KN	35	36 17N	72 4W	73- XI	•28	125-	21.6	16.4	0360	NCC
GSR6361	KN	35	37 5N	68 7W	73- XI	•30	125-	20.8	18.0	0361	DNS
GSR6362	KN	35	38 33N	68 22W	73-XII	• 1	125-	•0	7.8	0362	NSW
GSR6377	CN	125	38 29N	69 59W	75-VIII	• 1	119-	13.3	9.4	1377	ASW
GSR6378	CN	125	35 34N	68 35W	75-VIII	• 5	107-	20.0	18.2	1378	ACC
GSR6380	CN	125	34 32N	69 55W	75-VIII	• 8	118-	17.0	12.4	1380	ACC
GSR6382	CN	125	34 33N	69 55W	75-VIII	•10	121-	17.0	12.8	1382	ACC

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STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT. DEPTH	SURF. TEMP	ZOOM TEMP	GEAR	CODE
GSR6384	CN	125	34 9N	71 39W	75•VIII•12		106•	20.6	18.7	1384	ANS
GSR6468	KN	380	36 3N	61 42W	74•III •25		125•	18.6	.0		NS
GSR6469	KN	380	36 23N	62 4W	74•III •26		125•	19.1	.0		NS
GSR6470	KN	380	35 27N	61 19W	74•III •26		125•	17.8	.0		CC
GSR6471	KN	380	35 42N	61 0W	74•III •27		125•	17.9	.0		CC
GSR6472	KN	380	35 59N	60 52W	74•III •28		125•	18.0	.0		RF
GSR6473	KN	380	35 51N	61 23W	74•III •29		125•	17.7	.0		CC
GSR6474	KN	380	36 52N	64 74W	74•III •30		125•	19.0	.0		NS
GSR6475	KN	380	38 7N	67 52W	74• IV • 2		125•	13.2	.0		WC
GSR6476	KN	380	38 4N	68 48W	74• IV • 3		125•	.0	.0		WC
GSR6477	KN	380	39 37N	69 50W	74• IV • 3		125•	.0	.0		SW
GSR6717	KN	53	32 44N	71 10W	75• XI •17		125•	19.9	18.4	0717	ANS
GSR6719	KN	53	33 55N	71 54W	75• XI •21		120•	18.5	14.2	0719	ACC
GSR6723	KN	53	40 6N	68 7W	75• XI •30		125•	17.4	11.7	0723	AWC
GSR7005	KN	53	33 57N	71 53W	75• XI •23		150•	17.4	.0	CC•5	ACC
GSR7006	KN	53	34 10N	71 34W	75• XI •24		150•	19.0	.0	CC•6	ACC
GSR7007	KN	53	38 55N	57 45W	75• XI •28		150•	13.7	.0	CC•7	ASW
GSR7355	KN	35	39 45N	70 35W	73• XI •23		150•	13.2	9.2	0355	TSW
GSR7356	KN	35	38 19N	70 20W	73• XI •24		150•	13.2	8.1	0356	TSW
GSR7357	KN	35	35 55N	71 43W	73• XI •27		150•	15.4	11.1	0357	ACC
GSR7359	KN	35	35 54N	71 38W	73• XI •28		150•	16.0	10.8	0359	DCC
GSR7360	KN	35	36 17N	72 4W	73• XI •28		150•	21.6	16.4	0360	NCC

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STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT. DEPTH	SURF. TEMP	200M TEMP	GEAR	CODE
GSR7361	KN	35	37 5N	68 7W	73- XI -30		150-	19.9	18.0	0361	DNS
GSR7362	KN	35	38 33N	68 22W	73-XII - 1		150-	12.4	7.8	0362	NSW
GSR7377	CN	125	38 29N	69 59W	75-VIII- 1		142-	12.7	9.4	1377	ASW
GSR7378	CN	125	35 34N	68 35W	75-VIII- 5		123-	19.4	18.2	1378	ACC
GSR7380	CN	125	34 32N	69 55W	75-VIII- 8		141-	.0	12.4	1380	ACC
GSR7382	CN	125	34 33N	69 55W	75-VIII-10		141-	16.7	12.8	1382	ACC
GSR7384	CN	125	34 9N	71 39W	75-VIII-12		131-	20.1	18.7	1384	ANS
GSR7468	KN	380	36 3N	61 42W	74-III -25		150-	18.5	.0		NS
GSR7469	KN	380	36 23N	62 4W	74-III -26		150-	19.0	.0		NS
GSR7470	KN	380	35 27N	61 19W	74-III -26		150-	17.8	.0		CC
GSR7471	KN	380	35 42N	61 0W	74-III -27		150-	17.9	.0		CC
GSR7472	KN	380	35 59N	60 52W	74-III -28		150-	18.1	.0		RF
GSR7473	KN	380	35 51N	61 23W	74-III -29		150-	17.7	.0		CC
GSR7474	KN	380	36 52N	64 74W	74-III -30		150-	19.0	.0		NS
GSR7475	KN	380	38 7N	67 52W	74- IV - 2		150-	12.4	.0		WC
GSR7476	KN	380	38 4N	68 48W	74- IV - 3		150-	16.2	.0		WC
GSR7477	KN	380	39 37N	69 50W	74- IV - 3		150-	13.3	.0		SW
GSR7717	KN	53	32 44N	71 10W	75- XI -17		150-	19.4	18.4	0717	ANS
GSR7719	KN	53	33 55N	71 54W	75- XI -21		144-	17.3	14.2	0719	ACC
GSR7723	KN	53	40 6N	68 7W	75- XI -30		150-	15.8	11.7	0723	AWC
GSR8005	KN	53	33 57N	71 53W	75- XI -23		175-	17.1	.0	CC-5	ACC
GSR8006	KN	53	34 10N	71 34W	75- XI -24		175-	18.4	.0	CC-6	ACC

TABLE OF STATIONS

STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT. DEPTH	SURF. TEMP	200M TEMP	GEAR	CODE
GSR8007	KN	53	38 55N	57 45W	75• XI •28		175•	12.8	•0	CC•7	ASW
GSR8355	KN	35	39 45N	70 35W	73• XI •23		175•	•0	9.2	0355	TSW
GSR8356	KN	35	38 19N	70 20W	73• XI •24		175•	•0	8.1	0356	TSW
GSR8357	KN	35	35 55N	71 43W	73• XI •27		175•	14.7	11.1	0357	ACC
GSR8359	KN	35	35 54N	71 38W	73• XI •28		175•	14.8	10.8	0359	DCC
GSR8360	KN	35	36 17N	72 4W	73• XI •28		174•	20.7	16.4	0360	NCC
GSR8361	KN	35	37 5N	68 7W	73• XI •30		175•	19.4	18.0	0361	DNS
GSR8362	KN	35	38 33N	68 22W	73•XII • 1		175•	•0	7.8	0362	NSW
GSR8377	CN	125	38 29N	69 59W	75•VIII• 1		170•	12.3	9.4	1377	ASW
GSR8378	CN	125	35 34N	68 35W	75•VIII• 5		144•	19.1	18.2	1378	ACC
GSR8380	CN	125	34 32N	69 55W	75•VIII• 8		165•	16.4	12.4	1380	ACC
GSR8382	CN	125	34 33N	69 55W	75•VIII•10		170•	16.1	12.8	1382	ACC
GSR8384	CN	125	34 9N	71 39W	75•VIII•12		152•	19.7	18.7	1384	ANS
GSR8468	KN	380	36 3N	61 42W	74•III •25		175•	18.5	•0		NS
GSR8469	KN	380	36 23N	62 4W	74•III •26		175•	18.9	•0		NS
GSR8470	KN	380	35 27N	61 19W	74•III •26		175•	17.8	•0		CC
GSR8471	KN	380	35 42N	61 0W	74•III •27		175•	17.9	•0		CC
GSR8472	KN	380	35 59N	60 52W	74•III •28		175•	18.1	•0		RF
GSR8473	KN	380	35 51N	61 23W	74•III •29		175•	17.7	•0		CC
GSR8474	KN	380	36 52N	64 74W	74•III •30		175•	18.9	•0		NS
GSR8475	KN	380	38 7N	67 52W	74• IV • 2		175•	11.5	•0		WC
GSR8476	KN	380	38 4N	68 48W	74• IV • 3		175•	15.8	•0		WC

TABLE OF STATIONS

STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT. DEPTH	SURF. TEMP	200M TEMP	GEAR	CODE
GSR8477	KN	380	39 37N	69 50W	74- IV - 3		175-	12.6	.0		SW
GSR8717	KN	53	32 44N	71 10W	75- XI -17		175-	19.1	18.4	0717	ANS
GSR8719	KN	53	33 55N	71 54W	75- XI -21		166-	17.0	14.2	0719	ACC
GSR8723	KN	53	40 6N	68 7W	75- XI -30		176-	15.0	11.7	0723	AWC
GSR9005	KN	53	33 57N	71 53W	75- XI -23		200-	16.8	.0	CC-5	ACC
GSR9006	KN	53	34 10N	71 34W	75- XI -24		200-	18.1	.0	CC-6	ACC
GSR9007	KN	53	38 55N	57 45W	75- XI -28		200-	12.3	.0	CC-7	ASW
GSR9355	KN	35	39 45N	70 35W	73- XI -23		200-	11.5	9.2	0355	TSW
GSR9356	KN	35	38 19N	70 20W	73- XI -24		200-	11.0	8.1	0356	TSW
GSR9357	KN	35	35 55N	71 43W	73- XI -27		200-	13.8	11.1	0357	ACC
GSR9359	KN	35	35 54N	71 38W	73- XI -28		200-	13.3	10.8	0359	DCC
GSR9360	KN	35	36 17N	72 4W	73- XI -28		199-	.0	16.4	0360	NCC
GSR9361	KN	35	37 5N	68 7W	73- XI -30		200-	.0	18.0	0361	DNS
GSR9362	KN	35	38 33N	68 22W	73-XII - 1		200-	10.4	7.8	0362	NSW
GSR9377	CN	125	38 29N	69 59W	75-VIII- 1		197-	12.0	9.4	1377	ASW
GSR9378	CN	125	35 34N	68 35W	75-VIII- 5		164-	.0	18.2	1378	ACC
GSR9380	CN	125	34 32N	69 55W	75-VIII- 8		188-	15.3	18.2	1380	ACC
GSR9382	CN	125	34 33N	69 55W	75-VIII-10		195-	15.4	12.8	1382	ACC
GSR9384	CN	125	34 9N	71 39W	75-VIII-12		174-	19.3	18.7	1384	ANS
GSR9468	KN	380	36 3N	61 42W	74-III -25		200-	18.3	.0		NS
GSR9469	KN	380	36 23N	62 4W	74-III -26		200-	18.8	.0		NS
GSR9470	KN	380	35 27N	61 19W	74-III -26		200-	17.8	.0		CC

TABLE OF STATIONS

STATION	SHIP	CRUISE	LAT.	LONG.	DATE	ZONE	COLLECT. DEPTH	SURF. TEMP	200M TEMP	GEAR	CODE
GSR9471	KN	380	35 42N	61 0W	74-III -27		200-	14.3	.0		CC
GSR9472	KN	380	35 59N	60 52W	74-III -28		200-	17.9	.0		RF
GSR9473	KN	380	35 51N	61 23W	74-III -29		200-	17.7	.0		CC
GSR9474	KN	380	36 52N	64 74W	74-III -30		200-	18.8	.0		NS
GSR9475	KN	380	38 7N	67 52W	74- IV - 2		200-	11.1	.0		WC
GSR9476	KN	380	38 4N	68 48W	74- IV - 3		200-	.0	.0		WC
GSR9477	KN	380	39 37N	69 50W	74- IV - 3		200-	11.0	.0		SW
GSR9717	KN	53	32 44N	71 10W	75- XI -17		200-	19.0	18.4	0717	ANS
GSR9719	KN	53	33 55N	71 54W	75- XI -21		188-	17.0	14.2	0719	ACC
GSR9723	KN	53	40 6N	68 7W	75- XI -30		201-	13.5	11.7	0723	AWC

STATION	QUANTITY	CARB(IND)	CARBON (NG)
ARDIN			
AMPHISOLENIA SP.			
GSR5719	30	0 555	16.7
TOTAL	30	0 - 555	16.7
CERATIUM FUSUS			
GSR1380	30	0 1132	34.0
GSR1471	30	0 1132	34.0
GSR4005	30	0 1132	34.0
GSR4719	30	0 1132	34.0
GSR5719	30	0 1132	34.0
GSR6360	30	0 1132	34.0
GSR6361	30	0 1132	34.0
TOTAL	210	0 - 1132	238.0
CERATIUM MACROCEROS			
GSR2380	30	0 2396	71.9
TOTAL	30	0 - 2396	71.9
CERATIUM MINUTUM			
GSR1475	90	0 625	56.3
GSR3377	3600	0 625	2250.0
GSR3380	30	0 625	18.8
GSR9377	30	0 625	18.8
TOTAL	3750	0 - 625	2343.9
CERATIUM PENTAGONUM			
GSR1474	30	0 4217	126.5
GSR2361	30	0 4217	126.5
TOTAL	60	0 - 4217	253.0
CERATIUM TERES			
GSR1378	30	0 1031	30.9
GSR4360	30	0 1031	30.9
GSR5382	30	0 1031	30.9
TOTAL	90	0 - 1031	92.7

STATION	QUANTITY	CARB(IND)	CARBON (NG)
CERATIUM	TRICHOCEROS		
GSR1472	30	0 2180	65.4
GSR2719	30	0 2180	65.4
TOTAL	60	0 - 2180	130.8
CLADOPYXIS	SETIFERA		
GSR1006	30	0 91	2.7
GSR2382	30	0 91	2.7
GSR3384	150	0 91	13.7
GSR4384	30	0 91	2.7
TOTAL	240	0 - 91	21.8
DINOPHYSIS	SP.		
GSR3005	30	0 562	16.9
GSR3384	30	0 562	16.9
TOTAL	60	0 - 562	33.8
OXYTOXUM	MILNERII		
GSR1377	30	0 222	6.7
GSR1469	30	0 222	6.7
GSR3717	30	0 222	6.7
TOTAL	90	0 - 222	20.1
OXYTOXUM	SCOLOPAX		
GSR1007	60	0 582	17.5
GSR1377	120	0 582	69.8
GSR1471	30	0 582	17.5
GSR2377	210	0 582	122.2
GSR2380	30	0 582	17.5
GSR3719	60	0 582	17.5
GSR5006	60	0 582	17.5
GSR5719	60	0 582	17.5
TOTAL	630	0 - 582	297.0
OXYTOXUM	SPHAEROIDEUM		
GSR1005	60	0 361	21.7
GSR1359	30	0 361	10.8
GSR1378	120	0 361	43.3
GSR1380	30	0 361	10.8
GSR1382	30	0 361	10.8

STATION	QUANTITY	CARB(IND)		CARBON (G)
GSR1384	360	0	361	130.0
GSR1717	60	0	361	21.7
GSR1719	30	0	361	10.8
GSR2005	90	0	361	32.5
GSR2380	120	0	361	43.3
GSR2382	30	0	361	10.8
GSR2384	30	0	361	10.8
GSR2717	60	0	361	21.7
GSR2719	30	0	361	10.8
GSR3377	150	0	361	54.2
GSR3378	120	0	361	43.3
GSR3380	30	0	361	10.8
GSR3382	30	0	361	10.8
GSR3384	60	0	361	21.7
GSR3719	60	0	361	21.7
GSR4361	30	0	361	10.8
GSR4378	30	0	361	10.8
GSR4382	30	0	361	10.8
GSR5005	30	0	361	10.8
GSR5382	60	0	361	21.7
GSR5719	30	0	361	10.8
GSR6005	30	0	361	10.8
TOTAL	1770	0	361	638.8
OXYTOXUM	VARIABILE			
GSR1007	375	0	60	22.5
GSR1356	30	0	60	1.8
GSR1357	60	0	60	3.6
GSR1359	30	0	60	1.8
GSR1360	30	0	60	1.8
GSR1361	30	0	60	1.8
GSR1377	30	0	60	1.8
GSR1378	120	0	60	7.2
GSR1380	60	0	60	3.6
GSR1384	30	0	60	1.8
GSR1468	60	0	60	3.6
GSR1469	60	0	60	3.6
GSR1472	30	0	60	1.8
GSR1473	90	0	60	5.4
GSR1474	30	0	60	1.8
GSR1475	150	0	60	8.0
GSR1476	60	0	60	3.6
GSR1717	30	0	60	1.8
GSR2005	30	0	60	1.8

STATION	QUANTITY	CARB(IND)		CARBON NG)
GSR2006	90	0	60	5.4
GSR2007	180	0	60	10.8
GSR2355	100	0	60	6.0
GSR2356	30	0	60	1.8
GSR2357	30	0	60	1.8
GSR2359	30	0	60	1.8
GSR2360	60	0	60	3.6
GSR2377	270	0	60	16.2
GSR2380	180	0	60	10.8
GSR2382	30	0	60	1.8
GSR2468	200	0	60	12.0
GSR2717	30	0	60	1.8
GSR2719	60	0	60	3.6
GSR3005	30	0	60	1.8
GSR3004	30	0	60	1.8
GSR3007	240	0	60	14.4
GSR3359	60	0	60	3.6
GSR3361	60	0	60	3.6
GSR3378	60	0	60	3.6
GSR3380	180	0	60	10.8
GSR3382	30	0	60	1.8
GSR3468	100	0	60	6.0
GSR3469	30	0	60	1.8
GSR3719	30	0	60	1.8
GSR3723	60	0	60	3.6
GSR4005	30	0	60	1.8
GSR4377	60	0	60	3.6
GSR4380	300	0	60	18.0
GSR4382	210	0	60	12.6
GSR4384	120	0	60	7.2
GSR4468	100	0	60	6.0
GSR4719	30	0	60	1.8
GSR5005	60	0	60	3.6
GSR5360	30	0	60	1.8
GSR5382	270	0	60	16.2
GSR5384	60	0	60	3.6
GSR5468	50	0	60	3.0
GSR6361	60	0	60	3.6
GSR6378	30	0	60	1.8
GSR6382	180	0	60	10.8
GSR7378	30	0	60	1.8
TOTAL	5155	0 -	60	308.3

PERIDINIUM GLOBULUS

GSR1356	30	0	3553	106.6

	STATION	QUANTITY	CARB(IND)	CARBON NG)
	GSR1475	60	0 3553	21.2
	TOTAL	90	0 - 3553	127.8
PERIDINIUM	SP.			
	GSR1356	30	0 250	7.5
	GSR5378	30	0 250	7.5
	TOTAL	60	0 - 250	15.0
PERIDINIUM	SPP.			
	GSR1475	30	0 250	7.5
	TOTAL	30	0 - 250	7.5
PERIDINIUM	TROCHOIDEUM			
	GSR1717	30	0 268	8.0
	TOTAL	30	0 - 268	8.0
PHALACROMA	SPP.			
	GSR1005	30	0 2855	85.7
	GSR1006	30	0 2855	85.7
	GSR3361	60	0 2855	171.3
	GSR4005	30	0 2855	85.7
	GSR5361	30	0 2855	85.7
	TOTAL	180	0 - 2855	514.1
PODOLAMPAS	PALMIPES			
	GSR1006	30	0 1385	41.6
	GSR2005	30	0 1385	41.6
	GSR2719	30	0 1385	41.6
	GSR4005	30	0 1385	41.6
	GSR5719	30	0 1385	41.6
	TOTAL	150	0 - 1385	208.0
PORELLA	PERFORATA			
	GSR1355	450	0 284	127.8
	GSR1359	30	0 284	8.5
	GSR2355	100	0 284	28.4
	GSR3006	30	0 284	8.5
	GSR3361	60	0 284	17.0
	GSR5360	30	0 284	8.5
	TOTAL	700	0 - 284	198.7

STATION	QUANTITY	CARB(IND)	CARBON (UG)
PROROCENTRUM GRACILE			
GSR3007	60	0 244	14.6
TOTAL	60	0 - 244	14.6
PROROCENTRUM LEBOURAE			
GSR1382	30	0 1260	37.8
GSR2006	30	0 1260	37.8
GSR2007	60	0 1260	75.6
TOTAL	120	0 - 1260	151.2
PROROCENTRUM OBTUSIDENS			
GSR1007	150	0 260	39.0
GSR1356	30	0 260	7.8
GSR1377	30	0 260	7.8
GSR1468	90	0 260	23.4
GSR1470	420	0 260	109.2
GSR1471	510	0 260	132.6
GSR1472	180	0 260	46.8
GSR1473	300	0 260	78.0
GSR2007	60	0 260	15.6
GSR2377	30	0 260	7.8
GSR2719	30	0 260	7.8
GSR5006	30	0 260	7.8
TOTAL	1860	0 - 260	483.6
PROROCENTRUM STEINII			
GSR4382	30	0 254	7.6
TOTAL	30	0 - 254	7.6
PYROCYSTIS LUNULA			
GSR1356	30	0 986	29.6
GSR1361	30	0 986	29.6
GSR2357	30	0 986	29.6
TOTAL	90	0 - 986	88.8
NKDIN			
COCHLODINIUM SP.			
GSR1380	30	0 582	17.5
GSR4384	30	0 582	17.5
GSR8719	33	0 582	19.2
TOTAL	93	0 - 582	54.2

STATION	QUANTITY	CARB(IND)		CARBON NG)
DINOFLAGELLATE	SPP.			
GSR1006	30	0	60	1.8
GSR1007	300	0	60	18.0
GSR1356	30	0	60	1.8
GSR1360	30	0	60	1.8
GSR1377	90	0	60	5.4
GSR1378	90	0	60	5.4
GSR1380	210	0	60	12.6
GSR1382	540	0	60	32.4
GSR1384	630	0	60	37.8
GSR1469	60	0	60	3.6
GSR1473	60	0	60	3.6
GSR1475	90	0	60	5.4
GSR1476	60	0	60	3.6
GSR1717	150	0	60	9.0
GSR2005	90	0	60	5.4
GSR2007	120	0	60	7.2
GSR2356	30	0	60	1.8
GSR2360	30	0	60	1.8
GSR2377	12	0	60	.7
GSR2380	300	0	60	18.0
GSR2382	240	0	60	14.4
GSR2384	180	0	60	10.8
GSR2468	50	0	60	3.0
GSR2719	210	0	60	12.6
GSR2719	90	0	60	5.4
GSR2723	120	0	60	7.2
GSR3006	90	0	60	5.4
GSR3355	30	0	60	1.8
GSR3377	700	0	60	42.0
GSR3380	90	0	60	5.4
GSR3382	240	0	60	14.4
GSR3384	610	0	60	36.6
GSR3717	90	0	60	5.4
GSR4360	30	0	60	1.8
GSR4378	30	0	60	1.8
GSR4380	60	0	60	3.6
GSR4382	30	0	60	1.8
GSR4384	270	0	60	16.2
GSR4723	120	0	60	7.2
GSR5005	240	0	60	14.4
GSR5004	30	0	60	1.8
GSR5382	60	0	60	3.6
GSR5719	90	0	60	5.4
GSR5719	60	0	60	3.6

STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR5723	30	0	60	1.8
GSR6355	60	0	60	3.6
GSR6382	60	0	60	3.6
GSR6468	100	0	60	6.0
GSR7006	60	0	60	3.6
GSR7384	60	0	60	3.6
GSR7719	150	0	60	9.0
GSR7723	30	0	60	1.8
GSR8719	60	0	60	3.6
TOTAL	7322	0 -	60	439.3
ENTOMOSIGMA	PERIDINIOIDES			
GSR1355	150	0	55	8.3
GSR1380	30	0	55	1.7
GSR1382	30	0	55	1.7
GSR2361	30	0	55	1.7
GSR3356	30	0	55	1.7
GSR3380	30	0	55	1.7
GSR4355	20	0	55	1.1
GSR5382	30	0	55	1.7
GSR5384	30	0	55	1.7
GSR6355	20	0	55	1.1
TOTAL	400	0 -	55	22.4
GYMNODINIUM	PUNCTATUM			
GSR1005	60	0	60	3.6
GSR1007	75	0	60	4.5
GSR1355	600	0	60	36.0
GSR1356	240	0	60	14.4
GSR1377	30	0	60	1.8
GSR1378	300	0	60	18.0
GSR1380	630	0	60	37.8
GSR1382	300	0	60	18.0
GSR1384	300	0	60	18.0
GSR1468	1500	0	60	90.0
GSR1469	1290	0	60	77.4
GSR1470	780	0	60	46.8
GSR1471	1320	0	60	79.2
GSR1472	720	0	60	43.2
GSR1473	1020	0	60	61.2
GSR1474	360	0	60	21.6
GSR1475	1110	0	60	66.6
GSR1476	1470	0	60	88.2

STATION	QUANTITY	CARB(IND)		CARBON (G)
GSR1717	300	0	60	18.0
GSR2005	60	0	60	3.6
GSR2006	90	0	60	5.4
GSR2007	480	0	60	28.8
GSR2359	60	0	60	3.6
GSR2361	300	0	60	18.0
GSR2377	18	0	60	1.1
GSR2378	240	0	60	14.4
GSR2380	720	0	60	43.2
GSR2382	450	0	60	27.0
GSR2384	60	0	60	3.6
GSR2717	210	0	60	12.6
GSR2719	120	0	60	7.2
GSR2723	120	0	60	7.2
GSR3005	150	0	60	9.0
GSR3006	60	0	60	3.6
GSR3007	780	0	60	46.8
GSR3360	30	0	60	1.8
GSR3361	120	0	60	7.2
GSR3377	450	0	60	27.0
GSR3378	750	0	60	45.0
GSR3380	630	0	60	37.8
GSR3382	1040	0	60	62.4
GSR3384	30	0	60	1.8
GSR3717	150	0	60	9.0
GSR3719	120	0	60	7.2
GSR3723	180	0	60	10.8
GSR4006	90	0	60	5.4
GSR4359	20	0	60	1.2
GSR4361	90	0	60	5.4
GSR4377	30	0	60	1.8
GSR4382	150	0	60	9.0
GSR4384	60	0	60	3.6
GSR4717	30	0	60	1.8
GSR5005	270	0	60	16.2
GSR5007	30	0	60	1.8
GSR5719	90	0	60	5.4
GSR6006	30	0	60	1.8
GSR6378	30	0	60	1.8
GSR6382	130	0	60	1.8
GSR6717	60	0	60	3.6
GSR7005	30	0	60	1.8
GSR7378	60	0	60	3.6
GSR9471	30	0	60	1.8
TOTAL	21053	0 -	60	1257.2

STATION	QUANTITY	CARB(IND)		CARBON (NG)
GYRODINIUM	AUREOLUM			
GSR1380	30	0	521	15.6
GSR1382	30	0	521	15.6
GSR1384	90	0	521	46.9
GSR1469	30	0	521	15.6
GSR1719	60	0	521	15.6
GSR2377	30	0	521	15.6
GSR2379	30	0	521	15.6
GSR2380	60	0	521	31.3
GSR2382	90	0	521	46.9
GSR3006	30	0	521	15.6
GSR3377	150	0	521	78.2
GSR3379	30	0	521	15.6
GSR3382	30	0	521	15.6
GSR4384	30	0	521	15.6
GSR7006	30	0	521	15.6
TOTAL	750	0 -	521	374.9
GYRODINIUM	DOMINANS			
GSR9009	30	0	151	4.5
TOTAL	30	0 -	151	4.5
GYRODINIUM	GLAEBUM			
GSR1379	330	0	181	59.7
GSR1380	30	0	181	5.4
GSR1382	60	0	181	10.9
GSR1384	60	0	181	10.9
GSR2379	30	0	181	5.4
GSR2382	60	0	181	10.9
GSR3382	120	0	181	21.7
GSR6382	30	0	181	5.4
GSR7382	90	0	181	16.3
TOTAL	810	0 -	181	146.6
GYRODINIUM	METUM			
GSR1379	30	0	156	4.7
GSR2377	60	0	156	9.4
GSR2719	30	0	156	4.7
GSR2723	60	0	156	9.4
GSR3377	150	0	156	23.4
GSR3379	60	0	156	9.4
GSR5007	30	0	156	4.7

STATION	QUANTITY	CARB(IND)	CARBON (NG)
GSR7719	30	0 156	4.7
GSR8007	60	0 156	9.4
TOTAL	510	0 - 156	79.8
GYRODINIUM SP.			
GSR3356	30	0 150	4.5
TOTAL	30	0 - 150	4.5
GYRODINIUM SPIRALE			
GSR9007	30	0 2034	61.0
TOTAL	30	0 - 2034	61.0
GYRODINIUM UNCATENUM			
GSR5382	30	0 1079	32.4
TOTAL	30	0 - 1079	32.4
KATODINIUM ROTUNDATUM			
GSR1006	120	0 60	7.2
GSR1007	300	0 60	18.0
GSR1355	4500	0 60	270.0
GSR1356	60	0 60	3.6
GSR1357	30	0 60	1.8
GSR1378	90	0 60	5.4
GSR1380	240	0 60	14.4
GSR1382	90	0 60	5.4
GSR1384	240	0 60	14.4
GSR1468	30	0 60	1.8
GSR1469	30	0 60	1.8
GSR1470	60	0 60	3.6
GSR1472	90	0 60	5.4
GSR1473	30	0 60	1.8
GSR1476	90	0 60	5.4
GSR2006	60	0 60	3.6
GSR2007	180	0 60	10.8
GSR2356	30	0 60	1.8
GSR2360	30	0 60	1.8
GSR2361	30	0 60	1.8
GSR2378	270	0 60	16.2
GSR2380	450	0 60	27.0
GSR2382	150	0 60	9.0
GSR2468	50	0 60	3.0

	STATION	QUANTITY	CARB(IND)		CARBON NG)
	GSR2717	90	0	60	5.4
	GSR2719	30	0	60	1.8
	GSR2723	60	0	60	3.6
	GSR3005	60	0	60	3.6
	GSR3006	120	0	60	7.2
	GSR3007	60	0	60	3.6
	GSR3378	120	0	60	7.2
	GSR3380	540	0	60	32.4
	GSR3382	780	0	60	46.8
	GSR3384	300	0	60	18.0
	GSR3717	60	0	60	3.6
	GSR3719	60	0	60	3.6
	GSR4005	30	0	60	1.8
	GSR4355	20	0	60	1.2
	GSR4357	30	0	60	1.8
	GSR4360	30	0	60	1.8
	GSR4378	30	0	60	1.8
	GSR4380	60	0	60	3.6
	GSR4382	60	0	60	3.6
	GSR4384	90	0	60	5.4
	GSR4717	60	0	60	3.6
	GSR5005	30	0	60	1.8
	GSR5384	30	0	60	1.8
	GSR5468	50	0	60	3.0
	GSR6006	30	0	60	1.8
	GSR6378	30	0	60	1.8
	GSR6378	90	0	60	5.4
	GSR6382	30	0	60	1.8
	GSR6384	30	0	60	1.8
TOTAL		10260	0 -	60	615.6
OXYHRRIS		SP.			
	GSR1007	75	0	222	16.7
TOTAL		75	0 -	222	16.7
POLYKRIKOS		BARNEGATENSIS			
	GSR3005	30	0	1117	33.5
TOTAL		30	0 -	1117	33.5
PRONOCTILUCA		PELAGICA			
	GSR1354	60	0	53	6.2
	GSR1472	30	0	53	1.6

	STATION	QUANTITY	CARB(IND)		CARBON (NG)
	GSR1723	60	0	53	3.2
	GSR2005	30	0	53	1.6
	GSR2380	30	0	53	1.6
	GSR3007	180	0	53	9.5
	GSR3382	30	0	53	1.6
	GSR4005	30	0	53	1.6
	GSR4006	30	0	53	1.6
	GSR4007	99	0	53	5.2
	GSR4355	40	0	53	2.1
	GSR4384	30	0	53	1.6
	GSR4719	30	0	53	1.6
	GSR5007	30	0	53	1.6
	GSR6356	20	0	53	1.1
	GSR6382	60	0	53	3.2
	GSR6384	30	0	53	1.6
	GSR7005	30	0	53	1.6
	GSR8007	120	0	53	6.4
	GSR8382	30	0	53	1.6
	GSR9005	30	0	53	1.6
	GSR9007	30	0	53	3.2
	GSR9717	30	0	53	1.6
	TOTAL	1089	0 -	53	62.5
CDIAT					
	ASTEROLAMPRA	MARYLANDICA			
	GSR3006	30	0	3031	90.9
	TOTAL	30	0 -	3031	90.9
	BACTERIASTRUM	DELICATULUM			
	GSR1356	300	0	139	41.7
	GSR1362	600	0	139	83.4
	GSR2356	420	0	139	58.4
	GSR3362	1900	0	139	264.1
	GSR4355	100	0	139	13.9
	GSR4356	60	0	139	8.3
	GSR7469	480	0	139	66.7
	TOTAL	3860	0 -	139	536.5
	BACTERIASTRUM	ELONGATUM			
	GSR3356	150	0	136	20.4
	GSR4356	100	0	136	13.6
	TOTAL	250	0 -	136	34.0

STATION	QUANTITY	CARB(IND)		CARBON (NG)
BACTERIASTRUM	HYALINUM			
GSR1470	210	0	327	68.7
GSR2354	300	0	327	98.1
GSR2362	660	0	327	215.8
GSR3354	150	0	327	49.1
GSR3362	1000	0	327	327.0
GSR3469	270	0	327	88.3
GSR4356	180	0	327	58.9
GSR6361	150	0	327	49.1
TOTAL	2920	0 -	327	955.0
BACTERIASTRUM	SP.			
GSR5384	210	0	150	31.5
TOTAL	210	0 -	150	31.5
BACTERIASTRUM	SPP.			
GSR1471	210	0	150	31.5
TOTAL	210	0 -	150	31.5
CENTRIC	SPP.			
GSR1361	30	0	143	4.3
GSR1475	30	0	143	4.3
GSR2007	60	0	143	8.6
GSR2362	240	0	143	34.3
GSR3354	90	0	143	12.9
GSR3361	60	0	143	8.6
GSR3362	100	0	143	14.3
GSR4356	60	0	143	8.6
GSR4362	120	0	143	17.2
GSR5007	30	0	143	4.3
GSR5355	30	0	143	4.3
TOTAL	850	0 -	143	121.7
CERATAULINA	BERGONII			
GSR1007	900	0	398	35.8
GSR1354	120	0	398	47.8
GSR1361	180	0	398	71.6
GSR1362	3540	0	398	1408.9
GSR1471	30	0	398	11.9
GSR1472	60	0	398	23.9
GSR1723	120	0	398	47.7

STATION	QUANTITY	CARB(IND)		CARBON NG)
GSR2007	480	0	398	191.0
GSR2354	780	0	398	310.4
GSR2361	90	0	398	35.8
GSR2362	1260	0	398	501.5
GSR2723	60	0	398	23.9
GSR3007	60	0	398	23.9
GSR3356	180	0	398	71.6
GSR3361	300	0	398	119.4
GSR3362	1100	0	398	437.8
GSR3469	90	0	398	35.8
GSR4007	33	0	398	13.1
GSR4361	30	0	398	11.9
GSR4377	60	0	398	23.9
GSR4723	60	0	398	23.9
GSR5007	30	0	398	11.9
GSR5360	720	0	398	286.6
TOTAL	10283	0 -	398	3770.0
CHAETOCEROS	CONCAVICORNIS			
GSR1475	90	0	495	44.6
GSR3007	240	0	495	118.8
GSR4469	120	0	495	59.4
GSR7378	120	0	495	59.4
TOTAL	570	0 -	495	282.2
CHAETOCEROS	DANICUS			
GSR3362	200	0	68	13.6
TOTAL	200	0 -	68	13.6
CHAETOCEROS	DEBILIS			
GSR4356	140	0	293	41.0
TOTAL	140	0 -	293	41.0
CHAETOCEROS	DECIPIENS			
GSR1356	90	0	825	74.2
GSR1723	240	0	825	198.0
GSR4360	90	0	825	74.2
TOTAL	420	0 -	825	346.4
CHAETOCEROS	DENSUS			
GSR2356	60	0	215	12.9

STATION	QUANTITY	CARB(IND)		CARBON NG)
GSR3356	270	0	215	58.1
TOTAL	330	0 -	215	71.0
CHAETOCEROS	DIDYMUS			
GSR3007	60	0	173	10.4
GSR4723	120	0	173	20.8
TOTAL	180	0 -	173	31.2
CHAETOCEROS	DIVERSUS			
GSR1361	120	0	36	4.3
TOTAL	120	0 -	36	4.3
CHAETOCEROS	LACINIOSUS			
GSR1470	180	0	152	27.4
GSR8378	90	0	152	13.7
TOTAL	270	0 -	152	41.1
CHAETOCEROS	MESSANENSIS			
GSR1356	120	0	173	20.8
GSR4361	150	0	173	26.0
TOTAL	270	0 -	173	46.8
CHAETOCEROS	PENDULUS			
GSR1361	30	0	65	2.0
GSR1476	30	0	65	2.0
GSR3007	60	0	65	3.9
TOTAL	120	0 -	65	7.9
CHAETOCEROS	PERUVIANUS			
GSR1473	60	0	262	15.7
GSR4723	120	0	262	31.4
TOTAL	180	0 -	262	47.1
CHAETOCEROS	SP.			
GSR1007	2775	0	100	277.5
GSR1717	30	0	100	3.0
GSR2356	480	0	100	48.0
GSR3355	120	0	100	12.0

	STATION	QUANTITY	CARB(IND)		CARBON (NG)
	GSR4354	280	0	100	28.0
	GSR4362	60	0	100	6.0
TOTAL		3745	0	100	374.5
CHAETOCEROS	TERES				
	GSR1470	300	0	1061	318.3
	GSR1472	210	0	1061	222.8
	GSR2361	60	0	1061	63.7
	GSR4723	480	0	1061	509.3
	GSR6361	60	0	1061	63.7
TOTAL		1110	0	1061	1177.8
CLIMACODIUM	FRAUENFELDIANUM				
	GSR2723	480	0	722	346.6
	GSR3007	420	0	722	303.2
TOTAL		900	0	722	649.8
CORETHRON	HYSTRIX				
	GSR1355	150	0	1191	178.7
	GSR3007	60	0	1191	71.5
TOTAL		210	0	1191	250.2
COSCINODISCUS	CENTRALIS				
	GSR3355	60	0	9697	581.8
TOTAL		60	0	9697	581.8
COSCINODISCUS	CURVATULUS				
	GSR1468	30	0	1555	46.7
	GSR9007	30	0	1555	46.7
TOTAL		60	0	1555	93.4
COSCINODISCUS	EXCENTRICUS				
	GSR1356	30	0	1037	31.1
	GSR6355	40	0	1037	41.5
TOTAL		70	0	1037	72.6
COSCINODISCUS	RADIATUS				
	GSR1475	30	0	696	20.9

STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR1476	30	0	696	20.9
GSR1723	60	0	696	41.8
GSR2723	60	0	696	41.8
GSR3007	60	0	696	41.8
GSR3356	60	0	696	41.8
GSR8384	30	0	696	20.9
GSR9471	30	0	696	20.9
TOTAL	360	0	696	250.8
COSCINOSIRA	POLYCHORDA			
GSR1007	1425	0	496	706.8
GSR3355	120	0	496	59.5
TOTAL	1545	0	496	766.3
DACTYLIOSOLEN	MEDITERRANEUS			
GSR5378	60	0	135	8.1
GSR6005	60	0	135	8.1
TOTAL	120	0	135	16.2
EUCAMPIA	CORNUTA			
GSR5723	30	0	299	1.7
TOTAL	30	0	299	1.7
EUCAMPIA	ZOODIACUS			
GSR1723	120	0	318	6.6
GSR3362	3500	0	318	192.5
GSR4007	33	0	318	1.8
TOTAL	3653	0	318	200.9
GUINARDIA	FLACCIDA			
GSR1007	675	0	2409	1626.0
GSR1355	4800	0	2409	11563.2
GSR1468	30	0	2409	72.3
GSR1723	300	0	2409	722.7
GSR2007	360	0	2409	867.2
GSR2355	12500	0	2409	30112.5
GSR2362	60	0	2409	144.5
GSR3007	120	0	2409	289.0
GSR3355	510	0	2409	1228.6
GSR3723	120	0	2409	289.0

STATION	QUANTITY	CARB(IND)	CARBON NG)
GSR1723	720	0 121	87.1
GSR2007	180	0 121	21.8
GSR2361	60	0 121	7.3
GSR2362	240	0 121	29.0
GSR2723	420	0 121	50.8
GSR3007	1020	0 121	123.4
GSR3355	150	0 121	18.2
GSR3361	120	0 121	14.5
GSR3377	17700	0 121	2141.7
GSR3723	720	0 121	87.1
GSR4007	99	0 121	12.0
GSR4356	360	0 121	43.6
GSR4377	30	0 121	3.6
GSR4723	180	0 121	21.8
GSR6377	270	0 121	32.7
GSR7378	450	0 121	54.5
TOTAL	25374	0 - 121	3070.3
LEPTOCYLINDRICUS	MINIMUS		
GSR4356	80	0 15	1.2
TOTAL	80	0 - 15	1.2
PLANKTONIELLA	SOLL		
GSR2723	60	0 606	36.4
GSR5723	30	0 606	18.2
TOTAL	90	0 - 606	54.6
RHIZOSOLENIA	ALATA		
GSR1723	60	0 1555	93.3
GSR2007	120	0 1555	186.6
GSR3007	180	0 1555	279.9
GSR3356	60	0 1555	93.3
GSR3362	100	0 1555	155.5
GSR4355	20	0 1555	31.1
GSR5005	30	0 1555	46.7
TOTAL	570	0 - 1555	886.4
RHIZOSOLENIA	CALCARAVIS		
GSR1361	30	0 6262	187.9
GSR1362	60	0 6262	375.7
GSR2361	30	0 6262	187.9

STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR4355	20	0	2409	48.2
GSR4723	60	0	2409	144.5
GSR5355	30	0	2409	72.3
GSR6355	20	0	2409	48.2
GSR8355	30	0	2409	72.3
TOTAL	19635	0 -	2409	47300.5
HEMIAULUS	HAUCKII			
GSR1362	30	0	102	24.5
GSR2719	30	0	102	3.1
GSR4378	30	0	102	3.1
TOTAL	90	0 -	102	30.7
HEMIAULUS	MEMBRANACEUS			
GSR1007	75	0	672	50.4
GSR1356	30	0	672	20.2
GSR1361	30	0	672	20.2
GSR1362	360	0	672	241.9
GSR1469	30	0	672	20.2
GSR1723	120	0	672	80.6
GSR2007	360	0	672	241.9
GSR2355	1000	0	672	672.0
TOTAL	2005	0 -	672	1347.4
HEMIAULUS	SINENSIS			
GSR2362	620	0	119	14.3
GSR3362	600	0	119	71.4
TOTAL	1220	0 -	119	85.7
LAUDERIA	BOREALIS			
GSR1362	120	0	1559	1870.8
GSR2356	240	0	1559	374.2
GSR3361	1400	0	1559	2182.6
GSR4356	380	0	1559	592.4
TOTAL	3220	0 -	1559	5020.0
LEPTOCYLINDRICUS	DANICUS			
GSR1007	2025	0	121	245.0
GSR1355	600	0	121	72.6
GSR1472	30	0	121	3.6

STATION	QUANTITY	CARB(IND)	CARBON (NG)
GSR2723	60	0 6262	375.7
GSR3007	606	0 6262	375.7
GSR3360	30	0 6262	187.9
GSR3361	60	0 6262	375.7
GSR3362	200	0 6262	1252.4
GSR4360	30	0 6262	187.9
GSR4723	60	0 6262	375.7
TOTAL	1166	0 - 6262	3882.5
RHIZOSOLENIA	DELICATULA		
GSR1356	60	0 210	12.6
GSR1719	60	0 210	12.6
GSR2723	60	0 210	12.6
GSR3377	150	0 210	31.5
TOTAL	330	0 - 210	69.3
RHIZOSOLENIA	FRAGILISSIMA		
GSR1007	1200	0 450	540.0
GSR1355	600	0 450	270.0
GSR1356	60	0 450	27.0
GSR2007	540	0 450	243.0
GSR3356	30	0 450	13.5
GSR3361	60	0 450	27.0
GSR4007	33	0 450	14.9
GSR4356	20	0 450	9.0
GSR4723	60	0 450	27.0
GSR6362	240	0 450	108.0
TOTAL	2843	0 - 450	1279.4
RHIZOSOLENIA	IMBRICATA		
GSR1007	150	0 1481	222.2
GSR1355	1800	0 1481	2665.8
GSR1361	30	0 1481	44.4
GSR1362	120	0 1481	177.7
GSR1723	60	0 1481	88.9
GSR2355	6500	0 1481	9626.5
GSR2356	30	0 1481	44.4
GSR2362	150	0 1481	266.6
GSR2723	60	0 1481	88.9
GSR3355	510	0 1481	755.3
GSR3356	30	0 1481	44.4
GSR3362	1700	0 1481	2517.7

STATION	QUANTITY	CARB(IND)	CARBON (MG)
GSR4362	60	0 1481	88.9
GSR5355	90	0 1481	133.3
GSR6355	20	0 1481	29.6
GSR7355	300	0 1481	444.3
GSR8355	30	0 1481	44.4
GSR9355	150	0 1481	222.2
TOTAL	11790	0 - 1481	17505.5
RHIZOSOLENIA	SETIGERA		
GSR1471	30	0 1481	44.4
GSR1723	60	0 1481	88.9
GSR2723	120	0 1481	177.7
GSR3007	180	0 1481	266.6
GSR3355	90	0 1481	133.3
GSR3468	50	0 1481	74.1
GSR5355	60	0 1481	88.9
TOTAL	590	0 - 1481	873.9
RHIZOSOLENIA	STOLTERFOTHII		
GSR1007	1050	0 660	693.0
GSR1355	600	0 660	396.0
GSR1356	240	0 660	158.4
GSR1362	2400	0 660	1584.0
GSR1471	90	0 660	59.4
GSR1472	240	0 660	158.4
GSR1723	540	0 660	356.4
GSR2007	60	0 660	39.6
GSR2356	2160	0 660	1425.6
GSR2361	30	0 660	19.8
GSR2362	260	0 660	171.6
GSR2723	420	0 660	277.2
GSR3007	360	0 660	237.6
GSR3356	300	0 660	198.0
GSR3361	360	0 660	237.6
GSR3362	2100	0 660	1386.0
GSR3469	540	0 660	356.4
GSR3723	180	0 660	118.8
GSR4356	100	0 660	66.0
GSR4723	60	0 660	39.6
GSR5360	120	0 660	79.2
GSR5361	60	0 660	39.6
GSR7378	120	0 660	79.2
TOTAL	12390	0 - 660	8177.4

STATION	QUANTITY	CARB(IND)		CARBON NG)
SCHRODERELLA	DELICATULA			
GSR1356	130	0	683	122.9
GSR1362	300	0	683	204.9
GSR2362	180	0	683	122.9
GSR3356	360	0	683	245.8
TOTAL	970	0 -	683	696.5
SKELETONEMA	COSTATUM			
GSR1355	1500	0	42	63.0
GSR1475	120	0	42	5.0
GSR2356	300	0	42	12.6
GSR6355	120	0	42	5.0
TOTAL	2040	0 -	42	85.6
STEPHANOPYXIS	PALMERIANA			
GSR2356	60	0	2315	138.9
GSR2362	840	0	2315	1944.6
TOTAL	900	0 -	2315	2083.5
STREPTOTHECA	THALMENSIS			
GSR1362	540	0	1373	741.4
TOTAL	540	0 -	1373	741.4
THALASSIOSIRA	DECIPIENS			
GSR2356	60	0	660	39.6
TOTAL	60	0 -	660	39.6
THALASSIOSIRA	NORDENSKIOLDII			
GSR1355	300	0	158	47.4
GSR8384	90	0	158	14.2
TOTAL	390	0 -	158	61.6
THALASSIOSIRA	SUBTILIS			
GSR1362	3840	0	364	1397.8
GSR2362	2040	0	364	742.6
GSR3469	300	0	364	109.2
GSR3476	2250	0	364	819.0
GSR7476	30	0	364	10.9
TOTAL	8460	0 -	364	3079.5

STATION	QUANTITY	CARB(IND)		CARBON (NG)
TROPIDONEIS	ANTARCTICA V.POL			
GSR1470	30	0	3495	104.9
TOTAL	30	0 -	3495	104.9
PDIAT				
MASTOGLOIA	ROSTRATA			
GSR2384	30	0	117	3.5
TOTAL	30	0 -	117	3.5
NAVICULA	MEMBRANACEA			
GSR1007	1425	0	146	208.1
GSR1356	30	0	146	4.4
GSR1475	30	0	146	4.4
GSR1476	120	0	146	17.5
GSR1723	240	0	146	35.0
GSR2007	720	0	146	105.1
GSR2362	300	0	146	43.8
GSR3007	120	0	146	17.5
GSR3361	60	0	146	8.8
GSR3362	400	0	146	58.4
GSR4356	20	0	146	2.9
GSR5356	30	0	146	4.4
GSR5361	30	0	146	4.4
TOTAL	3525	0 -	146	514.7
NITZSCHIA	BICAPITATA			
GSR1007	75	0	4	.3
GSR1355	150	0	4	.6
GSR1357	30	0	4	.1
GSR1378	60	0	4	.2
GSR1476	60	0	4	.2
GSR1723	180	0	4	.7
GSR2719	30	0	4	.1
GSR2723	60	0	4	.2
GSR3356	30	0	4	.1
GSR3361	60	0	4	.2
GSR4007	33	0	4	.1
GSR5361	30	0	4	.1
GSR7378	30	0	4	.1
GSR7723	30	0	4	.1
TOTAL	858	0 -	4	3.1

STATION	QUANTITY	CARB(IND)		CARBON NG)
NITZSCHIA	BRAARUDII			
GSR1377	30	0	6	.2
GSR1476	120	0	6	.7
GSR2377	30	0	6	.2
GSR4007	33	0	6	.2
GSR4356	20	0	6	.1
GSR6356	40	0	6	.2
TOTAL	273	0	6	1.6
NITZSCHIA	CLOSTERIUM			
GSR1007	225	0	8	1.8
GSR1355	150	0	8	1.2
GSR1361	30	0	8	.2
GSR1468	270	0	8	2.2
GSR1469	60	0	8	.5
GSR1472	120	0	8	1.0
GSR1473	30	0	8	.2
GSR1475	30	0	8	.2
GSR1476	90	0	8	.7
GSR1723	240	0	8	1.9
GSR2007	180	0	8	1.4
GSR2359	30	0	8	.2
GSR2468	400	0	8	3.2
GSR2723	360	0	8	2.9
GSR3007	420	0	8	3.4
GSR3355	30	0	8	.2
GSR3356	60	0	8	.5
GSR3362	100	0	8	.8
GSR3377	150	0	8	.9
GSR3468	90	0	8	.7
GSR3476	180	0	8	1.4
GSR3723	240	0	8	1.9
GSR4007	66	0	8	.5
GSR4355	40	0	8	.3
GSR4356	30	0	8	.2
GSR4361	30	0	8	.2
GSR4468	200	0	8	1.6
GSR4723	180	0	8	1.4
GSR5007	30	0	8	.2
GSR5384	90	0	8	.7
GSR5468	60	0	8	.5
GSR5717	60	0	5	.8
GSR6006	30	0	8	.2
GSR6468	30	0	8	.2

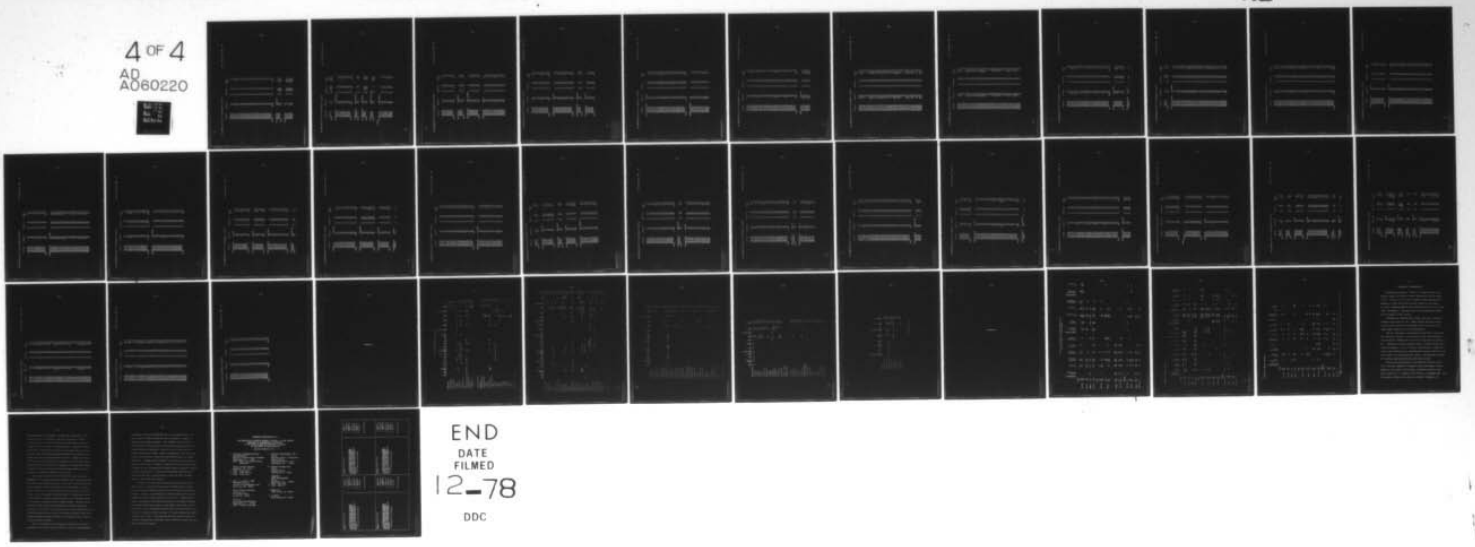
STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR8007	30	0	8	.2
GSR8378	30	0	8	.9
TOTAL	4391	0	8	35.3
NITZSCHIA	DELICATISSIMA			
GSR1007	150	0	20	3.0
GSR1356	60	0	20	1.2
GSR1359	150	0	20	3.0
GSR1361	120	0	20	2.4
GSR1362	1740	0	20	34.8
GSR1468	150	0	20	3.0
GSR1469	210	0	20	4.2
GSR1470	2310	0	20	46.2
GSR1471	510	0	20	10.2
GSR1472	1050	0	20	21.0
GSR1473	300	0	20	6.0
GSR1475	120	0	20	2.4
GSR1476	120	0	20	2.4
GSR1717	120	0	60	2.4
GSR1723	120	0	60	2.4
GSR2007	540	0	20	10.8
GSR2356	1290	0	20	25.8
GSR2360	120	0	20	2.4
GSR2361	90	0	20	1.8
GSR2362	720	0	20	14.4
GSR3007	300	0	20	6.0
GSR3356	3480	0	20	69.6
GSR3361	180	0	20	3.6
GSR3377	12900	0	20	18.0
GSR3378	60	0	20	1.2
GSR3476	60	0	20	1.2
GSR3723	240	0	20	4.8
GSR4007	132	0	20	2.6
GSR4355	40	0	20	.8
GSR4356	860	0	20	17.2
GSR4377	120	0	20	2.4
GSR4468	200	0	20	4.0
GSR4723	360	0	20	7.2
GSR5361	90	0	20	1.8
GSR5378	60	0	20	1.2
GSR5384	120	0	20	2.4
GSR5468	300	0	20	6.0
GSR6356	40	0	20	.8
GSR6377	210	0	20	4.2

STATION	QUANTITY	CARB(IND)		CARBON NG)
GSR6463	200	0	20	4.0
GSR7378	90	0	20	1.8
GSR8384	30	0	20	.6
TOTAL	30062	0 -	60	361.2
NITZSCHIA	SERIATA			
GSR1356	270	0	117	31.6
GSR1361	30	0	117	3.5
GSR1723	840	0	117	98.3
GSR2007	600	0	117	70.2
GSR2356	120	0	117	14.0
GSR2361	90	0	117	10.5
GSR2362	180	0	117	21.1
GSR3007	2040	0	117	238.7
GSR3356	330	0	117	38.6
GSR3377	4500	0	117	526.5
GSR4007	231	0	117	27.0
GSR4356	460	0	117	53.8
GSR4362	60	0	117	7.0
TOTAL	9751	0 -	117	1140.8
PENNATE	SPP.			
GSR1003	120	0	8	1.0
GSR1007	675	0	8	5.4
GSR1355	150	0	8	1.2
GSR1356	150	0	8	1.2
GSR1360	90	0	8	.7
GSR1361	60	0	8	.5
GSR1362	60	0	8	.5
GSR1377	180	0	8	1.4
GSR1378	90	0	8	.7
GSR1380	30	0	8	.2
GSR1384	30	0	8	.2
GSR1469	30	0	8	.2
GSR1470	90	0	8	.7
GSR1471	30	0	8	.2
GSR1472	60	0	8	.5
GSR1474	60	0	8	.5
GSR1475	330	0	8	2.6
GSR1476	1920	0	8	15.4
GSR1717	150	0	8	1.2
GSR1719	30	0	8	.2
GSR1723	420	0	8	3.4

STATION	QUANTITY	CARB(IND)		CARBON (MG)
GSR2005	60	0	8	.5
GSR2006	90	0	8	.7
GSR2007	900	0	8	7.2
GSR2356	30	0	8	.2
GSR2361	120	0	8	1.0
GSR2362	60	0	8	.5
GSR2380	60	0	8	.5
GSR2384	120	0	8	1.0
GSR2468	50	0	8	.4
GSR2717	60	0	8	.5
GSR2719	120	0	8	1.0
GSR2723	720	0	8	5.8
GSR3005	150	0	8	1.2
GSR3006	270	0	8	2.2
GSR3007	1140	0	8	9.1
GSR3356	300	0	8	2.4
GSR3357	30	0	8	.2
GSR3360	30	0	8	.2
GSR3361	120	0	8	1.0
GSR3362	200	0	8	1.6
GSR3380	120	0	8	.7
GSR3384	120	0	8	1.0
GSR3469	30	0	8	.2
GSR3476	30	0	8	.2
GSR3717	30	0	8	.2
GSR3719	90	0	8	.7
GSR3723	480	0	8	3.8
GSR4005	90	0	8	.7
GSR4006	30	0	8	.2
GSR4007	1485	0	8	11.9
GSR4355	60	0	8	.5
GSR4356	40	0	8	.3
GSR4357	30	0	8	.2
GSR4377	180	0	8	1.4
GSR4378	30	0	8	.2
GSR4380	60	0	8	.5
GSR4384	30	0	8	.2
GSR4469	90	0	8	.7
GSR4717	90	0	8	.7
GSR4723	420	0	8	3.4
GSR5005	120	0	8	1.0
GSR5007	30	0	8	.2
GSR5355	60	0	8	.5
GSR5356	780	0	8	6.2
GSR5360	30	0	8	.2

AD-A060 220 WOODS HOLE OCEANOGRAPHIC INSTITUTION MASS F/G 6/1
INVESTIGATIONS INTO THE SEASONAL DEEP CHLOROPHYLL MAXIMUM IN TH--ETC(U)
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STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR5361	30	0	8	.2
GSR5377	30	0	8	.2
GSR5384	30	0	8	.2
GSR5476	30	0	8	.2
GSR5717	450	0	8	3.6
GSR5717	120	0	8	1.0
GSR5719	90	0	8	.7
GSR5723	60	0	8	.5
GSR5723	30	0	8	.2
GSR6005	240	0	8	1.9
GSR6006	90	0	8	.7
GSR6355	20	0	8	.2
GSR6361	90	0	8	.7
GSR6377	30	0	8	.2
GSR6378	60	0	8	.5
GSR6384	30	0	8	.2
GSR6719	120	0	8	1.0
GSR6723	37	0	8	.3
GSR7005	30	0	8	.2
GSR7355	60	0	8	.5
GSR7359	30	0	8	.2
GSR7361	30	0	8	.2
GSR7377	30	0	8	.2
GSR7378	60	0	8	.5
GSR7384	30	0	8	.2
GSR7719	30	0	8	.2
GSR8354	30	0	8	.2
GSR8469	90	0	8	.7
GSR8717	30	0	8	.2
GSR9384	30	0	8	.2
TOTAL	16007	0 -	8	126.9
PLEUROSIGMA	ANGULATUM			
GSR1355	150	0	4985	747.8
GSR6355	20	0	4985	99.7
TOTAL	170	0 -	4985	847.5
PLEUROSIGMA	SP.			
GSR1007	75	0	4985	373.9
GSR1362	60	0	4985	299.1
GSR1723	60	0	4985	299.1
GSR3007	120	0	4985	598.2
GSR4007	66	0	4985	329.0

	STATION	QUANTITY	CARB(IND)			CARBON NG)
	GSR7007	60	0		4985	299.1
	TOTAL	441	0	-	4985	2198.4
	THALASSIONEMA	NITZSCHIODES				
	GSR1356	60	0		29	1.7
	GSR1723	60	0		29	1.7
	GSR2355	800	0		29	23.2
	GSR2359	30	0		29	.9
	GSR3355	240	0		29	7.0
	GSR4356	90	0		29	2.3
	GSR4361	60	0		29	1.7
	GSR5361	30	0		29	.9
	GSR5476	30	0		29	.8
	GSR6361	60	0		29	1.7
	TOTAL	1460	0	-	29	41.9
	THALASSIOTHRIX	FRAUENFELDII				
	GSR7378	90	0		76	6.8
	TOTAL	90	0	-	76	6.8
	THALASSIOTHRIX	LONGISSIMA				
	GSR4356	40	0		1207	48.3
	GSR5361	30	0		1207	36.2
	TOTAL	70	0	-	1207	84.5
	TROPIDONEIS	ANTARCTICA V.PAL				
	GSR3356	30	0		0	349.5
	TOTAL	30	0	-	0	349.5
COCCO						
	ACANTHOICA	ACANTHIFERA				
	GSR1470	30	0		27	.8
	GSR1472	30	0		27	.8
	GSR1717	30	0		27	.8
	GSR2005	30	0		27	.8
	GSR2007	60	0		27	1.6
	GSR2717	60	0		27	1.6
	GSR2719	30	0		27	.8
	GSR3007	60	0		27	1.6
	GSR3359	30	0		27	.8

STATION	QUANTITY	CARB(IND)		CARBON (MG)
GSR3360	60	0	27	1.6
GSR3378	30	0	27	.8
GSR3719	30	0	27	.8
GSR3723	60	0	27	1.6
GSR4005	30	0	27	.8
GSR5005	30	0	27	.8
GSR5468	100	0	27	2.7
GSR8719	30	0	27	.8
TOTAL	730	0	27	19.5
ACANTHOICA	MONOSPINA			
GSR1468	30	0	91	2.7
GSR2717	30	0	91	2.7
GSR4360	30	0	91	2.7
TOTAL	90	0	91	8.1
ANOPLOSOLENIA	BRASILIENSIS			
GSR1360	30	0	50	1.5
GSR2356	120	0	50	6.0
GSR2357	60	0	50	3.0
GSR2359	30	0	50	1.5
GSR2468	50	0	50	2.5
GSR6361	30	0	50	1.5
GSR7360	30	0	50	1.5
TOTAL	350	0	50	17.5
ANTHOSPHAERA	BRYZA			
GSR1007	375	0	60	22.5
GSR1362	60	0	60	3.6
GSR1469	90	0	60	5.4
GSR1470	30	0	60	1.8
GSR1474	30	0	60	1.8
GSR1475	60	0	60	3.6
GSR1476	150	0	60	9.0
GSR1723	600	0	60	36.0
GSR2007	300	0	60	18.0
GSR2362	60	0	60	3.6
GSR2723	120	0	60	7.2
GSR3007	60	0	60	3.6
GSR3359	30	0	60	1.8
GSR3723	180	0	60	10.8
GSR4359	30	0	60	1.8

STATION	QUANTITY	CARB(IND)		CARBON (MG)
GSR4723	540	0	60	32.4
GSR5382	150	0	60	9.0
GSR5384	60	0	60	3.6
GSR5717	90	0	60	5.4
GSR6355	30	0	60	1.8
GSR6362	30	0	60	1.8
GSR6382	150	0	60	9.0
GSR7382	420	0	60	25.2
GSR8007	30	0	60	1.8
GSR8355	30	0	60	1.8
GSR8382	30	0	60	1.8
GSR9005	90	0	60	5.4
TOTAL	3825	0 -	60	229.5
ANTHOSPHAERA	ROBUSTA			
GSR1360	30	0	60	1.8
GSR2004	30	0	60	1.8
GSR3476	60	0	60	3.6
GSR5468	100	0	60	6.0
GSR6005	30	0	60	1.8
GSR6719	90	0	60	5.4
GSR7382	240	0	60	14.4
GSR8356	30	0	60	1.8
GSR8357	30	0	60	1.8
GSR8359	30	0	60	1.8
GSR8469	60	0	60	3.6
GSR9359	30	0	60	1.8
GSR9719	30	0	60	1.8
TOTAL	790	0 -	60	47.4
BRAARUDOSPHAERA	BIGELOWI			
GSR8356	30	0	12	3.6
GSR9356	30	0	12	3.6
TOTAL	60	0 -	12	7.2
CALCIOSOLENIA	MURRAYI			
GSR1359	60	0	85	5.1
GSR2357	30	0	85	2.6
GSR4357	30	0	85	2.6
GSR4360	30	0	85	2.6
GSR6361	60	0	85	5.1
TOTAL	210	0 -	85	18.0

STATION	QUANTITY	CARB(IND)		CARBON (UG)
CALYPTROSPHAERA	OBLONGA			
GSR1378	30	0	128	3.8
GSR1380	540	0	128	69.1
GSR1382	60	0	128	7.7
GSR1384	60	0	128	7.7
GSR1476	30	0	128	3.8
GSR1717	90	0	128	11.5
GSR1719	30	0	128	3.8
GSR2005	90	0	128	11.5
GSR2361	30	0	128	3.8
GSR2378	90	0	128	11.5
GSR2380	210	0	128	26.9
GSR2382	60	0	128	7.7
GSR2717	120	0	128	15.4
GSR3378	60	0	128	7.7
GSR3380	90	0	128	11.5
GSR3382	30	0	128	3.8
GSR3717	30	0	128	3.8
GSR4005	60	0	128	7.7
GSR4361	30	0	128	3.8
GSR4380	150	0	128	19.2
GSR4717	60	0	128	7.7
GSR4719	60	0	128	7.7
GSR5006	30	0	128	3.8
GSR5361	30	0	128	3.8
GSR5378	30	0	128	3.8
GSR5382	30	0	128	3.8
GSR5719	30	0	128	3.8
TOTAL	2160	0 -	128	276.1
COCCOLITHOPHORE	SP.			
GSR1005	30	0	18	.5
GSR1006	90	0	18	1.6
GSR1354	60	0	18	1.1
GSR1360	30	0	18	.5
GSR1378	120	0	18	2.2
GSR1382	30	0	18	.5
GSR1384	30	0	18	.5
GSR1468	120	0	18	2.2
GSR1470	90	0	18	1.6
GSR1717	300	0	18	5.4
GSR2005	120	0	18	2.2
GSR2006	90	0	18	1.6
GSR2359	60	0	18	1.1

STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR2378	120	0	18	2.2
GSR2382	60	0	18	1.1
GSR2384	30	0	18	.5
GSR2468	400	0	18	7.2
GSR2717	3000	0	18	54.0
GSR2719	30	0	18	.5
GSR3359	60	0	18	1.1
GSR3360	210	0	18	3.8
GSR3378	420	0	18	7.6
GSR3382	30	0	18	.5
GSR3384	60	0	18	1.1
GSR3717	120	0	18	2.2
GSR4005	30	0	18	.5
GSR4006	60	0	18	1.1
GSR4355	20	0	18	.4
GSR4356	20	0	18	.4
GSR4357	30	0	18	.5
GSR4359	30	0	18	.5
GSR4378	30	0	18	.5
GSR4380	120	0	18	2.2
GSR4382	150	0	18	2.7
GSR4468	200	0	18	3.6
GSR4469	30	0	18	.5
GSR4469	30	0	18	.5
GSR4717	30	0	18	.5
GSR5378	60	0	18	1.1
GSR5382	30	0	18	.5
GSR5384	240	0	18	4.3
GSR5468	350	0	18	6.3
GSR5476	30	0	18	.5
GSR6005	30	0	18	.5
GSR6006	30	0	18	.5
GSR6378	30	0	18	.5
GSR6468	50	0	18	.9
GSR7476	30	0	18	.5
TOTAL	7370	0 -	18	132.3
COCCOLITHUS HUXLEYI				
GSR1005	1740	0	18	31.3
GSR1006	2520	0	18	45.4
GSR1007	7200	0	18	129.6
GSR1358	150	0	18	2.7
GSR1356	8370	0	18	150.7
GSR1357	10740	0	18	193.3

STATION	QUANTITY	CARB(IND)		CARBON (MG)
GSR1359	9690	0	18	174.4
GSR1360	6220	0	18	121.0
GSR1361	9570	0	18	172.3
GSR1362	3300	0	18	59.4
GSR1377	30	0	18	.5
GSR1378	630	0	18	11.3
GSR1380	90	0	18	1.6
GSR1384	1200	0	18	21.6
GSR1468	23940	0	18	430.9
GSR1469	10020	0	18	180.4
GSR1470	7170	0	18	129.1
GSR1471	5130	0	18	92.3
GSR1472	8130	0	18	146.3
GSR1473	3120	0	18	56.2
GSR1474	3570	0	18	64.3
GSR1475	8310	0	18	149.6
GSR1476	15450	0	18	278.1
GSR1717	2940	0	18	52.9
GSR1719	3090	0	18	55.6
GSR1723	17100	0	18	307.8
GSR2005	1440	0	18	25.9
GSR2006	1770	0	18	31.9
GSR2007	8800	0	18	158.4
GSR2355	100	0	18	1.8
GSR2356	3060	0	18	55.1
GSR2357	10260	0	18	184.7
GSR2359	9960	0	18	179.3
GSR2360	6720	0	18	121.0
GSR2361	10080	0	18	181.4
GSR2362	2160	0	18	38.9
GSR2378	900	0	18	16.2
GSR2380	60	0	18	1.1
GSR2384	30	0	18	.5
GSR2468	36900	0	18	664.2
GSR2719	1440	0	18	25.9
GSR2723	14040	0	18	252.7
GSR3005	1110	0	18	20.0
GSR3006	1980	0	18	35.6
GSR3007	19680	0	18	354.2
GSR3355	30	0	18	.5
GSR3356	5280	0	18	95.0
GSR3357	8010	0	18	144.2
GSR3357	30	0	18	.5
GSR3359	20460	0	18	368.3
GSR3360	10500	0	18	189.0

STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR3361	6480	0	18	116.6
GSR3362	1500	0	18	27.0
GSR3377	11700	0	18	210.6
GSR3378	420	0	18	7.6
GSR3382	30	0	18	.5
GSR3384	90	0	18	1.6
GSR3468	55100	0	18	991.8
GSR3469	8850	0	18	159.3
GSR3476	13320	0	18	239.8
GSR3717	3210	0	18	57.8
GSR3719	1710	0	18	130.8
GSR3723	8820	0	18	158.8
GSR4005	3600	0	18	64.8
GSR4006	2280	0	18	41.0
GSR4007	1683	0	18	30.3
GSR4356	1220	0	18	22.0
GSR4357	12450	0	18	224.1
GSR4359	7710	0	18	138.8
GSR4360	12660	0	18	227.9
GSR4361	8010	0	18	144.2
GSR4377	30	0	18	.5
GSR4378	480	0	18	8.6
GSR4380	60	0	18	1.1
GSR4382	150	0	18	2.7
GSR4384	1920	0	18	34.6
GSR4468	835	0	18	15.0
GSR4469	4530	0	18	81.5
GSR4717	3540	0	18	63.7
GSR4719	2700	0	18	48.6
GSR4723	4620	0	18	83.2
GSR5005	3840	0	18	69.1
GSR5006	300	0	18	5.4
GSR5007	270	0	18	4.9
GSR5356	330	0	18	5.9
GSR5357	270	0	18	4.9
GSR5359	9480	0	18	170.6
GSR5360	8730	0	18	157.1
GSR5361	5010	0	18	90.2
GSR5378	450	0	18	8.1
GSR5384	210	0	18	3.8
GSR5468	48350	0	18	870.3
GSR5474	180	0	18	3.2
GSR5719	4590	0	18	82.6
GSR5723	30	0	18	.5
GSR6007	90	0	18	1.6

STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR6356	80	0	18	1.4
GSR6357	130	0	18	3.2
GSR6359	390	0	18	7.0
GSR6360	9690	0	18	174.4
GSR6361	5340	0	18	96.1
GSR6378	120	0	18	2.2
GSR6468	17500	0	18	315.0
GSR6469	150	0	18	2.7
GSR6476	210	0	18	3.8
GSR6719	120	0	18	2.2
GSR7007	120	0	18	2.2
GSR7357	120	0	18	2.2
GSR7359	30	0	18	.5
GSR7360	5430	0	18	97.7
GSR7361	90	0	18	1.6
GSR7378	570	0	18	10.3
GSR7469	330	0	18	5.9
GSR7476	60	0	18	1.1
GSR8007	60	0	18	1.1
GSR8360	1200	0	18	21.6
GSR8361	90	0	18	1.6
GSR8469	240	0	18	4.3
GSR8723	30	0	18	.5
GSR9007	120	0	18	2.2
GSR9359	60	0	18	1.1
GSR9360	4470	0	18	80.5
GSR9361	60	0	18	1.1
GSR9469	90	0	18	1.6
GSR9470	90	0	18	1.6
GSR9471	420	0	18	7.6
TOTAL	653468	0 -	18	11872.1
COCCOLITHUS	PELAGICUS			
GSR1355	300	0	290	87.0
GSR2355	600	0	290	174.0
GSR3355	330	0	290	95.7
GSR4355	20	0	290	5.8
GSR6355	80	0	290	8.7
GSR9355	30	0	290	8.7
TOTAL	1360	0 -	290	379.9
CYCLOCOCCOLITHUS	FRAGILIS			
GSR1362	60	0	228	13.7

STATION	QUANTITY	CARB(IND)		CARBON NG)
GSR2362	60	0	228	13.7
GSR3355	30	0	228	6.8
TOTAL	150	0	228	34.2
CYCLOCOCCOLITHUS LEPTOPORUS				
GSR1005	60	0	214	12.8
GSR1006	60	0	214	12.8
GSR1007	75	0	214	16.1
GSR1356	90	0	214	19.3
GSR1357	150	0	214	32.1
GSR1359	90	0	214	19.3
GSR1360	90	0	214	19.3
GSR1361	810	0	214	173.3
GSR1378	180	0	214	38.5
GSR1380	30	0	214	6.4
GSR1384	120	0	214	25.7
GSR1468	570	0	214	122.0
GSR1469	240	0	214	51.4
GSR1470	180	0	214	38.5
GSR1471	360	0	214	77.0
GSR1472	270	0	214	57.8
GSR1473	150	0	214	32.1
GSR1476	90	0	214	19.3
GSR1717	60	0	214	12.8
GSR1719	60	0	214	12.8
GSR1723	240	0	214	51.4
GSR2005	90	0	214	19.3
GSR2006	30	0	214	6.4
GSR2356	270	0	214	57.8
GSR2357	210	0	214	44.9
GSR2359	360	0	214	77.0
GSR2360	150	0	214	32.1
GSR2361	930	0	214	199.0
GSR2362	180	0	214	38.5
GSR2378	120	0	214	25.7
GSR2380	30	0	214	6.4
GSR2384	270	0	214	57.8
GSR2468	150	0	214	32.1
GSR2717	240	0	214	51.4
GSR3005	30	0	214	6.4
GSR3006	60	0	214	12.8
GSR3355	30	0	214	6.4
GSR3356	360	0	214	77.0
GSR3357	390	0	214	83.5

STATION	QUANTITY	CARB(IND)		CARBON (MG)
GSR3359	390	0	214	83.5
GSR3361	120	0	214	25.7
GSR3362	100	0	214	21.4
GSR3378	120	0	214	25.7
GSR3384	30	0	214	6.4
GSR3717	90	0	214	19.3
GSR3719	60	0	214	12.8
GSR4005	120	0	214	25.7
GSR4006	30	0	214	6.4
GSR4356	160	0	214	34.2
GSR4357	60	0	214	12.8
GSR4359	390	0	214	83.5
GSR4360	270	0	214	57.8
GSR4361	420	0	214	89.9
GSR4378	210	0	214	44.9
GSR4384	30	0	214	6.4
GSR4717	120	0	214	25.7
GSR4719	90	0	214	19.3
GSR4723	60	0	214	12.8
GSR5005	150	0	214	32.1
GSR5006	90	0	214	19.3
GSR5356	120	0	214	25.7
GSR5360	210	0	214	44.9
GSR5361	360	0	214	77.0
GSR5378	30	0	214	6.4
GSR5717	30	0	214	6.4
GSR5719	240	0	214	51.4
GSR5723	30	0	214	6.4
GSR6005	30	0	214	6.4
GSR6007	30	0	214	6.4
GSR6356	20	0	214	4.3
GSR6357	120	0	214	25.7
GSR6360	210	0	214	44.9
GSR6361	60	0	214	12.8
GSR6476	30	0	214	6.4
GSR7359	60	0	214	12.8
GSR7360	270	0	214	57.8
GSR7719	30	0	214	6.4
GSR8360	60	0	214	12.8
GSR8378	30	0	214	6.4
GSR9360	90	0	214	19.3
GSR9468	150	0	214	32.1
GSR9471	150	0	214	32.1
TOTAL	13345	0 -	214	2855.6

STATION	QUANTITY	CARB(IND)		CARBON (NG)
DEUTZSCHLANDIA	ANTHOS			
GSR5357	90	0	91	8.2
GSR5360	30	0	91	2.7
GSR5382	180	0	91	16.4
GSR5384	30	0	91	2.7
GSR6005	30	0	91	2.7
GSR6382	30	0	91	2.7
GSR6717	30	0	91	2.7
GSR6719	60	0	91	2.7
GSR7378	30	0	91	2.7
TOTAL	510	0 -	91	43.5
DISCOSPHAERA	TUBIFER			
GSR1005	240	0	91	21.8
GSR1006	150	0	91	13.7
GSR1357	150	0	91	13.7
GSR1359	90	0	91	8.2
GSR1360	60	0	91	5.5
GSR1361	60	0	91	5.5
GSR1378	210	0	91	19.1
GSR1380	60	0	91	5.5
GSR1382	150	0	91	13.7
GSR1384	360	0	91	32.8
GSR1476	30	0	91	2.7
GSR1717	60	0	91	5.5
GSR1719	30	0	91	2.7
GSR2005	120	0	91	10.9
GSR2006	60	0	91	5.5
GSR2356	30	0	91	2.7
GSR2357	60	0	91	5.5
GSR2359	120	0	91	10.9
GSR2360	30	0	91	2.7
GSR2378	360	0	91	32.8
GSR2380	30	0	91	2.7
GSR2384	300	0	91	27.3
GSR2717	30	0	91	2.7
GSR2719	90	0	91	8.2
GSR3005	60	0	91	5.5
GSR3007	60	0	91	5.5
GSR3357	180	0	91	16.4
GSR3359	120	0	91	10.9
GSR3717	90	0	91	8.2
GSR3719	180	0	91	16.4
GSR4005	90	0	91	8.2

	STATION	QUANTITY	CARB(IND)		CARBON NG)
	GSR4357	150	0	91	13.7
	GSR4359	30	0	91	2.7
	GSR4378	30	0	91	2.7
	GSR4384	90	0	91	8.2
	GSR4717	60	0	91	5.5
	GSR4719	30	0	91	2.7
	GSR5005	120	0	91	10.9
	GSR5356	30	0	91	2.7
	GSR5361	60	0	91	5.5
	GSR5378	120	0	91	10.9
	GSR5719	30	0	91	2.7
	GSR6356	20	0	91	1.8
	GSR6360	30	0	91	2.7
TOTAL		4460	0 -	91	406.1
GEPHYROCAPSA		OCEANICA			
	GSR1007	150	0	1510	22.7
	GSR1356	840	0	151	126.8
	GSR1362	420	0	151	63.4
	GSR1468	180	0	151	27.2
	GSR1469	390	0	151	58.9
	GSR1472	240	0	151	36.2
	GSR1474	720	0	151	108.7
	GSR1476	540	0	151	81.5
	GSR1723	300	0	151	45.3
	GSR2007	180	0	151	27.2
	GSR2356	1510	0	151	77.0
	GSR2359	30	0	151	4.5
	GSR2362	60	0	151	9.1
	GSR2378	30	0	151	4.5
	GSR2468	400	0	151	60.4
	GSR3007	180	0	151	27.2
	GSR3355	30	0	151	4.5
	GSR3356	870	0	151	131.4
	GSR3361	60	0	151	9.1
	GSR3378	30	0	151	4.5
	GSR3468	250	0	151	37.8
	GSR3469	210	0	151	31.7
	GSR3476	180	0	151	27.2
	GSR3723	120	0	151	18.1
	GSR4007	420	0	151	63.4
	GSR4356	560	0	151	84.6
	GSR4361	60	0	151	9.1
	GSR4362	30	0	151	4.5

STATION	QUANTITY	CARB(IND)	CARBON MG)
GSR4384	30	0 151	4.5
GSR4468	300	0 151	45.3
GSR4469	90	0 151	13.6
GSR4723	180	0 151	27.2
GSR5356	240	0 151	36.2
GSR5468	650	0 151	98.2
GSR5723	60	0 151	9.1
GSR6354	20	0 151	3.0
GSR6361	60	0 151	9.1
GSR6468	200	0 151	30.0
GSR6469	30	0 151	4.5
GSR6723	37	0 151	5.6
GSR9356	60	0 151	9.1
GSR9359	30	0 151	4.5
GSR9469	90	0 151	13.6
GSR9470	30	0 151	4.5
GSR9471	60	0 151	9.1
TOTAL	11157	0 - 1510	1533.6
HALOPAPPUS	ADRIATICUS		
GSR1357	60	0 53	3.2
GSR1359	30	0 53	1.6
GSR1360	30	0 53	1.6
GSR2356	30	0 53	1.6
GSR2357	90	0 53	4.8
GSR2359	120	0 53	6.4
GSR3357	30	0 53	1.6
GSR3359	180	0 53	9.5
GSR3360	90	0 53	4.8
GSR3468	50	0 53	2.7
GSR3476	30	0 53	1.6
GSR4357	60	0 53	3.2
GSR4359	30	0 53	1.6
GSR4360	90	0 53	4.8
GSR4361	30	0 53	1.6
GSR5359	30	0 53	1.6
GSR5360	60	0 53	3.2
GSR5468	100	0 53	5.3
GSR6360	30	0 53	1.6
GSR7360	30	0 53	1.6
GSR9360	30	0 53	1.6
TOTAL	1230	0 - 53	65.5

STATION	QUANTITY	CARB(IND)			CARBON (NG)
HELICOSPHAERA	CARTERI				
GSR2007	120	0		118	14.2
GSR3006	30	0		118	3.5
GSR3377	450	0		118	53.1
GSR3382	30	0		118	3.5
GSR3723	60	0		118	7.1
GSR4377	330	0		118	38.9
GSR4384	30	0		118	3.5
GSR5356	30	0		118	3.5
GSR5356	30	0		118	3.5
GSR9719	30	0		118	3.5
TOTAL	1140	0	-	118	134.3
HELICOSPHAERA	HYALINA				
GSR1472	30	0		118	3.5
GSR2356	30	0		118	3.5
GSR3007	180	0		118	21.2
GSR3360	30	0		118	3.5
GSR4377	30	0		118	3.5
GSR5006	30	0		118	3.5
GSR5378	30	0		118	3.5
TOTAL	360	0	-	118	42.2
HELLADOSPHAERA	AURISINAE				
GSR1378	30	0		60	1.8
GSR1380	30	0		60	1.8
GSR1717	30	0		60	1.8
GSR1719	30	0		60	1.8
GSR2380	60	0		60	3.6
GSR3378	30	0		60	1.8
GSR3719	30	0		60	1.8
GSR4361	30	0		60	1.8
GSR4378	30	0		60	1.8
GSR4382	30	0		60	1.8
GSR4717	30	0		60	1.8
GSR5361	60	0		60	3.6
GSR6378	30	0		60	1.8
TOTAL	450	0	-	60	27.0
MICHAELSARSIA	ASYMMETRICA				
GSR4361	60	0		69	4.1
TOTAL	60	0	-	69	4.1

STATION	QUANTITY	CARB(IND)		CARBON (NG)
OPHIASTER	HYDROIDEUS			
GSR2359	30	0	22	.7
GSR2362	60	0	22	1.3
GSR2468	400	0	22	8.8
GSR3007	60	0	22	1.3
GSR3359	30	0	22	.7
GSR3468	100	0	22	2.2
GSR3476	30	0	22	.7
GSR4468	150	0	22	3.3
GSR4723	60	0	22	1.3
GSR5360	30	0	22	.7
GSR5468	450	0	22	9.9
GSR6382	30	0	22	.7
GSR6468	100	0	22	2.2
GSR6719	60	0	22	1.3
GSR7378	60	0	22	1.3
TOTAL	1650	0 -	22	36.4
PONTOSPHAERA	SYRACUSANA			
GSR1360	30	0	200	6.0
GSR1377	30	0	200	6.0
GSR2359	30	0	200	6.0
GSR2360	30	0	200	6.0
GSR2361	30	0	200	6.0
GSR4468	100	0	200	20.0
GSR4723	60	0	200	12.0
GSR6361	30	0	200	6.0
GSR8005	30	0	200	6.0
TOTAL	370	0 -	200	74.0
RHABDOSPHAERA	CLAVIGER			
GSR1005	30	0	74	2.2
GSR1719	30	0	74	2.2
GSR2361	30	0	74	2.2
GSR4005	30	0	74	2.2
GSR4719	90	0	74	6.7
GSR5005	30	0	74	2.2
GSR5719	30	0	74	2.2
TOTAL	270	0 -	74	19.9
RHABDOSPHAERA	HISPIDA			
GSR1006	30	0	91	2.7

	STATION	QUANTITY	CARB(IND)		CARBON (NG)
	GSR1378	30	0	91	2.7
	GSR1384	210	0	91	19.1
	GSR1469	30	0	91	2.7
	GSR1470	30	0	91	2.7
	GSR1717	30	0	91	2.7
	GSR2005	30	0	91	2.7
	GSR2382	30	0	91	2.7
	GSR2384	150	0	91	13.7
	GSR2717	60	0	91	5.5
	GSR3378	120	0	91	10.9
	GSR3382	90	0	91	8.2
	GSR3384	60	0	91	5.5
	GSR3717	30	0	91	2.7
	GSR3719	30	0	91	2.7
	GSR4005	30	0	91	2.7
	GSR4378	240	0	91	21.8
	GSR4380	90	0	91	8.2
	GSR4382	90	0	91	8.2
	GSR4384	210	0	91	19.1
	GSR5006	90	0	91	8.2
	GSR5378	30	0	91	2.7
	GSR5719	30	0	91	2.7
	GSR6719	90	0	91	8.2
	GSR9384	30	0	91	2.7
TOTAL		1890	0 -	91	171.7
RHABDOSPHAERA	STYLIFER				
	GSR1005	30	0	60	1.8
	GSR1006	60	0	60	3.6
	GSR1378	60	0	60	3.6
	GSR1384	60	0	60	3.6
	GSR1717	180	0	60	10.8
	GSR1719	30	0	60	1.8
	GSR2005	30	0	60	1.8
	GSR2378	30	0	60	1.8
	GSR2717	30	0	60	1.8
	GSR3006	30	0	60	1.8
	GSR3378	30	0	60	1.8
	GSR3384	30	0	60	1.8
	GSR3719	60	0	60	3.6
	GSR4005	120	0	60	7.2
	GSR4384	30	0	60	1.8
	GSR4717	30	0	60	1.8
	GSR4719	30	0	60	1.8

STATION	QUANTITY	CARB(IND)		CARBON (MG)
GSR5719	120	0	60	7.2
GSR6361	30	0	60	1.8
TOTAL	1020	0 -	60	61.2
SCYPHOSPHAERA	APSTEINI			
GSR1360	30	0	200	6.0
GSR1468	30	0	200	6.0
GSR2357	30	0	200	6.0
GSR3469	30	0	200	6.0
GSR4357	30	0	200	6.0
GSR4359	30	0	200	6.0
GSR5360	30	0	200	6.0
TOTAL	210	0 -	200	42.0
SYRACOSPHAERA	CORNIFERA			
GSR1377	30	0	60	1.8
GSR3378	30	0	60	1.8
TOTAL	60	0 -	60	3.6
SYRACOSPHAERA	DENTATA			
GSR1380	30	0	91	2.7
GSR2380	60	0	91	2.7
GSR3378	90	0	91	8.2
GSR3719	30	0	91	2.7
GSR4382	240	0	91	21.8
GSR5382	270	0	91	24.6
TOTAL	720	0 -	91	62.7
SYRACOSPHAERA	MEDITERRANEA			
GSR1356	30	0	151	4.5
GSR1378	60	0	151	9.1
GSR1382	30	0	151	4.5
GSR1384	60	0	151	9.1
GSR1468	90	0	151	13.6
GSR1471	30	0	151	4.5
GSR1717	60	0	151	9.1
GSR1719	30	0	151	4.5
GSR2007	60	0	151	9.1
GSR2378	30	0	151	4.5
GSR2384	180	0	151	27.2
GSR2468	300	0	151	45.3

STATION	QUANTITY	CARB(IND)		CARBON (MG)
GSR2717	30	0	151	4.5
GSR2723	60	0	151	9.1
GSR3361	60	0	151	9.1
GSR3384	30	0	151	4.5
GSR3468	60	0	151	9.1
GSR3476	30	0	151	4.5
GSR3717	150	0	151	22.7
GSR3719	120	0	151	18.0
GSR4005	60	0	151	9.1
GSR4357	30	0	151	4.5
GSR4384	30	0	151	4.5
GSR4468	100	0	151	15.1
GSR4717	120	0	151	18.0
GSR4719	30	0	151	4.5
GSR5361	30	0	151	4.5
GSR5378	30	0	151	4.5
GSR5468	60	0	151	9.1
GSR6468	30	0	151	4.5
GSR8360	30	0	151	4.5
TOTAL	2050	0 -	151	309.3
SYRACOSPHAERA	PROLONGATA			
GSR5719	30	0	68	2.0
TOTAL	30	0 -	68	2.0
SYRACOSPHAERA	PULCHRA			
GSR1005	30	0	151	4.5
GSR1006	30	0	151	4.5
GSR1357	30	0	151	4.5
GSR1378	30	0	151	4.5
GSR1384	30	0	151	4.5
GSR1717	60	0	151	9.1
GSR1719	60	0	151	9.1
GSR2005	60	0	151	9.1
GSR2007	60	0	151	9.1
GSR2356	30	0	151	4.5
GSR2357	30	0	151	4.5
GSR2361	60	0	151	9.1
GSR2378	180	0	151	27.2
GSR2384	60	0	151	9.1
GSR2717	30	0	151	4.5
GSR2719	240	0	151	36.2
GSR3005	30	0	151	4.5

STATION	QUANTITY	CARB(IND)	CARBON (MG)
GSR3006	120	0 151	18.1
GSR3357	120	0 151	18.1
GSR3360	30	0 151	4.5
GSR3378	210	0 151	31.7
GSR3384	60	0 151	9.1
GSR3476	30	0 151	4.5
GSR3717	90	0 151	13.4
GSR3719	30	0 151	4.5
GSR4005	150	0 151	22.7
GSR4006	150	0 151	22.7
GSR4357	30	0 151	4.5
GSR4359	30	0 151	4.5
GSR4360	30	0 151	4.5
GSR4378	30	0 151	4.5
GSR4380	120	0 151	18.1
GSR4382	60	0 151	9.1
GSR4717	30	0 151	4.5
GSR4719	60	0 151	9.1
GSR5005	120	0 151	18.1
GSR5006	60	0 151	9.1
GSR5361	30	0 151	4.5
GSR5378	90	0 151	13.6
GSR5468	50	0 151	7.6
GSR5719	60	0 151	9.1
GSR6360	30	0 151	4.5
GSR7360	30	0 151	4.5
TOTAL	2900	0 - 151	437.6
THO-ACOSPHAE-A HEIMII			
GSR6362	30	0 151	4.5
TOTAL	30	0 - 151	4.5
THORACOSPHAERA HEIMII			
GSR1005	30	0 151	4.5
GSR1356	30	0 151	4.5
GSR1361	60	0 151	9.1
GSR1468	30	0 151	4.5
GSR1469	150	0 151	22.7
GSR1471	120	0 151	18.1
GSR1474	90	0 151	13.6
GSR1717	30	0 151	4.5
GSR1719	60	0 151	9.1
GSR1723	60	0 151	9.1

	STATION	QUANTITY	CARB(IND)		CARBON NG)
	GSR2357	30	0	151	4.5
	GSR2359	90	0	151	13.6
	GSR2360	60	0	151	9.1
	GSR2382	60	0	151	9.1
	GSR2468	100	0	151	15.1
	GSR3357	30	0	151	4.5
	GSR3360	30	0	151	4.5
	GSR3361	60	0	151	9.1
	GSR3719	60	0	151	9.1
	GSR4005	60	0	151	9.1
	GSR4357	30	0	151	4.5
	GSR4359	60	0	151	9.1
	GSR4360	30	0	151	4.5
	GSR4361	60	0	151	9.1
	GSR4380	30	0	151	4.5
	GSR4384	30	0	151	4.5
	GSR5006	30	0	151	4.5
	GSR5356	30	0	151	4.5
	GSR5357	30	0	151	4.5
	GSR5359	30	0	151	4.5
	GSR5360	30	0	151	4.5
	GSR5361	30	0	151	4.5
	GSR5476	30	0	151	4.5
	GSR6359	30	0	151	4.5
	GSR6360	30	0	151	4.5
	GSR6361	30	0	151	4.5
	GSR6378	30	0	151	4.5
	GSR6468	50	0	151	7.6
	GSR7359	30	0	151	4.5
	GSR7360	60	0	151	9.1
	GSR7362	30	0	151	4.5
	GSR7476	30	0	151	4.5
	GSR8355	30	0	151	4.5
	GSR8359	30	0	151	4.5
	GSR8360	30	0	151	4.5
	GSR8469	30	0	151	4.5
	GSR9471	30	0	151	4.5
TOTAL		2160	0	151	325.8
UMBELLOSPHAERA	IRREGULARIS				
	GSR1005	30	0	109	3.3
	GSR1378	300	0	109	32.7
	GSR1384	360	0	109	39.2
	GSR1717	60	0	109	6.5

STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR2384	150	0	109	16.4
GSR2717	30	0	109	3.3
GSR3378	90	0	109	9.8
GSR3384	150	0	109	16.4
GSR4378	90	0	109	9.8
GSR4384	90	0	109	9.8
GSR4717	90	0	109	9.8
TOTAL	1440	0 -	109	157.0
UMBELLOSPHAERA	TENUIS			
GSR1005	30	0	74	2.2
GSR1006	30	0	74	2.2
GSR1380	30	0	74	2.2
GSR1384	60	0	74	4.4
GSR1476	60	0	74	4.4
GSR2006	30	0	74	2.2
GSR2378	60	0	74	4.4
GSR2382	90	0	74	6.7
GSR2384	60	0	74	4.4
GSR2717	30	0	74	2.2
GSR3360	30	0	74	2.2
GSR3382	60	0	74	4.4
GSR3384	180	0	74	13.3
GSR3476	90	0	74	6.7
GSR4006	120	0	74	8.9
GSR4355	20	0	74	1.5
GSR4378	30	0	74	2.2
GSR4380	660	0	74	48.8
GSR4382	2760	0	74	204.2
GSR4384	180	0	74	13.3
GSR4468	50	0	74	3.7
GSR4717	30	0	74	2.2
GSR5378	90	0	74	6.7
GSR5384	60	0	74	4.4
GSR6361	30	0	74	2.2
GSR6378	150	0	74	11.1
GSR6382	90	0	74	6.7
GSR6468	30	0	74	2.2
GSR6476	30	0	74	2.2
GSR8719	30	0	74	2.2
TOTAL	5200	0 -	74	384.4
UMBILICOSPHAERA	HULBURTIANA			
GSR1005	450	0	60	27.0

STATION	QUANTITY	CARB(IND)		CARBON (NG)
GSR1006	150	0	60	9.0
GSR1356	30	0	60	1.8
GSR1380	60	0	60	3.6
GSR1471	30	0	60	1.8
GSR1473	60	0	60	3.6
GSR1717	90	0	60	5.4
GSR1719	270	0	60	16.2
GSR2005	150	0	60	9.0
GSR2006	60	0	60	3.6
GSR2356	30	0	60	1.8
GSR2382	30	0	60	1.8
GSR2384	30	0	60	1.8
GSR2717	150	0	60	9.0
GSR2719	30	0	60	1.8
GSR3005	150	0	60	9.0
GSR3006	120	0	60	7.2
GSR3378	30	0	60	1.8
GSR3382	30	0	60	1.8
GSR3717	30	0	60	1.8
GSR3719	300	0	60	18.0
GSR4005	150	0	60	9.0
GSR4006	150	0	60	9.0
GSR4355	60	0	60	3.6
GSR4468	50	0	60	3.0
GSR4469	30	0	60	1.8
GSR4717	120	0	60	7.2
GSR4719	120	0	60	7.2
GSR5005	300	0	60	18.0
GSR5006	60	0	60	3.6
GSR5356	30	0	60	1.8
GSR5719	120	0	60	7.2
GSR6382	30	0	60	1.8
GSR6468	50	0	60	3.0
GSR6719	60	0	60	3.6
GSR9007	30	0	60	1.8
GSR9470	30	0	60	1.8
TOTAL	3670	0 -	60	220.2

UMBILICOSPHAERA MIRABILIS

GSR1006	30	0	483	14.5
GSR1469	60	0	483	29.0
GSR1471	30	0	483	14.5
GSR2005	30	0	483	14.5
GSR2360	60	0	483	29.0

STATION	QUANTITY	CARB(IND)		CARBON NG)
GSR3360	30	0	483	14.5
GSR3361	30	0	483	14.5
GSR4361	30	0	483	14.5
GSR4468	50	0	483	24.2
GSR4723	60	0	483	29.0
GSR5005	30	0	483	14.5
GSR5357	30	0	483	14.5
GSR6005	60	0	483	29.0
GSR6719	90	0	483	43.5
TOTAL	620	0 -	483	299.7
OTHER				
CARTERIA	SP.			
GSR1357	30	0	42	1.3
GSR1359	330	0	42	13.9
GSR1360	30	0	42	1.3
GSR1476	60	0	42	2.5
GSR2359	150	0	42	6.3
GSR2468	350	0	42	14.7
GSR3360	30	0	42	1.3
GSR4357	60	0	42	2.5
GSR4360	150	0	42	6.3
GSR4468	100	0	42	4.2
GSR6468	150	0	42	6.3
TOTAL	1440	0 -	42	60.6
CHILOMONAS	MARINA			
GSR1377	60	0	28	1.7
GSR1471	30	0	28	.8
GSR2006	30	0	28	.8
GSR2361	30	0	28	.8
GSR2377	4380	0	28	122.6
GSR2382	30	0	28	.8
GSR3006	30	0	28	.8
GSR3476	60	0	28	1.7
GSR3717	30	0	28	.8
GSR3719	30	0	28	.8
GSR4005	30	0	28	.8
GSR4007	33	0	28	.9
GSR4360	30	0	28	.8
GSR4377	60	0	28	1.7
GSR5382	90	0	28	2.5
GSR5468	100	0	28	2.8

STATION	QUANTITY	CARB(IND)		CARBON NG)
GSR6382	60	0	28	1.7
GSR7007	30	0	28	.8
TOTAL	5143	0 -	28	143.6
CRYPTOMONAS	SP.			
GSR3004	30	0	101	3.0
GSR5717	30	0	101	3.0
TOTAL	60	0 -	101	6.0
DANASPHAERA	INDICA			
GSR2359	30	0	109	3.3
GSR4377	30	0	109	3.3
GSR5378	30	0	109	3.3
GSR5384	30	0	109	3.3
GSR7384	30	0	109	3.3
TOTAL	150	0 -	109	16.5
DICTYOCHA	FIBULA			
GSR1007	150	0	280	42.0
GSR1356	30	0	280	8.4
GSR1468	30	0	280	8.4
GSR1473	60	0	280	16.8
GSR1723	180	0	280	50.4
GSR2007	360	0	280	100.8
GSR3006	30	0	280	8.4
GSR3007	420	0	280	117.6
GSR3356	30	0	280	8.4
GSR3361	60	0	280	16.8
GSR3380	120	0	280	33.6
GSR5005	30	0	280	8.4
GSR5360	30	0	280	8.4
GSR5719	30	0	280	8.4
TOTAL	1560	0 -	280	436.8
DINOBRYON	SP.			
GSR3362	300	0	42	12.6
TOTAL	300	0 -	42	12.6
DISTEPHANUS	SPECULUM			
GSR1355	1500	0	91	288.0

STATION	QUANTITY	CARB(IND)		CARBON (UG)
GSR1475	30	0	192	5.8
GSR2717	30	0	192	5.8
GSR6719	30	0	192	5.8
TOTAL	1590	0	- 192	305.4
EUTREPTIA	MARINA			
GSR1356	60	0	393	23.5
GSR1362	60	0	393	23.5
GSR2377	8820	0	393	3466.3
GSR3007	60	0	393	23.5
GSR3377	5400	0	393	2122.2
TOTAL	14400	0	- 393	5659.0
HALOSPHAERA	VIRIDIS			
GSR5382	30	0	2344	70.0
GSR9377	30	0	2344	70.0
TOTAL	60	0	- 2344	140.0
PLATYMONAS	SP.			
GSR1359	30	0	29	.9
TOTAL	30	0	- 29	.9
PLATYMONAS	SUECICA			
GSR1717	60	0	26	1.6
TOTAL	60	0	- 26	1.6
UNDETERMINED	CELLS			
GSR1005	720	0	60	43.2
GSR1006	330	0	60	19.8
GSR1007	1875	0	60	112.5
GSR1356	630	0	60	37.6
GSR1357	120	0	60	7.2
GSR1359	30	0	60	1.8
GSR1360	60	0	60	3.6
GSR1362	240	0	60	14.4
GSR1377	7980	0	60	478.8
GSR1378	1080	0	60	64.8
GSR1380	1230	0	60	73.8
GSR1382	1080	0	60	64.8
GSR1384	1740	0	60	104.4

STATION	QUANTITY	CARB(IND)		CARBON (G)
GSR1468	690	0	60	41.4
GSR1469	90	0	60	5.4
GSR1470	1110	0	60	66.6
GSR1471	900	0	60	54.0
GSR1472	810	0	60	48.6
GSR1473	750	0	60	45.0
GSR1474	450	0	60	27.0
GSR1475	1890	0	60	113.4
GSR1476	1980	0	60	118.8
GSR1717	900	0	60	54.0
GSR1719	210	0	60	12.6
GSR1723	300	0	60	18.0
GSR2005	420	0	60	25.2
GSR2006	630	0	60	37.8
GSR2007	1740	0	60	104.4
GSR2359	30	0	60	1.8
GSR2360	30	0	60	1.8
GSR2361	120	0	60	7.2
GSR2377	2820	0	60	169.2
GSR2378	1590	0	60	95.4
GSR2380	3510	0	60	210.6
GSR2382	1500	0	60	90.0
GSR2384	840	0	60	50.4
GSR2469	350	0	60	21.0
GSR2717	480	0	60	28.8
GSR2719	870	0	60	52.2
GSR2723	300	0	60	18.0
GSR3005	660	0	60	39.6
GSR3006	240	0	60	14.4
GSR3007	2400	0	60	144.0
GSR3355	60	0	60	3.6
GSR3356	60	0	60	3.6
GSR3357	30	0	60	1.8
GSR3360	30	0	60	1.8
GSR3361	120	0	60	7.2
GSR3377	4500	0	60	270.0
GSR3378	1080	0	60	64.8
GSR3380	2910	0	60	174.6
GSR3382	8580	0	60	514.8
GSR3384	1800	0	60	108.0
GSR3468	200	0	60	12.0
GSR3469	300	0	60	18.0
GSR3476	330	0	60	19.8
GSR3717	630	0	60	37.8
GSR3719	870	0	60	52.2

STATION	QUANTITY	CARB(IND)		CARBON (MG)
GSR3723	660	0	60	39.6
GSR4005	420	0	60	25.2
GSR4006	180	0	60	10.8
GSR4007	594	0	60	35.6
GSR4355	300	0	60	18.0
GSR4355	120	0	60	7.2
GSR4356	80	0	60	4.8
GSR4360	60	0	60	3.6
GSR4361	210	0	60	12.6
GSR4377	360	0	60	21.6
GSR4378	480	0	60	28.8
GSR4380	570	0	60	34.2
GSR4382	1770	0	60	106.2
GSR4384	1650	0	60	99.0
GSR4468	200	0	60	12.0
GSR4717	690	0	60	41.4
GSR4719	270	0	60	16.2
GSR4723	300	0	60	18.0
GSR5005	540	0	60	32.4
GSR5006	360	0	60	21.6
GSR5007	240	0	60	14.4
GSR5359	120	0	60	7.2
GSR5361	60	0	60	3.6
GSR5377	120	0	60	7.2
GSR5378	510	0	60	30.6
GSR5382	840	0	60	50.4
GSR5384	840	0	60	50.4
GSR5468	650	0	60	39.0
GSR5476	60	0	60	3.6
GSR5717	300	0	60	18.0
GSR5719	780	0	60	46.8
GSR6005	120	0	60	7.2
GSR6006	300	0	60	18.0
GSR6007	30	0	60	1.8
GSR6356	40	0	60	2.4
GSR6378	120	0	60	7.2
GSR6382	540	0	60	32.4
GSR6384	30	0	60	1.8
GSR6468	250	0	60	15.0
GSR6717	60	0	60	3.6
GSR6719	510	0	60	30.6
GSR7005	120	0	60	7.2
GSR7006	60	0	60	3.6
GSR7007	60	0	60	3.6
GSR7357	30	0	60	1.8

STATION	QUANTITY	CARB(IND)		CARBON (G)
GSR7360	30	0	60	1.8
GSR7377	30	0	60	1.8
GSR7378	150	0	60	9.0
GSR7382	210	0	60	12.6
GSR7384	30	0	60	1.8
GSR7476	30	0	60	1.8
GSR7717	30	0	60	1.8
GSR7719	90	0	60	5.4
GSR8005	120	0	60	7.2
GSR8007	120	0	60	7.2
GSR8361	30	0	60	1.8
GSR8377	60	0	60	3.6
GSR8378	30	0	60	1.8
GSR8382	150	0	60	9.0
GSR8469	60	0	60	3.6
GSR8717	30	0	60	1.8
GSR8723	30	0	60	1.8
GSR9005	60	0	60	3.6
GSR9007	90	0	60	3.4
GSR9356	30	0	60	1.8
GSR9377	30	0	60	1.8
GSR9378	90	0	60	5.4
GSR9384	60	0	60	3.6
GSR9471	60	0	60	3.6
GSR9717	30	0	60	1.8
GSR9719	30	0	60	1.8
GSR9723	30	0	60	1.8
TOTAL	85569	0	60	5131.8

APPENDIX B

CALCULATED CELL VOLUMES OF MARINE PHYTOPLANKTON (μm^3)

	LOHMANN 1908	BERNARD 1938b	MOROZOVA-VODIANITSKAYA 1954	CUSHING 1955	KUZMINA 1959	BOGOROV 1959	PAASCHE 1960	VIVES et FRAGA 1961	BERNARD *et al.* 1963	BERNARD *et* RAMPI 1967	MOYCHAN 1964	SMAYDA 1965	HICKEL 1967	HASLE 1969	HOLM-HANSEN *et al.* 1970b	MAJAROVA & PICHKILY 1970	BERNARD *et al.* 1971	HULBURT 1970	TRAVERS 1975	HULBERT (unpub. data) 1975	BEERS *et al.* 1975	ORTNER *et al.*
Diatoms, Pennate																						
Mastogloia rostrata																					12,367	1884
Navicula membranacea																					-	2516
Nitzschia bicapitata																					56–239	19
N. braarudii																					-	38
N. closterium			100			100–200			7500			121			90	90	300	80	60	220	27	57
N. delicatissima		34	170				70	850				130									-	188
N. seriata					650	500	2500	1660	2400–2830		900	763			300		400	2534	2000	2880	274	1884
Pleurosigma angulatum																					-	261,799
P. sp.																					-	261,799
Thalassionema nitzschioides	800	1500	400–2200		1700	400–600			576			460	800	194			580		600	2508–3205	259	302
Thalassiothrix frauenfeldii									988			2969					990		1800		851	1060
T. longissima																					9489	40,500
Tropidoneis antarctica v. poly.																					>6616 [1] 56,200	800,000

[1] in Beers, *Tropidoneis* spp.

Diatoms, Centric

Asterolampra marylandica																			4500		105,623	136,024
Bacteriastrum delicatulum																			1570–9400			2355
B. elongatum																			2800		1755–5323	2289
B. hyalinum																			38,000			7269
Cerataulina bergonii			22,000–158,000						3960			17,173	4000				12,600	20,763	13,800		9821	9424
Chaetoceros concavicornis																						12,566
C. debilis																				1830		6283
C. decipiens						3000	9760	3790	32,600		6700	2035					15,000		3500	11,000		12,000
C. densus																				21,210	7897	12,000
C. didymus																		4415	1100–3500	8100		3140
C. diversus																			375			393
C. laciniosus																			8000	3200		2830
C. lorenzianus																			7200			3016
C. messanensis																					11,759	1141
C. pendulus																			8200			863
C. peruvianus																			3400–13,000		6641	3426
C. teres																						34,195

[1] In Beers, *Bacteriastrum* spp.

	LOHMANN 1908	BERNARD 1938b	MOROZOVA-VODIANITSKAYA 1954	BOGDANOV 1959	PAASCHE 1960	VIVES & FRAGA 1961	OVERBECK 1962	AMITA *et al.* 1963	BERNHARD *et al.* 1963 BERNHARD & RAMPI 1967	SMAYDA 1965	MULLIN *et al.* 1966	HICKEL 1967	EPPLEY *et al.* 1968	FINENKO & LANSKAYA 1968	SCHNESE 1969	STRICKLAND *et al.* 1969	HOLM-HANSEN *et al.* 1970	MAKAROVA & PICHKILY 1970	BERNARD *et al.* 1971	HULBURT 1970	TRAVERS 1975	HULBURT (unpub. data) 1975	BEERS *et al.* 1975	ORTNER *et al.*
Climacodium frauenfeldianum																							8107	20,602
Corethron hystrix																							-	39,791
Coscinodiscus centralis																						311,650	-	628,319
C. curvatulus																					56,000		-	56,549
C. excentricus					60,000					8308											60,000	34,226	-	33,116
C. radiatus				10,000			24,800	311,000													30,000		-	19,634
Coscinosira polychorda																						9,884	-	12,566
Dactyliosolen mediterraneus																					5,200		6033	2,862
Eucampia cornuta																					21,000		-	6,458
E. zoodiacus																					15,000		-	6,996
Guinardia flaccida																					190,000	66,568	145,696	100,531
Hemiaulus hauckii			8000					14,500		1187									1580		42,000		7,124-33,977	1,570
H. membranaceus																							-	18,758
H. sinensis																							-	1,913
Lauderia borealis																					27,000		-	56,706
Leptocylindrius danicus			1200	1500		4060		3430		1840		200						2400	3400	2512	2260	2,260	-	1,963
L. minimus																							-	126
Liomphora lyngbei																								
Planktoniella sol																					5400			5400
Rhizosolenia alata																							21,642	16,362
R. calcaravis			170,000-490,000																		25,300	32,190	50,272	56,548
R. delicatula								2,283,000		261,600									2,800,000	32,952	1,000,000	33,050		353,429
R. fragilissima	6000			8000				100,000		4040		400								3735	5899	3454		4071
R. imbricata v. shrub.																								
R. setigera										230,000	13,200-174,000		422											
R. stolterfothii	5500							147,000		14,500		2920				6000	28,000		3800	12,101	6000	12,100		53,014
Schroderella delicatula																			84,000		62,000	8924	>3233	18,321
Skeletonema costatum	150		300					700		430-1300	312	150		124	400	400					13,000			19,155
Stephanopyxis palmeriana																		550	350	483	235	364-400	> 88	483
Streptotheca thalmensis																								95,426
Thalassiosira decipiens																								48,000
T. nordenskioldii																					1800	19,240		18,322
T. subtilis																					750	23,254		27[illegible]1
																								8363

[1] In Beers, *Thalassiosira* spp.

Coccolithophorids	LOHMANN 1908	MOROZOVA-VODYANITSKAYA 1956	KUZMINA 1959	BOROJEVIĆ 1959	BERNARD *et al.* 1963 BERNARD & RAMPI	MULLIN *et al.* 1966	FIPLEY *et al.* 1968	FINENKO & IANSKAYA 1968	HASLE 1969	SCHREFFE 1969	BERNARD *et al.* 1971	HULBURT 1970	THAYER'S 1975	HULBURT (unpub. data) 1975	BEERS *et al.* 1975	ORTNER *et al.*
Acanthoica acanthifera															560	180
A. monospina																904
Anoplosolenia brasiliensis															843	409
Anthosphaera oryza																523
A. robusta																523
Braarudosphaera bigelowi																65
Calciosolenia murrayi													1400			837
Calyptrosphaera oblonga												5572			2734	1436
Coccolithus huxleyi	100	250	250–400	130	220	14,200–20,600	115	153	113	110–180	246	220	70	211	146	113
C. pelagicus														2915		4189
Cyclococcolithus fragilis															3463	3054
C. leptoporus												2571		2455	2717	2806
Deutschlandia anthos															769	904
Discosphaera tubifer												902			98	904
Gephyrocapsa oceanica																1767
Halopappus adriaticus													325			452
Helicosphaera carteri															7462	1288
H. hyalina																1288
Helladosphaera aurisinae																523
Michaelarsia asymmetrica																628
Ophiaster hydroideus															144	143
Pontosphaera syracusana																2572
Rhabdosphaera claviger															884	697
R. hispida																904
R. stylifer													265		406	523
Scyphosphaera apsteini													2500			2572
Syracosphaera cornifera																523
S. dentata																904
S. mediterranea												1563			1171	1767
S. prolongata															1180	620
S. pulchra												2571	1300	2455	4125	1767
Thoracosphaera heimii															1548	1767
Umbellosphaera irregularis												902			538	1150
U. tenuis															579	696
Umbilicosphaera hulburtiana																523
U. mirabilis															10,333[1]	8180

[1] Beers estimated for *Umbilicosphaera*

	LOHMANN 1908	MOROZOVA-VODIANITSKAYA 1954	BOGOROV 1959	BERNHARD *et al.* 1963	BERNHARD AND RAMPI 1967	HICKEL 1967	BERNHARD *et al.* 1971	HULBURT 1970	TRAVERS 1975	HULBURT (Unpub. data) 1975	BEERS *et al.* 1975	OETHER *et al.*
Thecate Dinoflagellates												
Ceratium fusos	37,000	65,000	50,000	21,000		25,000	13,000		7,000		13,569	25,130
C. macroceros									45,000		21,622	67,355
C. minutum											46,361	11,494
C. pentagonum									150,000		46,361	141,690
C. teres									30,000		41,544	22,199
C. trichoceros									30,000		20,426	59,464
Cladopyxis setifera											1,094	905
Oxytoxum milneri											951[1]	2,945
O. scolopax									17,000		2,283	10,472
O. sphaeroideum												5,575
O. variabile								1,046		500	653	523
Peridinium globulus									130,000		10,499-44,654	113,097
P. trochoideum											444-3886	3,770
Phalacroma sp.												84,823
Podolampas palmipes									40,000[2]		25,072[3]	32,740
Porella perforata									3,500			4,072

[1] In Beers, *O. laticeps*
[2] In Travers, *P. elegans*
[3] In Beers, *P. elegans*

Phalacroma sp.	84,823
Porella perforata	4072
Prorocentrum gracile	3338
P. lebourae	28,903
P. obtusidens	3619
P. steinii	3519
Pyrocystis lunula	20,944
Non-Thecate Dinoflagellates	
Entomosigma peridinioides	469
Gymnodinium punctatum	523
G. [illegible]dinium sanguineum	9047
G. dominans	1767
G. glaucum	2257
G. metum	1847
G. esturiale	54,287
G. uncatenum	23,561
Katodinium rotundatum	523
Polykrikos barnegatensis	24,664
Prorocentrum pelagica	452

Other	MOROZOVA-VODIANITSKAYA 1954	BOGOROV 1959	OVERBECK 1962	HICKEL 1967	TRAVERS 1975	HULBURT (unpub. data) 1975	BEERS *et al.* 1975	ORTNER *et al.*
Chilomonas marina								196
Distyocha fibula					2500	8000	7100	4000
Distephanus speculum	2300	10,000	1400	1400	3000	4000	2661	2437
Eutreptia marina							1761[3]	6282
Halosphava viridis					1,000,000	42,600	59,780	65,449
Platymonas sp.								202
P. suecica								177
Danasphaera indica							255	1150

[3] In Beers, *Eutreptia* spp.

APPENDIX C

Abundance of Common Species at Different Hydrostations
(summed no./liter of all depths sampled).

		Dinoflagellates							Pennate Diatoms						Centric Diatoms		
		Oxytoxum sphaeroideum	*O. variabile*	*Gymnodinium punctatum*	*Katodinium rotundatum*	*Pronoctiluca pelagica*	*Prorocentrum obtusidens*		*Navicula membranacea*	*Nitzschia seriata*	*N. delicatissima*	*N. closterium*	*Thalassionema nitzschioides*		*Bacteriastrum delicatulum*	*B. hyalinium*	
	SLOPE																
	355		100	620	4520	40					80	220	1040		100		
Fall-One	356		60	240	90	80	30		80	1180	5690	90	150		780	630	
	362								700	240	2460	100			2500	1660	
	475		150	1110					30		120	30					
Spring	476		60	1470	90				120		180	270	60				
Summer	1377	150	360	580			60			4500	13,230	150					
	CC-7		795	1365	540	457	210		2265	2871	1120	811					
Fall-Two	723		60	300	60	60			240	840	720	1020	60				
	RING																
	357		90		60												
Fall-One	359	30	120	60							150	30	30				
	360		120	30	60						120						
	470			780	60		420				2310					210	
	471			1350			510				510						
Spring	472		30	720	90	30	180				1050	120					
	473		90	1020	30		30				300	30					
	1380	180	620	1980	1290	30											
Summer	1382	180	720	2170	1110	120											
	CC-5	210	120	570	120	120											
Fall-Two	CC-6		150	270	330	30	30					30					
	719	150	120	330	90	30	30										
	SARGASSO																
Fall-One	361	30	150	510	30				90	120	390	60	150			150	
	468		510	1500	130		90				850	1050					
Spring	469		90	1290	30						210	60			480	270	
	474		30	360													
	1378	270	240	2745	630						150						
Summer	1384	450	210	450	690	60					150						
Fall-Two	717	120	60	750	210	30					120	60					

Abundance of species, continued

		Centric Diatoms (continued)	*Cerataulina bergonii*	*Guinardia flaccida*	*Hemiaulus membranaceus*	*Leptocylindrus danicus*	*Rhizosolenia alata*	*R. calcavis*	*R. fragilissima*	*R. imbricata shrubsolei*	*R. stolterfothii*	*Chaetoceros teres*	Coccolithophores	*Calyptrosphaera oblonga*	*Coccolithus huxleyi*	*Cyclococcolithus leptoporus*	*Anthosphaera oryza*	*A. robusta*	*Discosphaera tubifer*	*Halopappus adriaticus*
	SLOPE																			
	355			17,910	1000	750	120		600	9400	600				280	30	60			
Fall-One	356		1080		30	360	60		110	60	2800				18,340	1020		30	20	30
	362		5900	60	360	240	100	260	240	1030	4760				6960	100	150			
Spring	475														8310		60			
	476													30	29,220	120	150	60	30	30
Summer	1377		60			1800									11,760					
Fall-Two	CC-7		1503	1155	335	99	300	606	1773	150	360				38,020	105	365			
	723		240	480	120	2040	60	120	60	120	1200	480			44,640	90	1440			
	RING																			
	357														44,140	930		30	540	240
Fall-One	359														57,780	1290	60	60	360	390
	360		720					60			120				66,020	1140		30	120	360
	470											120			10,110	180	30			
Spring	471		30								90				5550	510				
	472		60			30					240	210			8130	270				
	473														3120	150				
Summer	1380												1090		210	60			90	
	1382												180		180		750	240	150	
	CC-5						30						150		11,730	480	90	30	630	
Fall-Two	CC-6												30		8850	270		30	270	
	719												120		13,650	480		120	360	
	SARGASSO																			
Fall-One	361		600		30	180		120	60	30	450	120	90		44,730	2700			120	30
	468			30											182,625	870		100		150
Spring	469		90		30						540				24,210	240	90	60		
	474														3570		30			
Summer	1378					450					120		210		3570	690			720	
	1384												60		3450	450	60		750	
Fall-Two	717												300		19,800	540	90		240	

Abundance of species, continued

		Coccolithophores (continued)	*Helicosphaera carteri*	*Gephyrocapsa oceanica*	*Rhabdosphaera hispida*	*R. stylifer*	*Syracosphaera mediterranea*	*S. pulchra*	*Thoracosphaera heimi*	*Umbellosphaera tenuis*	*U. irregularis*	*Umbilicosphaera hulburtiana*	Other	*Dictyocha fibula*
	SLOPE													
Fall-One	355			30					30	20		60		
	356		60	4100			30	30	60			90		60
	362			510										
Spring	475													
	476			720			30	30	60	180				
Summer	1377		780											
Fall-Two	CC-7		120	930			60	60				30		930
	723		60	697			60		60					180
	RING													
Fall-One	357						30	210	190					
	359			60				30	270					
	360						30	120	270	30				30
Spring	470			30	30							30		
	471			60			30	150				30		
	472			240										
	473											60		60
Summer	1380		30		90			120	30	690		60		120
	1382				210		30	60	60	3000		90		
Fall-Two	CC-5		30		60	180	60	390	90	30	30	1200		30
	CC-6				120	90		360	30	180		540		30
	719		30		150	120	180	450	120	30		900		30
	SARGASSO													
Fall-One	361			180			90	90	240	30				60
Spring	468			2070			640	50	180	80		100		30
	469			720	30				180			30		
	474			720					90					
Summer	1378			60	420	120	120	540	30	330	480	30		
	1384		30	30	690	120	300	150	30	540	750	30		
Fall-Two	717				120	240	360	210	30	60	180	390		

a) Species included comprise at least .1% of total species list and occur in >3% (excepting *Chaetoceros teres:* 2.78%) of the samples collected.

BIOGRAPHICAL PERAMBULATIONS

Purportedly born August 6, 1948 in St. Joseph's Hospital, Far Rockaway, Queens, the author's earliest memory dates from the summer of 1952. He more or less distinctly remembers, perhaps subconsciously appealing to some fond parental account repeated in his presence *ad nauseum*, observing dolphins just outside the port hole of the family sloop, 'The Whimsey'. The significance of this incident has become, with the passage of time, obscure.

Throughout his childhood years, winters were spent in umbilical proximity to New York, New York. Summer habitats were more various: initially family retreats on Fire Island and Deer Isle, Maine; then summer camps in Maine, Cape Cod, and Pennsylvania.

Both as a child and as an adolescent he read books of facts with near competitive intensity. Fiction and poetry he airily dismissed; like the Beatles' "Nowhere Man" he had "too little time and too much to do." Insidiously he began to imagine himself a classical scholar and a natural philosopher - a sort of juvenile latter day Kant. Almost certainly he was influenced by an extraordinarily beautiful eighty-year old Latin teacher, the unforgettable Mrs. Kielty. Her benevolence redeemed his otherwise undistinguished high school grade average.

Miffed at Harvard University's and Haverford College's recalcitrance (and high standards in refusing to grant him premature college admission as an evident child prodigy), he nervously arrived in New Haven, Connecticut - a freshman at Yale College, in September 1966. For one semester, buoyed by near neurotic feelings of inadequacy, he

maintained dean's list standing. He suspected, appearances to the contrary, that his classmates at Yale were, one and all, the intellectual elite. His error revealed, he settled down to a mediocre college career as, in order: a classics major; a comparative literature major; an English major, and last, a philosophy major. By this time the author had completely ceased sublimating his energies on the tennis court and was enthusiastically "in love". Abruptly (from his point of view) the relationship was severed prior to his senior year. Despite this cruel circumstance, he stumbled (his already shaky mental and physical balance made more precarious through psychoactive abuse) through to an inglorious graduation in June 1970.

He was then faced with the stark realization that one must DO SOMETHING!!! He had been accepted at graduate school in philosophy but that prospect was uninviting at best. Law school? He had never theretofore exhibited concern for the health of the body-politic. Medical school? Too trite for a middle-class New York Jew from an Ivy League college. Then, the answer: Chris and Arthur!!! He had been best man at their wedding. They were obviously happy. To his benighted vision their existence seemed idyllically straight-forward. They were marine biologists whose troth was first plighted at the Marine Biological Laboratory. Utilizing to the fullest the one consummate grace, Mother Yale invariably bequests upon her sons, the incipient scientist talked then Biology Department Chairman, Ed Boell, into readmitting him to Yale as a special student in biology.

Utterly unincumbered by the baggage and prejudice of any prior knowledge (he had taken no science courses at all as an undergraduate),

he absorbed scientific information like a roll of Bounty towels absorbs a spill. Midway through that year he applied to a number of marine biology graduate programs. His remarkable lack of qualifications appealed to the theretofore well-concealed sporting instincts of various admissions committees. How else is one to explain why all offered admission and copious financial remuneration? Still believing W.H.O.I. to be the M.B.L. where Chris and Arthur had met, he visited Woods Hole. Although quickly disabused of this notion, the prospect of being the first W.H.O.I. student, a dockside tour of ALVIN (never since repeated) and the "representative" graduate students introduced to him by the canny John Teal (i.e., Kathy Burns and Charlene Van Raalte) convinced him that W.H.O.I. was the place to have come from. Besides, W.H.O.I. was at least near the M.B.L.

At W.H.O.I. he first found sanctuary with Stanley Watson and Freddy Valois. From them he learned much of SCIENCE and its doings. Yet, his interests gradually shifted up the food chain from bacteria to plankton. Further, his microbiological graduate advisor was given the traditional W.H.O.I. junior scientist *coup de grace*. Surprising both himself and numerous self-styled keen observers of the human condition, he inexorably gravitated to the one staff member, Peter Wiebe, who, on his initial visit, had helpfully advised him not to come to W.H.O.I. at all, but to accept the offer of Scripps. Six years and numerous oceanographic cruises later, a few papers and many good friends richer, the reluctant fledgling was forced under stern injunction to depart the nest. Which explains this thesis.

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2. Gulf Stream Rings
3. Phytoplankton-zooplankton interactions

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