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NITROGEN METABOLISM IN THE SEA

by

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October 31, 1972

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ABSTRACT

The major theme of the Biological Oceanography group at Lamont is "Nitrogen Metabolism in the sea".

The basic part of this study is supported by AEC. This report constitutes a turning point in our work in this field: we have compared the conventional method of water-sampling and biomass-sampling with bottles and nets, followed by gravimetric and analytical techniques, to a new method utilizing ^{15}N labeled systems. We found excellent agreement between both methods in our study at our Bermuda station this year. This report describes the results on nitrogen flux in the water column at our Bermuda station during January and February 1972, when we occupied the station on Bermuda on board the RV/ATLANTIC TWIN for a period of 23 days. Simultaneously, studies of ^{15}N transfer from $\text{NaN}^{15}\text{O}_3 \rightarrow ^{15}\text{N}$ labeled phytoplankton $\rightarrow ^{15}\text{N}$ labeled zooplankton on the 20 liter scale with organisms taken at the same station were done. The comparison of the results of both methods is so encouraging that the first "big bag" experiments with ^{15}N label will be undertaken in coastal waters near New York this winter prior to large scale studies at our Bermuda Station in March of 1973. This will enable us to considerably refine the methodology we have employed. As a result, considerably more emphasis will be given in our future work to "in situ big bag" experiments with $\text{NaN}^{15}\text{O}_3$ at our Bermuda Station to come to a precise understanding of nitrogen metabolism in the sea.

Our study of nitrogen metabolism at our St. Croix station ("Artificial Upwelling") and at our Tallman Island "Effluent Aquaculture" study in New York greatly strengthens the basic study with nitrogen metabolism in the ocean supported by AEC.

PERSONNEL RESPONSIBILITIES

Anderson, O.R.	Direction of ^{15}N experiments. Co-editor of Progress Report.
Currie, J.	Collection of phytoplankton samples.
Garside, C.	Chief Scientist (AT-72-1). Collection of chemical and hydrographic samples and synthesis of data. Statistical analysis. Report co-author.
Garside, J.	Computer programming.
Harris, V.	^{15}N experiments. Zooplankton live-sorting and culture. Report co-author.
Hillegas, J.	Zooplankton sampling, taxonomy and data synthesis. Report co-author.
Kostyk, N.	Carbon, hydrogen, nitrogen analysis.
Rice, G.E.	Phytoplankton taxonomy and data synthesis. Report co-author.
Roels, O.A.	Principal investigator. Co-editor.
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I INTRODUCTION

A. Review of Past Work

In past years, the emphasis of our field study of nitrogen flux in the western North Atlantic was on seasonal and geographic changes, which made possible the construction of a model of annual nitrogen flux.

Briefly, the model is based on the replenishment of nitrogen in the euphotic zone by winter turnover. The first stage of biological nitrogen flux occurs when light and temperature are no longer limiting and when, after turnover, dissolved inorganic nitrogen is available to the biological nitrogen pool. As light penetrates to the deeper layers and as the surface layers warm, a seasonal thermocline begins to form and productivity increases. As the vernal bloom progresses, the thermocline becomes a well-defined density barrier, preventing further influx of dissolved inorganic nitrogen.

During the remaining part of the year, the nitrogen is recycled through the various nitrogen pools shown in Figure 1. Nitrogen is lost from the biological nitrogen pool through the formation of detritus. That portion of the detritus that is regenerated below the thermocline is not available to primary producers, and as the year progresses, biological production, therefore, decreases. The cycle begins anew when the thermocline breaks down during winter turnover and nutrients again become available in the euphotic zone. This model has been discussed in greater detail in CU-3826-22, Technical Progress Report for

FIGURE 1

NOTE: WHILST THE BIOLOGICAL NITROGEN POOL IS REPRESENTED AS BEING ABOVE THE THERMOCLINE, THIS IS DONE FOR CONVENIENCE ONLY. WE ARE WELL AWARE OF THIS SIMPLIFICATION AND OF THE POSSIBLE INFLUENCE OF DIURNAL MIGRATORY ORGANISMS ON NITROGEN DISTRIBUTION

November 1970 - October 1971.

To estimate the magnitude of the annual nitrogen flux, weights of nitrogen were applied to the nitrogen pools in the model using data collected at our "Slope Station" (36°37.5'N, 74°39'W; ROC-69-1), and from the literature. Rates of flux could only be estimated very generally. It was known from the literature and from our work on St. Croix that the rate of nitrogen uptake by primary producers is rapid, and from the literature that regeneration of detritus is rapid. It was speculated, as few data were available that regeneration of dissolved inorganic nitrogen from dissolved organic nitrogen was a slower process. Considering the rapid uptake rate of nitrogen by primary producers and their persistence throughout the year in significant numbers, it became apparent that the nitrogen above the thermocline must necessarily be recycled many times. The application of weights of nitrogen to the nitrogen pools in the model and the literature sources have been discussed in detail in CU-3826-22, Technical Progress Report for November 1970 - October 1971.

B. Objectives of Present Work

From November 1971 - October 1972, emphasis has been placed on determination of rates of nitrogen flux and the magnitude of the nitrogen pools during the initial stages of the annual increase in productivity.

Using a combination of daily measurement of standing stocks over a long period of time, and rates derived from ¹⁵N uptake experiments, it was expected that rates and quantities of nitrogen transferred from the dissolved inorganic form to

the primary producers and hence to the herbivores could be determined.

The nitrogen flux during the first stage of the annual nitrogen cycle was chosen for examination at a single station off Bermuda (32°14'N; 64°37'W), nine and one-half miles east of Gibbs Hill Light in 2,100 m of water. A cruise was made on the ATLANTIC TWIN from Jan 17-Feb 19, 1972, and samples were collected daily for a period of three weeks at the Bermuda station. As in the past, standing stock measurements of all particulate nitrogen from 0.45 - 10,000 μ were made on samples collected with water bottles and plankton nets. Measurements of dissolved inorganic nitrogen, other nutrients, salinity, and temperature were made on samples taken with water bottles equipped with reversing thermometers. Three preliminary experiments were done with ^{15}N labeled phytoplankton to measure the rate of nitrogen transfer from primary producers to herbivores. A program was initiated to collect and maintain zooplankton cultures for continuation of ^{15}N tracer studies under laboratory conditions. The objectives and results of the cruise are described more fully in COO-3222-01, Cruise Report ATLANTIC TWIN-72-1 (Appendix I).

The Technical Progress Report will concentrate on the results and synthesis of the data collected on AT-72-1

II METHODS AND PROCEDURES

A. Hydrography

1. Shipboard

A bathythermograph cast was made to 274 m on each day that the station was occupied. On Day 1, samples were taken at standard hydrographic depths for nitrate, nitrite, ammonia, silicate, phosphate, dissolved oxygen, pH, alkalinity, salinity and temperature with 1.7-liter Niskin bottles equipped with reversing thermometers. On Day 2, only nutrients were sampled from 12-liter Niskin bottles not equipped with reversing thermometers. Samples were stored in 125-ml glass bottles for phosphate, nitrate, and ammonia determinations, and in 125-ml polyethylene bottles for silicate and nitrite determinations, and analyzed within a few hours of reaching shore at the Bermuda Biological Station. Oxygen samples were taken in 300-ml BOD bottles and fixed with Winkler reagents. These were stored in the dark for later analysis ashore. Salinity samples were stored in 300-ml BOD bottles.

2. Laboratory

All samples were returned to the Bermuda Biological Station for analysis in a temporary laboratory set up for the cruise. Nutrient determinations were made using a Technicon 3-channel AutoAnalyzer II. Dissolved oxygen was determined using a modified Winkler method (Strickland and Parsons, 1968). Salinity was determined with a Hytech Model 621 salinity conductivity meter. Alkalinity and pH were determined using a

Corning Model 12 pH meter.

All analyses were completed within 3 days of collection of samples.

3. Data Processing

The output from the Technicon AAII system for nutrient analysis consists of a strip-chart record of peaks corresponding to 40 samples/hr whose height over a distilled water baseline is directly proportional to concentration. Standards were run before and after each sample series to calibrate the chart. A computer program has been written to calculate the calibration and standard error of the standards at the start and end of each run, after allowance has been made for baseline drift. Calibration and error are then interpolated linearly during the run to obtain the concentration and error for each sample. Output is a tabulation of station number, nutrient, sample number, concentration and error.

Oxygen, pH, alkalinity and salinity were calculated manually and errors were calculated where duplicates were available. The reversing thermometer corrections and thermometric depths were computed using a standard STD data reduction program. However, L-Z values indicated that too many of the thermometers were unreliable. All data have been stored on Disc on an IBM 1130 computer. These data have been used in conjunction with a program to plot all parameters with depth, and also to produce station summary sheets tabulating all data for each station. (See section III, A below).

B. Phytoplankton Ecology

1. Shipboard

(a) Dry Weight, Carbon and Nitrogen

Hydrocasts for phytoplankton dry weight, carbon and nitrogen determinations were made on the second day of each two day sampling schedule (see cruise report COO-3222-01). Therefore, under ideal conditions these samples were collected every other day; interruptions in this routine, however, limited us to 7 such stations occurring on the dates 1/23, 1/25, 1/27, 1/30, 2/2, 2/7, and 2/13. Each hydrocast deployed 12 liter Niskin bottles at eleven standard hydrographic depths ranging from 0 to 1,000 meters.

Samples for dry weight analysis of the 0.45-79 μ "phytoplankton" size fraction were prepared by prefiltering 3.5-liter aliquots from each Niskin bottle through a 79 μ mesh to remove larger particulate matter. Each 3.5-liter water sample was then filtered through a pair (sample and blank) of preweighed, 0.45 μ , 47 mm diameter Millipore filters, type HA. This filtration was performed on a multiplace manifold fitted with standard 47 mm glass Millipore filter holders on which 3-liter plexi-glass columns were mounted. Following filtration the apparatus was washed down with approximately 50 ml of filtered distilled water. The filter pairs were washed with an additional 50 ml of the distilled water which was applied in 5-ml aliquots with a pipet. Each sample and blank

filter was then placed in a separate disposable Millipore petri dish and dried under vacuum for approximately 24 hours in a dessicator containing silica gel. The filters were stored in dessicators until dry weight could be determined at Lamont.

The preparatory procedure for carbon, nitrogen determinations of the phytoplankton fraction from each water sample was similar to that of the dry weight procedure. In this case, however, 6 liter aliquots per Niskin sample were prefiltered through the 79μ mesh and then filtered through a pair (sample and blank) of Gelman 0.33μ , 47 mm diameter glass fiber filters. The filtering apparatus and washing procedure was identical with that used for the dry weight samples, except the filters were washed with distilled water containing 4.5% Na_2SO_4 (isotonic with sea water) to remove chloride ion. The glass fiber filter samples were immediately frozen for preservation.

(b) Taxonomy

Two types of samples for taxonomic determinations were collected. Those to be used for electron microscopic examination were collected on Day 2 of the sampling cycle and were from the same Niskin bottle as the dry weight, carbon and nitrogen samples. One hundred fifty ml were filtered through a single 0.45μ , 25 mm diameter Millipore filter, after prefiltration through a 20μ mesh. The filter was washed, dried and stored in a dessicator as previously described for the dry weight samples.

Preserved samples consisting of 500 ml of water prefiltered through a 79 μ mesh and preserved in 2% buffered glutaraldehyde were also taken. These samples were collected from standard hydrographic depths (down to 1,000 meters) on both Day 1 and Day 2 of the sampling cycle (19 stations). The samples were stored at 45° F to be used later for identification and counting by light microscopy.

2. Laboratory

(a) Dry Weight, Carbon and Nitrogen

The Millipore filters (both sample and blank) utilized in collecting the dry weight samples were dried in a Model 19 Precision Thelco vacuum oven at 40°C for 1 hour. The filters were then placed in an isolation chamber where they were allowed to equilibrate with the condition of the chamber over night. The following day the filters were weighed in the chamber at the same temperature and humidity at which they had been preweighed. The Millipore filters were then stored in dessicators for possible microscopic examination in the future.

The glass fiber filters used for carbon, nitrogen analysis were dried in a Blue M hot air oven at 75° C for two hours. They were then ground by mortar and pestle—producing a homogeneous mixture of glass fiber filter paper and sample material. The ground samples were placed in small individual vials which, in turn, were stored in dessicators until analyses could

be run. Carbon, and nitrogen analysis consisted of burning the entire sample mixture in a Hewlett-Packard Model 185 Carbon-Hydrogen-Nitrogen analyzer, using the direct recording method. A detailed discussion of this instrument and analysis is presented in Research Document CU-3826-17.

(b) Taxonomy

Replicas of the 25 mm diameter Millipore filters collected for electron microscopy were made by the following procedure:

1. The filters were shadowed with platinum and carbon in a Denton DV 503 FP vacuum evaporator.
2. The shadowed filters were cut into small (approximately 2 mm X 2 mm) squares and placed into acetone for approximately 2 days where the filter was dissolved.
3. The small square replica (and sample) were mounted on 200 mesh copper grids.
4. The organic matter of the sample was removed from the replica by dipping each grid into concentrated HF for 1-2 minutes, followed by distilled water for 30 seconds, HCl acid for 1-2 minutes and finally distilled water for 30 seconds.* (see Research Document CU-3826-07 for comparison with previous taxonomic preparations)

*an additional step of placing the grid into a mixture of KMNO_4 , $\text{K}_2\text{Cr}_2\text{O}_7$, and concentrated H_2SO_4 for 15-30 seconds was utilized with half of the grids.

The replicas were then observed on a Phillips 75 electron microscope. Generally organisms from a total of approximately 30 squares on 2-3 grids were counted for a specific station and depth. All depths were examined and counted for stations 8(1/23), 74(2/2), and 126(2/13). In addition the 10 meter depth was observed and counted for all 7 days on which the electron microscopy samples were collected. Other random stations and depths were examined and counted as a general check on the consistency of the taxonomic data.

The samples, preserved in 2% glutaraldehyde, were to be observed on an inverted phase light microscope after the cells had settled for several days in an Uttermohl chamber. However, all of these samples had developed a very thick white precipitate which obscured the identification of organisms. Removal of the precipitate by filtration would also have removed the plankton. Therefore, this portion of the taxonomy was eliminated. The precipitate was, no doubt, polymerized glutaraldehyde produced during storage at 45°F.

C. Zooplankton Ecology

1. Shipboard

(a) Dry Weight, Carbon, Nitrogen, and Taxonomy

(i) Net design and specifications

The nets were designed to be highly efficient under bloom conditions. This aim was achieved through high open area to mouth area ratios and generous reserve filtration areas (Tranter and Heron, 1967; Tranter and Smith, 1968; Ahlstrom, et al, 1969).

Figures 2 and 3 show the shape and specifications of the three nets used. A circular mouth opening was incorporated to insure uniform flow around the nets (Tranter and Smith, 1968). The cylinder-cone shape was chosen for the increased open area possible for a given length. The .125 m² mouth area of the two smaller nets permitted large filtration areas without the sacrifice of manageability (National Academy of Sciences, 1969). The size ranges were continued from previous studies (Roels et al., 1971) with the exception of the 75 μ mesh net and the 1000 μ mesh net. The 75 μ mesh net was changed to 79 μ mesh material of much finer fiber (43 μ) giving an almost 100% gain in porosity per unit surface of the net. The 1000 μ monofilament mesh was changed to 1050 μ stiff monofilament mesh material to improve the durability and filtering characteristics of the net.

(ii) Sampling procedure

Three zooplankton size fractions were sampled: 79-202 μ , 202-1050 μ , 1050-10,000 μ . Size fractioning was accomplished as the samples were taken through the use of

SPECIFICATIONS FOR HIGH OPEN AREA 79u AND 202u NETS

TYPE: Cylinder-Cone

MOUTH AREA: $.125\text{m}^2$ DIA: 40 cm

LENGTH: 3.95m (Cyl: 2m, Cone: 1.75m)

AREA OF MESH: 3.6m^2

POROSITY, 79u MESH: 42%

OPEN AREA RATIO: 12:1

POROSITY, 202u MESH: 47%

OPEN AREA RATIO: 13.5:1

MATERIAL

Mouth collar and cod end collar:
6.5oz. Dacron sailcloth.

Seam tape: 9/16" Nylon binding
tape.

Mesh: 79u mesh Nitex Heavy Duty
Screen Cloth or 202u Nitex Monofila-
ment Bolting Cloth.

Grommets: 3/16" I.D., Plain lock.

SPECIFICATIONS FOR HIGH OPEN AREA
1050u-1m² NET

TYPE: Modified WP-3; Cylinder-Cone
MOUTH AREA: 1m² DIA: 113cm
LENGTH: 4.0m (Cyl: 2m, Cone: 2m)
AREA OF MESH: 10.6m²

POROSITY: 59%

OPEN AREA RATIO: 6.25:1

MATERIAL

Mouth collar and cod end collar:
6.5oz. Dacron sailcloth.

Seam tape: 9/16" Nylon binding
tape.

Tape ties: 9/16" Nylon binding
tape. Placed every 6" around cir-
cumference of cylinder base and
down seam tape at 90 intervals.

Mesh: 1050u Nitex Heavy Duty
Screen Cloth.

COD END SIEVE

flared cod-end sieves (Roels et al., 1971; Fig. 4). The data are reported for the nominal size fractions of 79-202 μ , 202-1000 μ , and 1000-10,000 μ . Volume sampled was measured with an inner and an outer TSK flowmeter on the 79 μ and 202 μ nets and with an inner TSK flowmeter on the 1000 μ net. Inner flowmeters were located one-half the distance between the edge and the center of the net mouth, such that they were not obstructed by the bridle.

Figure 5 shows the double towing arrangement used for the 79 μ and 202 μ nets to determine population variance over the short distance between net centers, and Figure 6 shows the single towing arrangement used with the 1000 μ net.

On Day 1 of the two-day sampling cycle, two series of net samples were taken to determine daily population variance. On Day 2 only one series of net samples was taken (COO-3222-01; Cruise Report AT-72-1).

All samples were taken vertically from 1000 m at a towing velocity of 60 m/min. A Benthos time depth recorder was attached below the net to determine the maximum depth sampled.

The nets were washed down thoroughly from the outside after each tow to catch any organisms adhering to the net fabric.

(iii) Laboratory

The sample from each net tow was washed from the cod-end sieve to a Folsom Splitter with filtered sea water. The sample was made up to 700 ml and split. One half of the sample was made up to 500 ml of 4% buffered sea water/formaldehyde solution with 100 ml of glass-fiber filtered sea water and 50 ml of 40% borate-buffered formaldehyde. After washing with 20 ml of 40% sodium sulfate solution and 20 ml of

deionized water, the other half of the sample was frozen on a mesh disc corresponding to the mesh of the net.

If a subsample for fresh sorting was taken, the right-hand half split was split again after it was made up to 700 ml. One half of this second split was preserved in formaldehyde and the other half was held for fresh sorting.

(b) Fresh sorting

To obtain measurement of dry weight, carbon, and nitrogen in the major zooplankton groups in the $>202 \mu$ size ranges, subsamples were held for fresh sorting.

On Day 2 of the sampling cycle, one-quarter splits from the $202-1000 \mu$ and $1000-10,000 \mu$ size fractions were kept in 900 ml of filtered seawater at ambient temperature and light. The samples were transferred from the ship to the Bermuda Biological Station within four hours of the time when they were taken, and held under gentle aeration at ambient temperature and light until sorting was begun (see section II,C,2,c).

(c) Culture program

Culture specimens were at first taken from one-quarter splits of the $>202 \mu$ size fractions. However, as few organisms were found in viable condition, surface tows of five minutes duration were made specifically for culture material.

Samples were held in 900 ml of filtered seawater at ambient temperature and light, and transferred from the ship to the Bermuda Biological Station within four hours of the time when they were taken.

2. Laboratory

(a) Dry Weight, Carbon, Nitrogen

The subsamples frozen on mesh discs were freeze dried for three days with a RePP Portable Model 15 Sublimator;

and then dried in an air oven at 75°C for two hours. The samples were held in dessicators and weighed to constant dry weight.

After dry weight had been measured, the sample material was removed from the mesh discs and the mesh discs were weighed. Dry weight of sample material was calculated by subtracting the weight of the mesh disc from the weight of disc plus sample.

The plankton material was ground to homogeneity with a mortar and pestle, and then analyzed for carbon and nitrogen content with a Hewlett-Packard Model 185 Carbon-Hydrogen-Nitrogen Analyzer using the ratio recording method. From the percentage figures obtained and the dry weights obtained previously, the weight of carbon and nitrogen were calculated.

(b) Taxonomy

The formaldehyde preserved samples were split further if required and poured into a raised grid sorting dish containing 2500 ml of a 4% buffered formaldehyde/seawater solution (CU-3826-07, Technical Progress Report, 1969). The organisms were allowed to settle overnight, excess water was carefully siphoned off, the settling column was removed, and counts of the major zooplankton groups were made.

The entire final split of the 1000-10,000 μ size fraction was sorted and counted. Fifteen random squares of the 202-1000 μ size fraction were counted and sorted. Fifteen random squares of the 79-202 μ size fraction were counted. The first in the list of random squares was also sorted to provide material for dry

weight, carbon, and nitrogen analysis of the major groups in the 79-202 μ size fraction.

(c) Fresh Sorting

(i) Population analysis

The subsamples of both the 202-1000 μ and 1000-10,000 μ size fractions were poured into a large specimen dish and made up to one liter with filtered seawater. Twenty ml aliquots were removed with a modified 20 cc disposable syringe and placed in a small petri dish.

The 1000-10,000 μ organisms, being the most perishable, were sorted first. Sorting was done with micro-forceps and an automatic pipette. A Wild-Heerbrugg M-5 Stereomicroscope was used for the 202-1000 μ size fraction, but was not needed for the 1000-10,000 μ size fraction.

The number of organisms in each major group required for dry weight, carbon, and nitrogen analysis are presented in Table 1. If the quota for a particular group was met, counting of that group was continued until all quotas had been met.

The sorted groups were placed on mesh discs corresponding to the mesh of the nets in which they were caught, and washed with 10 ml of 40% sodium sulfate solution and 10 ml of deionized water. The mesh discs were then placed in vials and frozen for later dry weight, carbon, and nitrogen analysis.

(ii) Dry weight, carbon, and nitrogen

The frozen major groups were transferred from the mesh discs to tared aluminum boats, and dried in an air oven at 75°C for 2 hours. The boat with sample was then weighed on

TABLE 1
DOMINANT ZOOPLANKTERS FOUND IN THE BERMUDA AREA IN JANUARY
AND SORTING QUOTAS

Size Fraction	Group	Minimum No. to be Sorted
202-1,000 μ	Copepods	200
	Ostracods	200
	Foraminifera	100
	Dinoflagellates	200
	Radiolaria	100
	Pteropods	100
	Chaetognaths	100
	Appendicularia	100
	Eggs	100
	Siphonophores	100
	Medusae	100
1,000-10,000 μ	Copepods	25
	Euphausiids	5
	Chaetognaths	25
	Appendicularia	25
	Ostracods	25
	Decapods	10
	Fish Larvae	5
	Amphipods	10
	Siphonophores	25

a Kahn Electrobalance and combusted in a Hewlett-Packard Model 185 CHN analyzer. The formaldehyde preserved major groups from the 79-202 μ size fraction were spun down four times at 2,500 rpm (532 RCF at center of tube) for five minutes each with a clinical centrifuge. The pellet was resuspended between runs with 3X-distilled water to remove salts. The pellet was transferred to a tared aluminum boat and dried in an air oven at 75°C for two hours. The boat with sample was then weighed on a Kahn Electrobalance and combusted in a Hewlett-Packard Model 185 CHN analyzer.

Dry weight, carbon, and nitrogen/organism were calculated from the results.

(d) Culture Program

The unsorted cultures were aerated immediately upon arrival at the Bermuda Biological Station's laboratory (no more than 4 hours after collection).

The culture vessels were 1000-ml Blake flasks, each filled with 750 ml of glass-fiber filtered sea water, protected from contamination by means of a cotton plug, and aerated continuously. The cultures were kept at ambient temperature (approx. 21°C) under reduced lighting conditions.

Organisms of dominant taxonomic groups from each size fraction were taken for culture. A maximum of ten organisms of like kind and size were placed in each culture vessel.

The cultures were fed immediately after sorting and once per week thereafter. Media exchange preceded feeding. Three phytoplankton cultures were maintained for feeding of zooplankton:

Chaetoceros simplex, Monochrysis lutheri, and Coccolithus huxleyi. A culture of Artemia salina nauplii was also maintained for feeding purposes.

Zooplankton cultures of the 202-1,000 μ size fraction were fed Monochrysis lutheri and Coccolithus huxleyi at the combined density of 2×10^4 cells/ml per culture flask. Cultures of the 1,000-10,000 μ size fraction were fed Monochrysis lutheri and Chaetoceros simplex at the same density. Carnivorous organisms of the larger size fraction were fed Artemia salina nauplii (approximately 100 per culture flask) in addition to the phytoplankton.

A total of 61 cultures were taken over a 3 week-period. Of the 202-1,000 μ size fraction, the following were taken: 27 cultures of copepods, 3 cultures of amphipods, 2 cultures each of chaetognaths and siphonophores, and 1 culture each of decapods, euphausiids, and ostracods.

Twenty-two cultures were brought back to the laboratory at Lamont Observatory, including 15 cultures of copepods of the 202-1,000 μ size fraction, and 5 cultures of copepods, 1 culture each of amphipods and decapods of the 1,000-10,000 μ size fraction. Media exchange and feeding was increased to 2 times per week.

D. ^{15}N Experiment

1. Shipboard

Zooplankton were collected by means of surface tows using a double or single 79 μ net and 79-202 μ cod-end sieves. One 10-minute single net tow was made for Experiment 1.

The zooplankton collected in this tow were transferred to a 20-liter polyethylene carboy, fed 490 ml of ^{15}N -labeled Coccolithus huxleyi at a density of 1.5×10^6 cells/ml, and brought to a volume of 20 liters with 0.33μ glass-fiber filtered sea water. Two 5-minute single-net tows were made for Experiment 2. The zooplankton were transferred as above, fed 480 ml of ^{15}N -labeled C. huxleyi at a density of 8.7×10^5 cells/ml, and brought to a volume of 20 liters. Two 5-minute double-net tows were made for Experiment 3. The zooplankton were transferred as before, fed 480 ml of ^{15}N -labeled C. huxleyi at a density of 1.7×10^6 cells/ml, and brought to a volume of 10 liters with filtered sea water.

In each experiment a 10-ml aliquot of the C. huxleyi feeding culture was taken immediately prior to feeding, refrigerated and returned to the Bermuda Biological Station laboratory for cell count and frozen on glass-fiber filters for analysis of total Kjeldahl nitrogen and ^{15}N content at Lamont. The experimental carboys were kept in reduced light intensity on board ship and delivered to the Bermuda Biological Station within 3 hours of experimental inception.

2. Laboratory

Laboratory cultures of Coccolithus huxleyi were labeled with ^{15}N by growing them in F/4 medium (Guillard and Ryther, 1962) containing $\text{Na}^{15}\text{NO}_3$ as explained hereafter.

The culture for Experiment 1 was grown in a 60% ^{15}N medium for 12 hours. For Experiment 2, the phytoplankton were grown in a 60% ^{15}N medium for 12 hours and then transferred

to an 80% ^{15}N medium in which they grew for 20 hours. For Experiment 3, the phytoplankton were grown in a 60% ^{15}N medium for 12 hours and then transferred to an 80% ^{15}N medium for 43 hours. These cultures were the phytoplankton inoculum for the ^{15}N experiments.

Upon return to the laboratory, the experimental carboys were kept in reduced light intensity at room temperature and aerated constantly. Experiments 1, 2, and 3 were terminated after 30, 18, and 6 hours of feeding time, respectively. Phytoplankton cell counts were made at the end of each experiment. The zooplankton were collected by passing the carboy contents through a 79 μ net, resuspending the collected organisms in filtered sea water, and filtering them onto a Gelman glass-fiber filter. The carboy was rinsed three times with a small volume of the carboy filtrate to ensure removal of all zooplankton. The zooplankton samples were frozen and transported to Lamont-Doherty Geological Observatory to be analyzed for total Kjeldahl nitrogen and ^{15}N content. Following removal of the zooplankton, three 1-liter volumes of the carboy filtrate were glass-fiber filtered to obtain samples of the ^{15}N -labeled Coccolithus huxleyi which remained in the carboy at the end of the experiment. These three phytoplankton filters were frozen and transported to Lamont for analysis of total Kjeldahl nitrogen and ^{15}N content. The three 1-liter filtrates resulting from the phytoplankton filtration were frozen and returned to Lamont for analysis of total Kjeldahl nitrogen and ^{15}N content.

Cell counts were made using a Speirs-Levy eosinophil counting chamber and Kjeldahl nitrogens were determined using

a standard digestion technique followed by steam distillation of the ammonia into boric acid. An aliquot of the Kjeldahl distillate was used for the determination of total nitrogen on a Technicon AA-II AutoAnalyzer and a second aliquot was used after isotopic dilution and redistillation into hydrochloric acid to determine the ^{15}N content by mass spectrometry.*

*Mass spectrometric determinations were made courtesy of Dr. Calvin Long at the College of Physicians and Surgeons, Columbia University. The analytical method gives an error of ± 0.0012 mg-at N on a sample containing 0.5 mgN (all samples for mass spectrometric analysis were prepared by isotopic dilution so that they had a 0.5-1.0 mgN content).

III RESULTS

A. Hydrography and Chemistry

1. Description

Our choice of the Bermuda station for more intensive study was based on the following precepts.

We postulated a model of nitrogen flux in the open ocean in which annual renewal of nutrients to the surface layers occurred as a result of the mixing across the seasonal thermocline. Incorporation of these nutrients into the food chain occurs during the vernal phytoplankton bloom at which time the seasonal thermocline redevelops. At this time, the water column is divided into two nitrogen pools above and below the thermocline, between which the major exchange is downward advection of particulate nitrogen. We have argued that to maintain any significant food chain in the surface layers, the nitrogen in the upper layer of the ocean must be recycled with reasonably high efficiency. A simplified model of such a system has been presented (CU-3826-17, Technical Progress Report for November 1970-October 1971).

The Bermuda station, apart from its purely logistical advantages, seemed likely to conform most closely to our model. The upper 800m or so of the water column receives a more or less constant inflow of nutrients across the permanent thermocline. The only other source of nitrogen inflow is the small eddies of slope water which are introduced by meandering of the Gulf Stream. These eddies persist for up to a year, but except in their own quite small areas

(28,000 km²/yr) they cannot represent a significant influx of nitrogen to the Sargasso Sea. The nitrogen balance of this water is most probably maintained by downward advection of particulate nitrogen.

Within this relatively constant upper 800m of the water column a seasonal thermocline develops during the spring and a vernal bloom of phytoplankton takes place. We hoped to observe these phenomena and to measure nitrogen transfers during the development of the major food chains, as well as nitrogen regeneration.

As will be readily seen from the biological data no such "bloom" occurred during the three weeks of our observation probably for the following reasons. The BT traces show a thermocline was present during the entire period, represented by a drop of about 4°C between 100 and 140 m. The low nutrient concentrations above this thermocline compared to values below the thermocline suggest that the previous years thermocline never broke down. We thus conclude, that as a result of the very mild winter the situation we observed was atypical of the area and not in accord with previously reported observations. Thus, no phytoplankton bloom could be expected. The situation we observed is therefore best considered as a continuation of the conditions pertaining during the previous fall. The observed data are presented in (see section II,A,2; Data Collected).

The water above 100m was too warm during the entire period of our experiment to permit mixing through the 18°

water which extends from the seasonal thermocline down to about 400m. All parameters suggest that the upper 100m of the water column was homogeneous, with a temperature close to 20°C, a salinity slightly greater than 36.4‰, and very low nutrient concentrations $1\mu\text{-at NO}_3\text{-N/l}$. $0\text{-}0.1\mu\text{g-at PO}_4\text{-P/l}$, $0\text{-}2\mu\text{g-at SiO}_4\text{-Si/l}$. Below this the main body of 18° water ($S=36.4\text{‰}$) is encountered extending down to 300-400m. In this layer there is an increase of nutrients with depth, nitrate rising to $10\mu\text{g-at NO}_3\text{-N/l}$, phosphate to $0.3\mu\text{g-at PO}_4\text{-P/l}$ but with little change in silicate. The permanent thermocline represents the major nutrient gradient between 600 and 800 m at which depths the nitrate values increase to $25\mu\text{g-at NO}_3\text{-N/l}$. The phosphate to about $1.5\mu\text{g-at PO}_4\text{-P/l}$ and the silicate to about $15\mu\text{g-at SiO}_4\text{-Si/l}$. Oxygen values in the upper 100 m were constant and near saturation, with minima just below the seasonal and permanent thermocline. pH generally showed a gradual and expected decrease from ~ 8.3 at the surface to 7.9 at 1000 m, while alkalinity showed little correlation with depth and was in the region 2.4-2.6 m eq/l.

2. Data Collected

Tabulation of all data collected at specific depths for each date, includes: temperature; salinity; oxygen; pH; alkalinity; NO_3 ; NO_2 ; NH_3 ; PO_4 ; SiO_4 ; total N, PO_4 , and SiO_4 integrated per square meter to depth over the water column; and dry weight, carbon, nitrogen for the 0.45-79 μ

79-202 μ , 202-1000 μ , and 1000-10,000 μ particulate size fractions. The dry weight, carbon and nitrogen for the 0.45-79 μ fractions are additionally shown integrated per square meter over the various depths of the water column.

Also shown are profiles at each station for the various nutrients and other hydrographic parameters.

ATT-072-001- 4

TEMP (DEG C)	20.19			19.20	18.99	19.69	18.44	17.29	16.52	16.27	6.10
DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL (0/00)	36.659	36.658	36.653	36.704	36.642	36.650	36.740	36.493	36.465	36.471	35.350
J2 (ML/L)	5.25	5.30	5.12		5.21	5.09	4.69	4.95	4.89	4.45	4.77
NO3 (UGAT/L)	1.8	1.3	0.7	1.0	1.3	1.0	4.4	6.1	7.3	10.7	24.9
NO2 (UGAT/L)	0.27	0.24	0.24	0.34	0.34	0.35	0.10	0.11	0.13	0.10	0.10
NH3 (UGAT/L)	0.4	0.4	0.3	0.5	0.4	0.3	0.3	0.4	0.5	0.4	0.4
ΣN (G)	0.00	0.16	0.23	0.54	1.09	2.14	6.25	13.55	23.12	35.70	163.42
PO4 (UGAT/L)	0.43	0.54	0.35	0.34	0.35	0.34	0.45	0.55	0.60	0.81	1.73
ΣPO4 (G)	0.00	0.08	0.14	0.30	0.57	1.11	2.33	3.88	5.66	7.85	27.53
SIO4 (UGAT/L)	1.28	1.18	1.12	2.22	1.08	1.12	1.38	1.74	1.94	6.90	16.29
ΣSIO4 (G)	0.00	0.17	0.33	1.03	2.19	3.73	7.23	11.60	16.75	29.13	191.46

76-202 MICRON

ATT-072-001-006

DW (MG/M3)	NET A	0.376	NET B	0.359	MEAN	0.367
C (MG/M3)	NET A	0.151	NET B	0.133	MEAN	0.142
N (MG/M3)	NET A	0.027	NET B	0.021	MEAN	0.024

202-1000 MICRON

ATT-072-001-005

DW (MG/M3)	NET A	0.764	NET B	0.585	MEAN	0.670
C (MG/M3)	NET A	0.288	NET B	0.249	MEAN	0.269
N (MG/M3)	NET A	0.053	NET B	0.047	MEAN	0.050

ATT-072-001- 8

DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
NO3 (UGAT/L)	0.7	0.8	2.3	1.5	2.3	2.4	3.0	5.0	6.4	7.8	27.7
NO2 (UGAT/L)	0.20	0.21	0.56	0.48	0.52	0.65	0.27	0.19	0.14	0.18	0.14
NH3 (UGAT/L)	0.4	0.4	0.7	0.8	0.8	1.0	0.6	0.6	1.0	0.5	0.5
EN (G)	0.00	0.10	0.23	0.85	1.71	3.95	8.46	13.55	21.82	31.78	160.04
PO4 (UGAT/L)	0.42	0.49	0.34	0.27	0.29	0.23	0.35	0.48	0.50	0.59	1.83
EP04 (G)	0.00	0.07	0.13	0.28	0.49	0.90	1.80	3.08	4.60	6.29	25.05
SI04 (UGAT/L)	2.05	9.21	6.33	2.02	1.16	6.74	1.83	6.81	1.95	2.59	13.39
ES104 (G)	0.00	0.79	1.88	3.63	4.74	10.27	22.27	34.37	46.63	52.99	164.85

0.45-76 MICRON

DW (MG/M3)	313.1	190.0	202.2	242.0	137.1	143.1	88.2	103.4	89.7	94.2	76.0
EDW (MG/M2)	0.0	1257.8	2238.5	5570.6	10309.9	17316.8	28887.8	38472.8	48129.3	57328.8	99898.8
ORG N (MG/M3)	10.7	6.5	6.7	7.3	5.8	4.0	3.8	2.4	1.6	1.1	2.6
EDORGN (MG/M2)	0.0	43.2	76.3	181.6	346.3	593.8	987.8	1299.3	1502.8	1645.3	2607.8
C (MG/M3)	97.8	53.1	60.8	80.4	49.5	37.1	44.6	44.0	31.8	24.6	37.7
EC (MG/M2)	0.0	377.4	662.2	1721.5	3345.5	5511.0	9598.5	14032.0	17823.0	20644.5	36244.5

75-202 MICRON

ATT-072-001-009

DW (MG/M3)	NET A	0.464	NET B	0.417	MEAN	0.441
C (MG/M3)	NET A	0.187	NET B	0.157	MEAN	0.172
N (MG/M3)	NET A	0.034	NET B	0.028	MEAN	0.031

202-1000 MICRON

ATT-072-001-010

DW (MG/M3)	NET A	0.226	NET B	0.889	MEAN	0.557
C (MG/M3)	NET A	0.088	NET B	0.349	MEAN	0.219
N (MG/M3)	NET A	0.019	NET B	0.073	MEAN	0.046

1000-10000 MICRON

ATT-072-001-011

DW (MG/M3)	0.170
C (MG/M3)	0.063
ORG N (MG/M3)	0.014

ATT-072-001- 14

TEMP (DEG C)	19.91	19.91	19.90	19.87	19.81	19.73	18.54	17.66	16.60	16.68	6.45
DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL (0/00)	36.395	36.395	36.340	36.412	36.425	36.398	36.494	36.432	36.373	36.299	35.079
O2 (ML/L)	5.20	5.03	5.22	5.15	5.12	4.95	4.46	4.73	4.73	4.62	4.45
NO3 (UGAT/L)	0.6	0.0	0.4	0.3	0.9	3.9	4.2	5.1	6.1	9.7	24.7
NO2 (UGAT/L)	0.17	0.12	0.14	0.16	0.27	0.45	0.13	0.11	0.14	0.15	0.12
NH3 (UGAT/L)	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2
SiN (G)	0.00	0.05	0.07	0.21	0.53	2.51	8.51	14.81	22.71	33.85	156.82
PO4 (UGAT/L)	0.27	0.16	0.16	0.14	0.13	0.14	0.23	0.29	0.31	0.38	1.30
EP04 (G)	0.00	0.03	0.06	0.13	0.23	0.44	1.02	1.82	2.75	3.82	16.84
SiO4 (UGAT/L)	1.39	2.42	1.17	1.45	1.16	1.06	1.55	1.63	2.08	2.43	14.37
ZSiO4 (G)	0.00	0.27	0.52	1.07	1.98	3.54	7.19	11.64	16.84	23.15	140.75
76-202 MICRON ATT-072-001-015						76-202 MICRON ATT-072-001-018					
DW (MG/M3) NET A	0.406	NET B	0.355	MEAN	0.381	DW (MG/M3) NET A	0.499	NET B	0.496	MEAN	0.498
C (MG/M3) NET A	0.161	NET B	0.140	MEAN	0.151	C (MG/M3) NET A	0.209	NET B	0.210	MEAN	0.210
V (MG/M3) NET A	0.030	NET B	0.026	MEAN	0.028	V (MG/M3) NET A	0.041	NET B	0.041	MEAN	0.041
202-1000 MICRON ATT-072-001-016						202-1000 MICRON ATT-072-001-019					
DW (MG/M3) NET A	1.127	NET B	0.820	MEAN	0.974	DW (MG/M3) NET A	0.925	NET B	0.770	MEAN	0.848
C (MG/M3) NET A	0.439	NET B	0.340	MEAN	0.389	C (MG/M3) NET A	0.383	NET B	0.326	MEAN	0.354
V (MG/M3) NET A	0.096	NET B	0.071	MEAN	0.083	V (MG/M3) NET A	0.081	NET B	0.066	MEAN	0.074
1000-10000 MICRON ATT-072-001-017						1000-10000 MICRON ATT-072-001-020					
DW (MG/M3)	0.079					DW (MG/M3)	1.46				
C (MG/M3)	0.033					C (MG/M3)	0.463				
ORG N (MG/M3)	0.0076					ORG N (MG/M3)	0.107				

ATT-072-001- 22

DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
NO3 (UGAT/L)	1.6	1.7	0.9	1.7	1.1	1.4	3.7	5.8	6.3	9.8	21.7
NO2 (UGAT/L)	0.78	0.51	0.41	0.38	0.48	0.56	0.28	0.32	0.23	0.50	0.42
NH3 (UGAT/L)	1.1	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4
ΣN (G)	0.00	0.22	0.27	0.63	1.25	2.48	6.63	13.23	21.73	33.20	148.83
PO4 (UGAT/L)	0.16	0.13	0.12	0.11	0.11	0.16	0.65	0.64	0.67	0.72	1.43
ΣPO4 (G)	0.00	0.02	0.04	0.10	0.18	0.39	1.65	3.64	5.68	7.83	24.49
SiO4 (UGAT/L)	4.51	3.76	7.12	2.34	2.96	2.46	3.67	2.14	7.26	8.94	13.81
ΣSiO4 (G)	0.00	0.58	1.34	3.33	5.18	8.98	17.56	25.69	38.85	61.53	220.78

0.45-76 MICRON

DW (MG/M3)	167.1	164.0	150.2	208.0	139.7	108.5	66.5	207.4	57.1	101.1	98.0
ΣDW (MG/M2)	0.0	827.8	1613.5	4300.7	8647.1	14854.1	23611.1	37310.6	50538.6	58452.6	108237.5
ORG N (MG/M3)	6.6	6.7	4.9	5.2	2.6	2.3	1.0	1.5	0.7	0.4	0.3
ΣORG N (MG/M2)	0.0	33.4	62.7	139.4	238.0	362.2	533.7	652.7	776.2	835.7	1033.2
C (MG/M3)	55.9	58.4	42.0	47.0	22.5	19.2	18.4	21.2	16.5	20.7	9.6
ΣC (MG/M2)	0.0	285.8	537.0	1205.1	2074.1	3118.8	5006.3	6990.3	8875.3	10739.3	18339.3

76-202 MICRON

ATT-072-001-023

DW (MG/M3) NET A	0.408	NET B	0.530	MEAN	0.469
C (MG/M3) NET A	0.171	NET B	0.212	MEAN	0.191
N (MG/M3) NET A	0.033	NET B	0.041	MEAN	0.037

202-1000 MICRON

ATT-072-001-024

DW (MG/M3) NET A	0.819	NET B	0.827	MEAN	0.823
C (MG/M3) NET A	0.353	NET B	0.343	MEAN	0.348
N (MG/M3) NET A	0.0683	NET B	0.0679	MEAN	0.0681

1000-10000 MICRON

ATT-072-001-025

DW (MG/M3)	1.55
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TEMP (DEG C)	19.87	19.88	19.87		19.93	19.83	18.36	17.89	16.88	17.02	7.15
DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL (0/00)	36.359	36.360	36.365	36.358	36.411	36.376	36.472	36.426	36.379	36.297	35.070
O2 (ML/L)	5.15	5.29	5.22	5.28	5.39	5.23	4.59	4.65	4.67	4.73	4.12
NO3 (UGAT/L)	0.0	0.0	0.0	0.0	0.0	0.6	3.0	4.6	5.9	7.5	26.4
NO2 (UGAT/L)	0.13	0.14	0.14	0.13	0.14	0.42	0.14	0.17	0.17	0.21	0.16
PO4 (UGAT/L)	0.24	0.17	0.15	0.14	0.15	0.17	0.25	0.31	0.34	0.45	1.62
EPO4 (G)	0.00	0.03	0.06	0.12	0.24	0.48	1.14	2.00	3.01	4.24	20.28
SIO4 (UGAT/L)	1.14	1.03	0.93	1.18	0.98	0.99	1.32	1.53	1.78	2.49	13.61
ESIO4 (G)	0.00	0.15	0.29	0.73	1.49	2.87	6.10	10.09	14.73	20.70	133.40

76-202 MICRON ATT-072-001-030

76-202 MICRON ATT-072-001-033

DW (MG/M3) NET A	0.354	NET B	0.449	MEAN	0.401	DW (MG/M3) NET A	0.399	NET B	0.507	MEAN	0.453
C (MG/M3) NET A	0.142	NET B	0.171	MEAN	0.157	C (MG/M3) NET A	0.166	NET B	0.207	MEAN	0.186
N (MG/M3) NET A	0.026	NET B	0.030	MEAN	0.029	N (MG/M3) NET A	0.030	NET B	0.040	MEAN	0.035

202-1000 MICRON ATT-072-001-031

202-1000 MICRON ATT-072-001-034

DW (MG/M3) NET A	1.070	NET B	0.750	MEAN	0.910	DW (MG/M3) NET A	0.951	NET B	1.02	MEAN	0.986
C (MG/M3) NET A	0.406	NET B	0.305	MEAN	0.355	C (MG/M3) NET A	0.413	NET B	0.458	MEAN	0.435
N (MG/M3) NET A	0.084	NET B	0.063	MEAN	0.073	N (MG/M3) NET A	0.085	NET B	0.091	MEAN	0.088

1000-10000 MICRON ATT-072-001-029

1000-10000 MICRON ATT-072-001-032

DW (MG/M3)	0.877	DW (MG/M3)	0.946
C (MG/M3)	0.275	C (MG/M3)	0.323
ORG N (MG/M3)	0.061	ORG N (MG/M3)	0.076

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DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
N03 (UGAT/L)	0.5	0.4	0.2	0.3	0.3	1.4	4.2	4.1	4.4	9.0	24.7
N02 (UGAT/L)	0.20	0.20	0.16	0.17	0.19	0.36	0.17	0.14	0.14	0.14	0.15
P04 (UGAT/L)	0.20	0.17	0.15	0.15	0.15	0.15	0.24	0.25	0.16	0.47	1.51
ΣP04 (G)	0.00	0.03	0.05	0.12	0.24	0.47	1.08	1.84	2.47	3.45	18.79
S104 (UGAT/L)	1.08	1.01	0.92	1.54	0.93	0.87	1.51	1.53	1.81	2.78	13.26
ΣS104 (G)	0.00	0.15	0.28	0.80	1.66	2.92	6.25	10.51	15.19	21.61	133.89

0.45-76 MICRON

DW (MG/M3)	159.7	190.8	122.0	133.7	168.5	29.7	142.0	108.8	42.0	100.5	89.7
ΣDW (MG/M2)	0.0	876.4	1658.5	3576.3	7354.8	12311.8	20897.3	33439.8	40982.3	46110.8	95680.8
ORG N (MG/M3)	3.7	4.0	4.0	4.2	4.2	1.8	0.6	1.2	0.5	1.4	1.0
ΣORG N (MG/M2)	0.0	19.4	39.7	102.0	208.2	362.0	490.0	588.0	677.0	773.0	1378.0
C (MG/M3)	33.8	32.8	33.9	37.6	32.6	17.2	10.5	15.5	14.0	22.8	7.6
ΣC (MG/M2)	0.0	166.7	333.7	870.3	1748.2	2994.9	4387.4	5692.4	7169.4	9010.4	16627.9

76-202 MICRON ATT-072-001-040

DW (MG/M3)	NET A 0.574	NET B 0.411	MEAN 0.492
C (MG/M3)	NET A 0.254	NET B 0.168	MEAN 0.211
N (MG/M3)	NET A 0.046	NET B 0.033	MEAN 0.039

202-1000 MICRON ATT-072-001-041

DW (MG/M3)	NET A 0.824	NET B 1.030	MEAN 0.927
C (MG/M3)	NET A 0.347	NET B 0.450	MEAN 0.399
N (MG/M3)	NET A 0.078	NET B 0.097	MEAN 0.087

1000-10000 MICRON ATT-072-001-042

DW (MG/M3)	1.090
C (MG/M3)	0.409
ORG N (MG/M3)	0.071

ATT-072-001- 45

TEMP (DEG C)	20.05	20.09		20.07	19.47	19.67	18.27	16.34	17.03	16.14	
DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL (0/00)	36.462	36.469	36.464	36.467	36.454	36.454	36.492	36.456	36.355	36.224	35.088
O2 (ML/L)	5.17	5.00	5.10	5.15	5.13	5.05	4.55	4.70	4.63	4.54	4.67
NO3 (UGAT/L)	0.7	0.4	0.1	0.1	0.2	0.8	4.0	5.6	7.7	9.2	24.2
NO2 (UGAT/L)	0.23	0.25	0.19	0.21	0.23	0.50	0.19	0.15	0.19	0.18	0.18
NH3 (UGAT/L)	1.4	1.8	2.6	1.9	2.1	2.2	1.8	1.5	1.4	1.8	1.2
ΣN (G)	0.00	0.18	0.24	0.63	0.98	2.39	7.35	13.38	22.41	34.44	161.01
PO4 (UGAT/L)	0.13	0.13	0.12	0.12	0.12	0.12	0.10	0.11	0.10	0.11	0.39
ΣPO4 (G)	0.00	0.02	0.04	0.10	0.19	0.37	0.72	1.04	1.37	1.69	5.57
SID4 (UGAT/L)	1.47	0.99	0.89	1.13	0.79	0.83	1.42	1.46	1.70	2.33	11.32
ΣSID4 (G)	0.00	0.17	0.30	0.73	1.40	2.53	5.68	9.72	14.14	19.78	115.33

76-202 MICRON

ATT-072-001-047

DW (MG/M3)	NET A	0.477	NET B	0.562	MEAN	0.520
C (MG/M3)	NET A	0.203	NET B	0.224	MEAN	0.213
N (MG/M3)	NET A	0.040	NET B	0.043	MEAN	0.042

202-1000 MICRON

ATT-072-001-048

DW (MG/M3)	NET A	0.927	NET B	0.809	MEAN	0.868
C (MG/M3)	NET A	0.398	NET B	0.333	MEAN	0.366
N (MG/M3)	NET A	0.084	NET B	0.072	MEAN	0.078

1000-10000 MICRON

ATT-072-001-046

DW (MG/M3)	0.504
C (MG/M3)	0.138
ORG N (MG/M3)	0.033

76-202 MICRON

ATT-072-001-050

DW (MG/M3)	NET A	0.833	NET B	0.441	MEAN	0.637
C (MG/M3)	NET A	0.253	NET B	0.182	MEAN	0.217
N (MG/M3)	NET A	0.052	NET B	0.035	MEAN	0.043

1000-10000 MICRON

ATT-072-001-049

DW (MG/M3)	0.968
C (MG/M3)	0.275
ORG N (MG/M3)	0.064

ATT-072-001- 52

TEMP (DEG C)	19.95	19.93	19.91	19.89	19.89	19.70		17.58	16.75	15.34	
DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL (0/00)	36.413	36.414	36.421	36.403	36.415	36.397	36.490	36.441	36.417	36.300	
O2 (ML/L)	5.26	5.21	5.26	5.28	5.26	5.24	4.62	4.70	4.68	4.70	
NO3 (UGAT/L)	0.2	0.2	2.1	0.1	1.2	0.7	3.6	4.9	5.9	7.2	
NO2 (UGAT/L)	0.17	0.18	0.23	0.16	0.22	0.43	0.17	0.17	0.17	0.15	0.08
NH3 (UGAT/L)	1.0	1.1	0.9	1.0	0.8	0.9	0.7	0.5	0.4	0.5	2.0
SiN (G)	0.00	0.10	0.19	0.59	0.97	2.15	6.04	11.61	19.06	28.27	9.83
PO4 (UGAT/L)	0.38	0.34	0.30	0.28	0.27	0.22	0.20	0.23	0.21	0.37	0.27
SiPO4 (G)	0.00	0.06	0.11	0.24	0.45	0.83	1.48	2.15	2.83	3.73	8.69
SiO4 (UGAT/L)	0.66	0.72	0.74	0.64	0.55	0.64	0.97	1.23	1.43	1.70	10.85
ESiO4 (G)	0.00	0.10	0.20	0.49	0.91	1.74	3.99	7.07	10.80	15.18	103.03

76-202 MICRON ATT-072-001-054

DW (MG/M3)	NET A	0.335	NET B	0.288	MEAN	0.311
C (MG/M3)	NET A	0.141	NET B	0.119	MEAN	0.130
N (MG/M3)	NET A	0.026	NET B	0.023	MEAN	0.025

202-1000 MICRON ATT-072-001-055

DW (MG/M3)	NET A	0.814	NET B	0.629	MEAN	0.722
C (MG/M3)	NET A	0.305	NET B	0.257	MEAN	0.281
N (MG/M3)	NET A	0.064	NET B	0.055	MEAN	0.059

1000-10000 MICRON ATT-072-001-053

DW (MG/M3)	0.891
C (MG/M3)	0.244
ORG N (MG/M3)	0.058

76-202 MICRON ATT-072-001-057

DW (MG/M3)	NET A	0.498	NET B	0.482	MEAN	0.490
C (MG/M3)	NET A	0.205	NET B	0.190	MEAN	0.197
N (MG/M3)	NET A	0.041	NET B	0.038	MEAN	0.039

202-1000 MICRON ATT-072-001-058

DW (MG/M3)	NET A	0.728	NET B	0.661	MEAN	0.695
C (MG/M3)	NET A	0.316	NET B	0.279	MEAN	0.297
N (MG/M3)	NET A	0.064	NET B	0.057	MEAN	0.060

1000-10000 MICRON ATT-072-001-056

DW (MG/M3)	0.728
C (MG/M3)	0.316
ORG N (MG/M3)	0.064

ATT-072-001- 60

DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
V03 (UGAT/L)	3.7	3.9	3.5	3.8	4.4	4.2	7.6	8.3	9.7	12.4	26.2
V02 (UGAT/L)	0.22		0.19	0.22	0.26	1.14	0.82	0.74	0.78	0.75	0.73
VH3 (UGAT/L)	1.4		1.3	1.3	1.2	1.3	1.2	1.0	1.2	0.5	0.5
ΣN (G)	0.00	19.17	0.76	1.63	3.27	7.18	17.30	27.99	40.68	55.90	198.18
PD4 (UGAT/L)	0.07		0.11	0.10	0.08	0.08	0.10	0.10	0.17	0.37	1.24
EPD4 (G)	0.00	0.59	0.03	0.08	0.15	0.27	0.55	0.86	1.28	2.11	14.59
SI04 (UGAT/L)	0.65		0.62	0.70	0.63	8.71	9.17	9.04	9.38	10.12	18.29
ΣSI04 (G)	0.00	0.02	0.18	0.45	0.92	7.46	32.49	57.98	83.77	111.07	309.94

0.45-76 MICRON

DW (MG/M3)	136.0	170.5	113.0	121.1	96.5	43.7	0.0	80.5	0.0	73.1	70.2
ΣDW (MG/M2)	0.0	766.4	1475.3	3231.3	5952.7	9459.7	11645.2	15673.7	19702.2	23359.2	59214.2
ORG N (MG/M3)	3.8	3.4	3.1	3.7	3.7	1.2	0.9	1.4	0.7	0.4	0.3
ΣORG N (MG/M2)	0.0	18.1	34.4	96.0	179.9	303.1	409.6	527.6	635.1	692.1	884.6
C (MG/M3)	34.2	29.4	22.2	27.2	43.1	8.4	18.2	17.2	1.3	11.0	10.0
ΣC (MG/M2)	0.0	159.2	288.5	659.5	1538.8	2827.6	4160.1	5932.1	6861.6	7481.6	12739.1

76-202 MICRON ATT-072-001-061

DW (MG/M3)	NET A 0.545	NET B 0.564	MEAN 0.555
C (MG/M3)	NET A 0.234	NET B 0.245	MEAN 0.239
N (MG/M3)	NET A 0.049	NET B 0.051	MEAN 0.049

202-1000 MICRON ATT-072-001-063

DW (MG/M3)	NET A 1.200	NET B 0.910	MEAN 1.055
C (MG/M3)	NET A 0.514	NET B 0.399	MEAN 0.457
N (MG/M3)	NET A 0.113	NET B 0.088	MEAN 0.100

1000-10000 MICRON ATT-072-001-064

DW (MG/M3)	0.892
C (MG/M3)	0.273
ORG N (MG/M3)	0.065

ATT-072-001- 66

TEMP (DEG C)	20.17	20.12	20.15	19.27		19.82	17.81	16.89	17.03	8.85	
DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL (0/00)	36.444	36.445	36.439	36.436	36.441	36.414	36.494	36.436	36.433	36.351	35.168
O2 (ML/L)	5.08	4.96	4.93	5.08	4.99	4.24	4.41	4.59	4.62	4.53	4.36
NO3 (UGAT/L)	0.2	0.6	0.8	0.4	0.3	0.7	3.1	3.6	4.1	4.9	15.5
NO2 (UGAT/L)	0.31	0.30	0.33	0.28	0.33	0.37	0.37	0.35	0.40	0.30	0.31
NH3 (UGAT/L)	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.3	0.2	0.3	0.3
EN (G)	0.00	0.07	0.12	0.35	0.57	1.19	4.45	9.23	14.65	20.97	96.11
PO4 (UGAT/L)	0.27	0.22	0.19	0.18	0.18	0.16	0.24	0.29	0.31	0.38	1.23
IP04 (G)	0.00	0.04	0.07	0.16	0.30	0.56	1.18	2.00	2.93	4.00	16.48
SI04 (UGAT/L)	1.56	1.36	1.58	1.41	1.34	1.27	1.76	2.06	2.26	2.62	12.06
ESI04 (G)	0.00	0.20	0.41	1.04	2.00	3.83	9.07	13.42	19.47	26.30	129.06
76-202 MICRON ATT-072-001-067						76-202 MICRON ATT-072-001-070					
DW (MG/M3) NET A	0.443	NET B	0.509	MEAN	0.476	DW (MG/M3) NET A	0.396	NET B	0.391	MEAN	0.393
C (MG/M3) NET A	0.177	NET B	0.198	MEAN	0.138	C (MG/M3) NET A	0.161	NET B	0.165	MEAN	0.163
N (MG/M3) NET A	0.034	NET B	0.038	MEAN	0.036	N (MG/M3) NET A	0.031	NET B	0.031	MEAN	0.031
202-1000 MICRON ATT-072-001-068						202-1000 MICRON ATT-072-001-071					
DW (MG/M3) NET A	1.028	NET B	1.015	MEAN	1.021	DW (MG/M3) NET A	1.159	NET B	1.169	MEAN	1.164
C (MG/M3) NET A	0.416	NET B	0.409	MEAN	0.412	C (MG/M3) NET A	0.478	NET B	0.500	MEAN	0.489
N (MG/M3) NET A	0.091	NET B	0.088	MEAN	0.090	N (MG/M3) NET A	0.101	NET B	0.106	MEAN	0.103
1000-10000 MICRON ATT-072-001-069						1000-10000 MICRON ATT-072-001-072					
DW (MG/M3)	0.915					DW (MG/M3)	1.258				
C (MG/M3)	0.283					C (MG/M3)	0.364				
ORG N (MG/M3)	0.070					ORG N (MG/M3)	0.092				

ATT-072-001- 74

DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
VJ3 (UGAT/L)	0.3	0.1	0.1	0.3	0.2	0.7	2.1		2.4	3.3	13.5
VJ2 (UGAT/L)		0.31	0.27	0.29	0.27	0.34	0.28		0.30	0.31	0.30
VH3 (UGAT/L)	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.3	0.2	0.2
N (G)	0.00		0.07	0.19	0.38	0.90	3.31	0.25	10.16	13.89	75.73
PD4 (UGAT/L)	0.16	0.13	0.12	0.12	0.13	0.15	0.25		0.37	0.49	1.49
PD4 (G)	0.00	0.02	0.04	0.10	0.19	0.41	1.03	0.01	2.95	4.29	19.63
S104 (UGAT/L)		1.29	1.12	1.26	1.16	1.30	1.70		2.12	2.14	14.10
S104 (G)	0.00	0.00	0.17	0.67	1.52	3.24	7.44	0.00	18.13	24.10	137.78
0.45-76 MICRON											
DW (MG/M3)	94.5	120.8	93.1	91.4	41.4	67.4	37.1	80.0	48.2	64.2	72.5
DW (MG/M2)	0.0	538.5	1073.5	2457.8	4118.3	6839.3	12067.3	17924.3	24338.3	29966.3	64178.8
ORG N (MG/M3)	3.5	4.0	4.6	3.6	5.1	4.8	1.3	1.1	3.2	0.5	1.4
ORG N (MG/M2)	0.0	18.9	40.7	103.1	213.7	465.0	773.5	894.5	1110.5	1299.0	1809.0
C (MG/M3)	34.4	0.0	37.9	39.1	47.9	54.4	15.4	13.0	17.0	10.1	12.5
C (MG/M2)	0.0	86.0	180.7	758.8	1847.9	4407.9	7899.9	9323.4	10825.9	12183.4	17850.9

ATT-072-001- 77

TEMP (DEG C)	19.89	19.89	19.88	19.82		19.74		17.82	16.74	15.82	7.54
DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL (10/00)	36.395	36.401	36.401	36.395	36.412	36.397	36.477	36.450	36.384	36.302	35.096
PH	8.200	8.160	8.165	8.225	8.236	8.250	8.189	8.180	8.154	8.150	7.905
ALK (MEQ/L)	2.539	2.528	2.549	2.559	2.570	2.580	2.580	2.580	2.580	2.570	2.528
NO3 (UGAT/L)	0.1	0.2	0.2	0.3	0.4	0.5	4.3	5.6	7.5	9.1	32.2
NH3 (UGAT/L)	1.4	1.3	1.2	1.4	1.4	1.5	0.8	0.8	0.7	0.4	0.4
N (G)	0.00	0.11	0.12	0.38	0.74	1.63	5.62	12.05	21.22	32.68	180.00
PO4 (UGAT/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94
PO4 (G)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.28

ATT-072-001- 82

TEMP (DEG C)	19.78	19.79	19.74	19.74	19.70	19.66	16.63	16.69	16.37	15.41	5.92
DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL (0/00)	36.403	36.407	36.428	36.381	36.398	36.423	36.471	36.413	36.319	36.082	35.043
O2 (ML/L)	5.18	5.25	5.17	5.24	5.20	5.25	4.56	4.64	4.56	4.22	4.81
PH	8.040	8.126	8.194	8.224	8.212	8.187	8.153	8.139	8.116	8.056	7.851
ALK (MEQ/L)	2.559	2.048	2.528	2.538	2.528	2.549	2.538	2.528	2.528	2.506	2.458
NO3 (UGAT/L)	0.3	0.9	0.9	1.0	1.1	1.4	5.2	7.4	9.2	13.2	26.5
NO2 (UGAT/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.22
NH3 (UGAT/L)	0.8	0.7	0.8	0.9	0.8	0.6	0.3	0.6	0.5	0.6	0.6
ΣN (G)	0.00	0.10	0.16	0.51	1.03	2.13	6.97	15.82	27.61	43.33	187.10
PO4 (UGAT/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.21	0.34	0.48	1.24
ΣPO4 (G)	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.70	1.55	2.82	16.15
SIO4 (UGAT/L)	0.07	0.11	0.06	0.06	0.05	0.03	0.60	0.93	1.44	2.82	12.18
ΣSIO4 (G)	0.00	0.01	0.02	0.05	0.09	0.14	1.03	3.17	6.49	12.45	117.45

76-202 MICRON ATT-072-001-083

DW (MG/M3)	NET A 0.549	NET B 0.605	MEAN 0.577
C (MG/M3)	NET A 0.215	NET B 0.243	MEAN 0.229
N (MG/M3)	NET A 0.042	NET B 0.048	MEAN 0.045

202-1000 MICRON ATT-072-001-084

DW (MG/M3)	NET A 1.025	NET B 0.556	MEAN 0.790
C (MG/M3)	NET A 0.435	NET B 0.225	MEAN 0.330
N (MG/M3)	NET A 0.093	NET B 0.049	MEAN 0.071

1000-10000 MICRON ATT-072-001-085

DW (MG/M3)	2.303
C (MG/M3)	0.693
ORG N (MG/M3)	0.179

76-202 MICRON ATT-072-001-086

DW (MG/M3)	NET A 0.613	NET B 0.687	MEAN 0.650
C (MG/M3)	NET A 0.250	NET B 0.262	MEAN 0.256
N (MG/M3)	NET A 0.051	NET B 0.053	MEAN 0.052

202-1000 MICRON ATT-072-001-037

DW (MG/M3)	NET A 1.229	NET B 1.045	MEAN 1.137
C (MG/M3)	NET A 0.510	NET B 0.401	MEAN 0.455
N (MG/M3)	NET A 0.110	NET B 0.089	MEAN 0.099

1000-10000 MICRON ATT-072-001-089

DW (MG/M3)	1.126
C (MG/M3)	0.364
ORG N (MG/M3)	0.092

ATT-072-001- 91

DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
NO3 (UGAT/L)	5.0	5.5	5.1	5.3	5.2	5.7	9.2	9.9	11.4	12.3	27.8
NO2 (UGAT/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
NH3 (UGAT/L)	0.8	0.7	0.9	1.0	1.0	0.8	0.4	0.3	0.3	0.0	0.1
N (G)	0.00	0.42	0.80	2.05	4.05	8.20	18.96	32.11	47.03	63.47	204.93
PO4 (UGAT/L)	0.58	0.53	0.48	0.51	0.37	0.44	0.44	0.12	0.50	0.46	1.42
PO4 (G)	0.00	0.09	0.16	0.39	0.74	1.36	2.73	3.60	4.56	6.04	20.61
SIO4 (UGAT/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.51	0.75	1.13	11.36
SIO4 (G)	0.00	0.00	0.00	0.00	0.00	0.00	0.57	1.86	3.63	6.26	93.69
0.45-76 MICRON											
DW (MG/M3)	109.1	129.1	67.1	94.8	107.4	78.8	49.7	47.7	35.1	34.8	47.7
DW (MG/M2)	0.0	595.7	1086.4	2301.3	4829.7	9486.4	15914.4	20785.4	24927.9	28427.4	49067.4
ORG N (MG/M3)	5.1	3.3	3.3	3.4	3.4	5.1	1.0	1.7	0.6	0.8	0.3
ORG N (MG/M2)	0.0	21.2	37.8	88.4	173.8	387.0	695.0	835.5	957.0	1032.0	1322.0
C (MG/M3)	35.3	29.0	31.2	28.6	35.8	31.1	14.6	12.8	8.4	10.3	9.3
C (MG/M2)	0.0	160.8	311.3	760.5	1567.4	3243.7	5536.7	6911.7	7973.7	8912.2	13842.2

ATT-072-001-104

TEMP	(DEG C)	20.12		20.10		20.11	20.08	18.14	17.61	16.40	15.64	6.23
DEPTH	(M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL	(O/00)	36.411	36.408	36.401	36.406	36.403	36.404	36.441	36.390	36.304	36.119	35.029
O2	(ML/L)	5.09	5.12	5.06	5.17	5.18	5.11	4.45	4.29	4.63	4.72	4.58
PH		8.294	8.288	8.282	8.240	8.214	8.288	8.205	8.215	8.120	8.100	7.925
ALK	(MEQ/L)	2.588	2.580	2.588	2.570	2.580	2.607	2.607	2.607	2.559	2.599	2.559
NO3	(UGAT/L)	0.0	0.0	0.0	0.0	0.0	0.0	3.8	5.4	6.7	10.9	23.8
NO2	(UGAT/L)	0.02	0.03	0.00	0.02	0.01	0.02	0.02	0.04	0.03	0.01	0.71
PO4	(UGAT/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.15	0.20	0.40	1.12
EP04	(G)	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.54	1.08	2.01	13.79
SI04	(UGAT/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.87	1.31	2.55	12.47
ESI04	(G)	0.00	0.00	0.00	0.00	0.00	0.00	0.69	2.59	5.64	11.05	116.19

76-202 MICRON ATT-072-001-106

DW	(MG/M3)	NET A	0.586	NET B	0.654	MEAN	0.620
C	(MG/M3)	NET A	0.248	NET B	0.263	MEAN	0.256
N	(MG/M3)	NET A	0.052	NET B	0.055	MEAN	0.053

202-1000 MICRON ATT-072-001-107

DW	(MG/M3)	NET A	1.163	NET B	1.026	MEAN	1.094
C	(MG/M3)	NET A	0.473	NET B	0.424	MEAN	0.449
N	(MG/M3)	NET A	0.104	NET B	0.097	MEAN	0.101

1000-10000 MICRON ATT-072-001-108

DW	(MG/M3)	0.838
C	(MG/M3)	0.257
ORG N	(MG/M3)	0.064

ATT-072-001-116

DEPTH (M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
SAL (0/00)	36.381	36.377	36.374	36.367	36.364	36.365	36.430	36.379	36.325	36.253	35.039
O2 (ML/L)	5.14	5.12	5.12	5.18	5.17	5.17	4.50	4.58	4.56	4.60	4.02
PH	8.246	8.282	8.299	8.300	8.300	8.294	8.230	8.220	8.210	8.175	7.930
ALK (MEQ/L)	2.599	2.607	2.607	2.616	2.616	2.624	2.624	2.624	2.624		
NO3 (UGAT/L)	0.2	0.0	0.1	0.1	0.0	0.1	2.4	4.1	6.2	7.0	25.5
PO4 (UGAT/L)	0.01	0.00	0.00	0.00	0.00	0.04	0.12	0.20	0.26	0.26	1.27
EP04 (G)	0.00	0.00	0.00	0.00	0.00	0.03	0.28	0.78	1.49	2.29	14.15
SIO4 (UGAT/L)	0.33	0.49	0.15	0.05	0.00	2.64	2.76	3.02	3.52	3.95	15.26
ESIO4 (G)	0.00	0.06	0.10	0.14	0.16	2.01	9.57	17.66	26.82	37.28	171.75

76-202 MICRON ATT-072-001-117

DW (MG/M3)	NET A 0.510	NET B 0.428	MEAN 0.469
C (MG/M3)	NET A 0.216	NET B 0.188	MEAN 0.202
N (MG/M3)	NET A 0.045	NET B 0.041	MEAN 0.043

202-1000 MICRON ATT-072-001-118

DW (MG/M3)	NET A 1.270	NET B 1.014	MEAN 1.142
C (MG/M3)	NET A 0.538	NET B 0.405	MEAN 0.471
N (MG/M3)	NET A 0.122	NET B 0.093	MEAN 0.108

1000-10000 MICRON ATT-072-001-119

DW (MG/M3)	0.649
C (MG/M3)	0.242
ORG. N (MG/M3)	0.045

ATT-072-001-126

TEMP	(DEG C)	19.98		20.00	20.02	20.09	19.91	18.87	18.07	16.74	16.89	7.37
DEPTH	(M)	0.	5.	10.	25.	50.	100.	200.	300.	400.	500.	1000.
NO3	(UGAT/L)	0.1	0.0	0.0	0.0	0.0	0.4	2.1	3.7	6.0	7.1	27.5
PO4	(UGAT/L)	0.08	0.04	0.05	0.05	0.12	0.00	0.20	0.21	0.38	0.43	1.54
ΣPO4	(G)	0.00	0.01	0.02	0.04	0.11	0.20	0.51	1.14	2.06	3.31	18.58
SIO4	(UGAT/L)	2.41	2.13	2.30	2.06	2.03	2.34	2.33	2.92	1.20	1.68	13.11
ΣSIO4	(G)	0.00	0.32	0.63	1.54	2.97	6.03	12.57	19.92	25.69	29.72	133.25

0.45-76 MICRON

DW (MG/M3)	100.0	131.4	126.5	87.7	118.2	140.0	58.8	104.2	0.0	46.5	63.1
ΣDW (MG/M2)	0.0	578.5	1223.5	2830.6	5405.5	11862.5	21805.0	29961.4	35175.4	37503.9	64931.4
ORG N (MG/M3)	3.5	3.2	2.2	2.2	2.8	1.5	1.4	2.1	0.6	0.5	0.6
ΣORGN (MG/M2)	0.0	16.7	30.3	63.9	127.8	238.5	389.5	572.0	713.5	772.0	1052.0
C (MG/M3)	39.1	26.4	21.5	21.6	26.0	18.3	18.5	16.0	4.6	15.1	11.0
ΣC (MG/M2)	0.0	164.0	284.0	607.9	1203.8	2313.0	4155.5	5885.5	6920.5	7908.0	14438.0

76-202 MICRON ATT-072-001-127

DW (MG/M3)	NET A 0.584	NET B 0.499	MEAN 0.541
C (MG/M3)	NET A 0.251	NET B 0.223	MEAN 0.237
N (MG/M3)	NET A 0.055	NET B 0.048	MEAN 0.051

202-1000 MICRON ATT-072-001-129

DW (MG/M3)	NET A 1.268	NET B 0.927	MEAN 1.097
C (MG/M3)	NET A 0.534	NET B 0.380	MEAN 0.457
N (MG/M3)	NET A 0.121	NET B 0.087	MEAN 0.104

1000-10000 MICRON ATT-072-001-130

DW (MG/M3)	1.014
C (MG/M3)	0.310
ORG N (MG/M3)	0.078

ATT 072 001 4 3

ATT 072 001 4 4

ATT 072 001 4 -7

ATT 072 001 4 8

ATT 072 001- 4 -9

ATT-072 001 4-11

ATT-072-001- 4-12

ATT 072-001 4 -1

ATT-072-001- B -7

ATT-072-001- B -8

ATT-072-001- B -9

ATT-072-001- B-11

ATT-072-001- 8-12

UG-AT-SIO4-SI/L

ATT-072-001-14-3

ATT-072-001-14-4

ATT-072-001-14-7

ATT-072-001-14-E

ATT 072-001- 14 -9

ATT 072-001- 14-11

ATT 072-001- 14-12

ATT 072-001 14- 1

ATT-072-001- 22 -7

ATT-072-001 22 -8

ATT-072-001- 22 -9

ATT-072-001- 22

ATT-072-001- 22-12

UG-AT-SIO4-SI/L

ATT-072-001- 28 -3

ATT-072-001- 28 -4

ATT-072-001- 28 -7

ATT-072-001- 28

P.P.T.

M.L.

UG-AT-N03-N/L

UG-AT-N02-N/L

ATT-072-001- 28-11

ATT-072-001- 28-12

ATT-072 001 28 -1

UG-AT-P04-P/L

UG-AT-S104-S1/L

DEG C

ATT-072-001- 37 -7

ATT-072-001- 37 -8

ATT-072-001- 37-11

ATT-072-001- 37-12

ATT-072-001- 45 -3

ATT-072-001- 45 -4

ATT-072-001- 45 -7

ATT-072-0

ATT-072-001- 45 -9

ATT-072-001- 45-11

ATT-072-001- 45-12

ATT 072-001 45 -1

LG-AT-NH3-N/L

LG-AT-PO4-P/L

LG-AT-SIO4-S/L

DEG C.

ATT-072-001- 52 -3

ATT-072-001- 52 -4

ATT-072-001- 52 -7

ATT-072-0

ATT-072-001- 52 -9

ATT-072-001- 52-11

ATT-072-001- 52-12

ATT 072 001- 52 1

LG-AT-N-B-N/L

LG-AT-PO4-P/L

LG-AT-SIO4-SI/L

DEG C

ATT-072-001- 60 -7

ATT-072-001- 60 -8

ATT-072-001- 60 -9

ATT-072-001- 60-11

UG-AT-N03-N/L

UG-AT-N02-N/L

UG-AT-N03-N/L

UG-AT-P04-P/L

ATT-072-001- 60-12

UG-AT-SIO4-SI/L

ATT-072-001- 66 -3

ATT-072-001- 66 -4

ATT-072-001- 66 -7

ATT-072-001- 66 -8

ATT-072-001- 66 -9

ATT-072-001- 66-11

ATT-072-001- 66-12

ATT 072 001 66 1

ATT-072-001- 74 -7

ATT-072-001- 74 -8

ATT-072-001- 74 -9

ATT-072-001- 74-11

ATT-072-001- 74-12

ATT-072-001- 77 -3

ATT-072-001- 77 -4

ATT-072-001- 77 -5

ATT-072-001-

ATT-072-001- 77 -7

ATT-072-001- 77 -9

ATT-072-001- 77-11

ATT-072-001- 77 -1

UG-AT-N03-N/L

UG-AT-N08-N/L

UG-AT-P04-P/L

DEG C

ATT-072-001- 82 -3

ATT-072-001- 82 -4

ATT-072-001- 82 -5

ATT-072-001

ATT-072-001- 82 -7

ATT-072-001- 82 -8

ATT-072-001- 82 -9

ATT-072-001- 82-1

UG-AT-N03-N/L

UG-AT-N02-N/L

UG-AT-N03-N/L

UG-AT-P04-P/L

ATT-072-001- 82-12

ATT 072 001 82 1

ATT-072-001-91-2

ATT-072-001-91-8

ATT-072-001-91-9

ATT-072-001

ATT-072-001- 91-12

ATT-072-001-104 -3

ATT-072-001-104 -4

ATT-072-001-104 -5

ATT-072-001-104 -6

ATT-072-001-104 -7

ATT-072-001-104 -8

ATT-072-001-104-11

ATT-072-001-104-12

ATT-072-001 104 -1

ATT-072-001-116 -3

ATT-072-001-116 -4

ATT-072-001-116 -5

ATT-072-001-116 -6

ATT-072-001-116-7

ATT-072-001-116-11

ATT-072-001-116-12

ATT-072-001-126 -7

ATT-072-001-126-11

ATT-072-001-126-12

ATT-072-001 126 -1

B. Phytoplankton Ecology

1. Standing Stocks

The profiles of dry weight, carbon and nitrogen versus depth, for the most part, are fairly consistent with one another—maxima and minima and longer-term trends often occur simultaneously for these different parameters (see Table 2 and Figs. 7-13). Although the greatest concentration of dry weight, carbon, and nitrogen varied for particular days, the maximum concentration of particulate matter (based on all 3 criteria of dry weight, carbon, and nitrogen) was always in the upper 50 m of the water column. Below 50 m there was, with some exception, a general decrease in concentration with depth.

The dry weight, carbon, and nitrogen values for the 0.45-79 μ particulate fraction, integrated over the upper 100 m of the water column, show a very similar change in carbon and nitrogen values with time, but a peculiar lack of similarity between these values and the dry weight (Table 3; Fig. 14). Both carbon and nitrogen decline rather erratically from 1/23 to 1/30; they then increase in the interval 1/30 to 2/2 followed by a rather steady decline from 2/2 to 2/13. Dry weight, however, shows a steady decline from 1/23 to 2/2, followed by a steady increase from 2/2 to 2/13. This lack of parallelism is unexplained, but suggests that a good portion of the dry weight is detrital and is subject to different environmental influences in the water column than the living fraction.

This very obvious parallelism between carbon and nitrogen

TABLE 2: WATER SAMPLES: 0.45-79 μ fraction

Dry Weight, Nitrogen and Carbon at various depths and sampling dates

Date	1/23			1/25			1/27			1/30			2/2			2/7			2/13		
Depth (m)	Dry Wt.	N	C	Dry Wt.	N	C	Dry Wt.	N	C	Dry Wt.	N	C	Dry Wt.	N	C	Dry Wt.	N	C	Dry Wt.	N	C
	(mg/m ³)			(mg/m ³)			(mg/m ³)			(mg/m ³)			(mg/m ³)			(mg/m ³)			(mg/m ³)		
0 m	313	10.71	97.9	167	6.60	55.9	160	3.75	33.8	136	3.83	34.2	95	3.52	34.4	109	5.18	35.3	100	3.50	39.
5	190	6.57	53.1	164	6.78	58.4	191	4.03	32.9	171	3.43	29.5	121	4.07	--	129	3.32	29.0	131	3.20	26.
10	202	6.70	60.8	150	4.95	42.1	122	4.08	33.9	113	3.10	22.2	93	4.65	37.9	67	3.32	31.2	127	2.25	21.
25	242	7.33	80.4	208	5.27	47.0	134	4.23	37.6	121	3.78	27.2	91	3.67	39.2	95	3.43	28.7	88	2.23	21.
50	137	5.85	49.5	140	2.62	22.5	169	4.27	32.6	97	3.73	43.1	41	5.18	48.0	107	3.40	35.9	118	2.88	26.
100	143	4.05	37.1	109	2.35	19.3	30	1.88	17.3	44	1.20	8.4	67	4.87	54.4	79	5.13	31.2	140	1.55	18.
200	88	3.83	44.7	67	1.08	18.5	142	.68	10.6	0	.93	18.2	37	1.30	15.4	50	1.03	14.7	59	1.47	18.
300	103	2.40	44.0	207	1.50	21.2	109	1.28	15.5	81	1.43	17.2	80	1.12	13.1	48	1.78	12.8	104	2.18	16.
400	90	1.67	31.8	57	.77	16.5	42	.50	14.0	0	.72	1.4	48	3.20	17.0	35	.65	8.4	0	.65	4.
500	94	1.18	24.6	101	.42	20.8	101	1.42	22.8	73	.42	11.0	64	—	57 10.2	35	.85	10.4	46	.52	15.
1,000	76	2.67	37.8	98	.37	9.6	90	1.00	7.7	70	.35	10.0	73	1.47	12.5	48	.31	9.4	63	.60	11.

ATT-072-001- B 21

ATT-072 001 B 22

ATT 072 001 B 23

FIGURE 7

ATT-072-001-22-21 ATT-072-001-22-22 ATT-072-001-22-23

FIGURE 8

ATT-072-001- 37-21

ATT-072-001- 37-22

ATT-072-001- 37-23

FIGURE 9

ATT-072-001- 60-21

ATT-072-001- 60-22

ATT-072-001- 60-23

FIGURE 10

ATT-072-001- 74-21

ATT-072-001- 74-22

ATT-072-001- 74-23

FIGURE 11

ATT-072-001- 91-21

ATT-072-001- 91-22

ATT-072-001- 91-23

FIGURE 12

ATT-072-001-126-21

ATT-072-001-126-22

ATT-072-001-126-23

FIGURE 13

TABLE 3

INTEGRATED DRY WEIGHT, NITROGEN AND CARBON VALUES OF 0.45-79 μ
 PARTICULATE FRACTION FOR A WATER COLUMN 1 METER SQUARE
 BY 100 & 1000 METERS DEEP

Date	Height of Water Column	Dry Wt. (g/m ²)	N (g/m ²)	C (g/m ²)
1/23	100 m	17.3	.59	5.51
	1,000 m	99.9	2.61	36.24
1/25	100 m	14.9	.36	3.12
	1,000 m	97.4	1.03	18.34
1/27	100 m	12.3	.36	2.99
	1,000 m	95.7	1.38	16.63
1/30	100 m	9.46	.30	2.83
	1,000 m	59.2	.88	12.74
2/2	100 m	6.84	.47	4.59
	1,000 m	64.2	1.07	18.03
2/7	100 m	9.49	.39	3.24
	1,000 m	49.1	1.32	13.84
2/13	100 m	11.9	.24	2.31
	1,000 m	64.9	1.05	14.44

Dry Wt.
g/m²

FIGURE 14

Integrated Dry Wt., C, N of the 0.45-76 μ fraction
for a water column 1m² by 100 meters deep
as a function of time (sampling dates)

and the lack of parallelism with respect to dry weight, within the 100 m water column may also result in part from the depth to which the water column was integrated.

2. Taxonomy

Relative frequencies of different phytoplankters were compared at specific stations and depths for trends or noticeable changes over the 3-week sampling period. However, the loss of the glutaraldehyde-preserved samples (see section II,B,2,b; p. 11) limited our taxonomy to major group identification of the phytoplankton fraction smaller than 20μ .

Only one organism, a diatom less than 5μ in size, appeared to show any consistent change with time. We list this diatom as two separate species in Table 4 (diatom X and diatom Y, shown in photographs 1, 2 & 3, but it is believed more likely that these are the same species of diatom with one being more flattened than the other. Identification of these organisms by experts in phytoplankton taxonomy is underway. The combined totals of diatom X and Y are shown on the graph (Figure 15) illustrating the relative abundance of the variable diatom vs. depth. As can be seen, samples from January 23 (Day 2) show this organism (or combination of two organisms) to be about five times more abundant (in the upper water column) than it was on February 2 (Day 12) and to be about ten times more abundant than found on February 13 (Day 23). In addition, the 10-m depths, where counts were made on the additional sampling days, show a consistent decline of this diatom with time. Such a result suggests the decline or end of a bloom for this particular diatom; all other organisms in the $0.45\text{--}20\mu$ fraction

TABLE 3
RELATIVE ABUNDANCE OF THE MAJOR GROUPS OF ORGANISMS
in the 0.45-20 μ fraction for 3 separate days

	meters	0	5	10	25	50	100	200	300	500	1000
1/23											
coccolithophores	0	0	0	11	0	3	0	0	-	-	-
diatom x	95	128	132	148	184	47	7	5	-	-	-
diatom y	30	72	84	70	88	62	7	0	-	-	-
all other diatoms	45	86	68	77	124	90	78	60	-	-	-
star	75	82	124	115	192	84	7	0	-	-	-
pollen	520	260	812	196	148	106	193	95	-	-	-
bacteria	-	-	-	-	-	41	150	1810	-	-	-
unknown origin	215	84	48	89	108	103	107	40	-	-	-
2/2											
coccolithophores	0	4	3	3	3	6	0	0	0	0	0
diatom x	21	15	21	15	12	12	0	6	0	0	0
diatom y	7	19	18	15	22	3	0	0	0	0	0
all other diatoms	48	80	60	36	59	62	13	36	29	0	0
star	72	73	55	90	97	31	0	0	0	0	0
pollen	96	112	55	61	44	44	20	20	12	32	32
bacteria	45	42	70	9	22	-	13	73	6	0	0
unknown origin	130	165	139	100	90	62	33	43	17	35	35
2/13											
coccolithophores	0	3	7	0	0	0	0	0	0	0	0
diatom x	15	3	4	11	3	6	0	0	0	0	0
diatom y	0	6	0	4	3	0	0	0	0	0	0
all other diatoms	20	22	26	24	39	21	16	26	25	14	14
star	69	47	107	93	77	33	6	0	0	0	0
pollen	27	60	133	13	39	27	63	40	23	22	22
bacteria	-	16	11	13	0	6	50	50	6	0	0
unknown origin	112	43	111	63	75	48	73	52	46	28	28

FIGURE 15

Relative abundance of a single diatom as a function of depth for 3 different sampling dates. (Data for four additional dates are also shown at the 10 meter depth in the form of points.)

show a relatively constant population over this period. This diatom remains unidentified but it may be the "small unidentified centric diatom" observed by others to bloom off of Bermuda (Hulbert, Ryther and Guillard, 1960).

Coccolithophores have been reported to be the dominant form of phytoplankton in these waters (Hulbert, Ryther & Guillard, 1960). We found them to be almost totally absent, although our collecting procedures were designed to keep coccolithophores intact. Moreover, the several coccolithophores which were observed appeared in good condition—excluding the possibility of loss in our sampling procedure.

Flagellates were generally unrecognizable after our collection and electron microscope preparation techniques. Considerable numbers of possible flagellates were observed, but positive identification was impossible, and if present, most were therefore classified as unknown organisms.

A "star"-shaped organism (see photograph 4) was observed in considerable numbers throughout these samples. This organism consisted of 5 long, very thin spines which radiate outward forming a large star, sometimes 50μ in diameter. In addition, the 5 spines join together in the center of the array and overlap—forming another small hollow star-shape within the larger "star". The basic shape of this organism is similar to a Discoaster but was not identified as such by David Erickson (Erickson, Ewing and Wollin, 1963).

Variable amounts of bacteria and pollen were also identified within the water column.

PHOTOGRAPH 1

DIATOM "X"

MAGNIFICATION ~24,000

PHOTOGRAPH 2

DIATOM "X" MAGNIFICATION $\sim 18,000$

PHOTOGRAPH 3

DIATOM "Y"

MAGNIFICATION $\sim 16,000$

PHOTOGRAPH 4

"STAR"

MAGNIFICATION ~16,000

C. Zooplankton Ecology

1. Dry Weight, Carbon and Nitrogen Content

The dry weight, carbon, and nitrogen in milligrams per cubic meter (mg/m^3) were determined for all samples in the three zooplankton size fractions (see section II,C,2,a). These data are presented on the "Zooplankton Summary Data Forms."

After determination of standard deviation (SD) and rejection of non-representative samples (see section E,1,b and Appendix II), the standing stocks for each size fraction were graphed vs. time. Double samples and replicate samples taken on the same day were averaged.

(a) Dry Weight, Carbon and Nitrogen in the 79-202 μ Size Fraction

Figure 16, the dry weight, carbon, and nitrogen content of the 79-202 μ size fraction, indicates that dry weight, carbon and nitrogen changed in approximately the same ratio. The largest observed daily change in dry weight was a decrease of $175 \text{ mg}/\text{m}^2/1000\text{m}$ from 1/28-29, and the range over the 23-day sampling period was $365 \text{ mg}/\text{m}^2/1000\text{m}$ to $625 \text{ mg}/\text{m}^2/1000\text{m}$. The largest daily change in carbon was an increase of $75 \text{ mg}/\text{m}^2/1000\text{m}$ from 1/29-30 and the range was $140\text{-}230 \text{ mg}/\text{m}^2/1000\text{m}$. The largest daily change in nitrogen was an increase of $18 \text{ mg}/\text{m}^2/1000\text{m}$ from 1/29-30, and the range was $24\text{-}53 \text{ mg}/\text{m}^2/1000\text{m}$. There appeared to be a general increase in all three parameters with time (see section E,2,a).

FIGURE 16:

DRY WEIGHT, CARBON, NITROGEN AND NUMBERS OF ORGANISMS IN THE 79-202 μ SIZE FRACTION

Comparisons with the data of others cannot be made for the 79-202 μ size fraction because no other estimates of zooplankton standing stocks in the Bermuda area in the literature included the <202 μ organisms.

(b) Dry Weight, Carbon, and Nitrogen in the
202-1000 μ Size Fraction

Figure 17, the DW, C, N content of the 202-1000 μ size fraction, shows that dry weight, carbon and nitrogen changed from day-to-day in approximately the same ratio. The greatest daily change in dry weight was an increase of 340 mg/m²/1000m; for carbon, an increase of 165 mg/m²/1000m; and for nitrogen, an increase of 40 mg/m²/1000m. These changes occurred on the same day (January 29-30, 1972) as the greatest changes in the 79-202 μ standing stocks (except the 79-202 μ dry weight, which decreased on January 28-29). The dry weight ranged from 675-1140 mg/m²/1000m; the carbon from 270-470 mg/m²/1000m, and the nitrogen from 50-98 mg/m²/1000m over the 23-day sampling period. There appeared to be a general increase in all three standing stocks with time (see section E,2,a).

Rough comparisons can be made with the data of Menzel and Ryther (1961) and Beers (1966). However, as both studies used a 366 μ mesh net, sampled to 500 m, and did not separate their catches into size fractions, comparisons will be deferred until the 1000-10,000 μ standing stock data has been presented and combined with the 202-1000 μ standing stocks.

FIGURE 17:

DRY WEIGHT, CARBON, NITROGEN AND NUMBERS OF ORGANISMS IN THE 202-1000 μ SIZE FRACTION

(c) Dry Weight, Carbon and Nitrogen in the
1000-10,000 μ Size Fraction

Figure 18, the standing stocks of the 1000-10,000 μ size fractions shows that dry weight, carbon and nitrogen changed from day-to-day in approximately the same ratio. The greatest daily change in dry weight was an increase of 780 mg/m²/1000m from 1/24-25; a decrease of 200 mg/m²/1000m for carbon from 1/27-28; and for nitrogen, an increase of 34 mg/m²/1000m from 1/12-13. The dry weight ranged from 670-1715 mg/m²/1000m; the carbon from 210-530 mg/m²/1000m; and the nitrogen from 48-135 mg/m²/1000m over the 21-day sampling period. It was uncertain whether or not there was a trend in the 1000-10,000 μ standing stocks (see section E,2,a).

Table shows the average standing stocks for each day, the mean standing stocks, the combined mean standing stocks of the 202-1000 μ and 1000-10,000 μ size fractions, and the combined standing stocks corrected for depth and mesh size for comparison with the data of Menzel and Ryther (1961) and Beers (1966).

Mean dry weight in late January over three years was 1.25 mg/m³ (Menzel and Ryther, 1961) in the Sargasso Sea off Bermuda, and nitrogen, calculated as the mean of January and February from the data of Menzel and Ryther (1961) and Beers (1966) was .130 mg/m³. Our data, corrected for depth and mesh differences, were 1.17 mgDW/m³ and .0937 mgN/m³.

2. Abundance and Taxonomy

In addition to rough estimates of abundance and taxonomic breakdown from the fresh sorting procedure, additional

FIGURE 18:

DRY WEIGHT, CARBON AND NITROGEN IN THE

1000-10,000 μ SIZE FRACTION

TABLE 5

MEAN DRY WEIGHT, CARBON, AND NITROGEN STANDING STOCKS
(mg/m³)

	<u>79-202μ</u>	
$\bar{X}_{DW}$		.4891
$\bar{X}_C$		.2024
$\bar{X}_N$		.0396

	<u>202-1000μ</u>	
$\bar{X}_{DW}$		.9466
$\bar{X}_C$		.3944
$\bar{X}_N$		.0849

	<u>1000-10,000μ</u>	
$\bar{X}_{DW}$		1.0024
$\bar{X}_C$		.3073
$\bar{X}_N$		.0711

Combined 202-1000μ & 1000-10,000μ

$\bar{X}_{DW}$	1.9490
$\bar{X}_C$	.7017
$\bar{X}_N$	.1560

Corrected Combined 202-1000μ & 1000-10,000μ*

$\bar{X}_{DW}$	1.1700
$\bar{X}_C$	.4210
$\bar{X}_N$	.0937

* See text: -20% for mesh; -40% for depth.

counts on selected samples were made using more sophisticated techniques (see section II,C,2,a).

The 1000-10,000 μ and 202-1000 μ samples were selected so as to fill in the time gaps between the fresh sort estimates. The results of the 202-1000 μ counts are the means of double samples. The 79-202 μ samples were selected after the dry weight data were available. The 79-202 μ samples from the early part of the cruise, when they were taken daily, and which most clearly approached the mean dry weight for each day were counted. No duplicates of this size fraction were counted.

(a) 79-202 μ Size Fraction

Figure 16 shows the total numbers of organisms/m³ and copepods/m³ vs. time. It is obvious that changes in numbers did not correspond well with changes in dry weight, carbon or nitrogen standing stocks. Changes in total numbers were due primarily to changes in the copepod population, which, in this size fraction was composed primarily of nauplii, copepodites, and small adults. The greatest daily change was over 100 organisms/m³ on 1/25-26, and, in actuality, may have been larger. The data of Beers and Stewart (1969) indicated that the majority of the microzooplankters (organisms <202 μ) are found in the euphotic zone, and as our tows covered a 1000m water column, the resulting abundance data will be underestimates of the concentration of the organisms in the euphotic zone.

Other major groups present at <100 organisms/m³, in order of abundance, were eggs, radiolaria, foraminifera, dinoflagellates, tintinnids, ostracods, and pteropods.

As mentioned previously, there have been no comparable studies of the standing stock of this size fraction. However, a study of the microzooplankton of the California Current (Beers and Stewart, 1969) found the same major groups that were present in the Bermuda area.

(b) 202-1000 μ Size Fraction

Figure 17 shows the total number of organisms per cubic meter and the number of copepods per cubic meter vs. time. The fresh sorting data have not been included in this graph as the results of comparative counts of the same station did not agree very closely.

The numbers/ m^3 correspond more closely with dry weight, carbon, and nitrogen content in this size fraction than did the same comparison in the 79-202 μ size fraction. Changes in the total numbers were primarily a reflection of changes in the numbers of copepods. The greatest daily change was an increase of almost 70 copepods/ m^3 on January 29-30, and total organisms/ m^3 ranged from 57-145.

Numerical abundances are, as in the 79-202 μ fraction, low because the 1000m tows did not take into account vertical distribution. Comparisons with the data of Deevey and Brookes (1971) are possible, however, as these workers provide data for the entire water column broken into 500m intervals.

Samples taken toward the end of January, 1969, by Deevey and Brookes contained approximately 110 copepods/ m^3 for the upper 500 meters and approximately 18 copepods/ m^3 for the 500-1000m interval. The average for a 1000m water column would have been 64/ m^3 , which falls within the range of our abundance

figures. It should be noted that our greatest daily change, 70 organisms/m³ on 1/29-30, exceeds the monthly changes observed by Deevey and Brookes with the exception of the fall bloom of 1968.

Other major groups present at generally < 5 organisms/m³, in approximate order of abundance, were ostracods, foraminifera, eggs, pteropods, radiolaria, siphonophores, and chaetognaths.

(c) 1000-10,000 μ Size Fraction

Figure 19 shows the total number of organisms/m³, copepods/m³, siphonophores/m³, and euphausiids/m³. Fresh-sorting counts have been included, and are indicated by the circled points of total organisms/m³.

The numbers/m³ appear to be generally associated with standing stocks of dry weight, carbon, and nitrogen, except on February 6, when there was a peak in dry weight, carbon, and nitrogen, but not in the number of organisms/m³.

Changes in the total number of organisms appear to be a reflection of changes in the numbers of copepods and siphonophores/m³. Only a single daily change, .17 organisms/m³ on 1/24-25, was determined. The largest two-day change, a decrease of well over 1 organism/m³ on 1/26-27, was based on a fresh-sort estimate.

Comparison of the entire 100-10,000 μ size fraction with the data of Deevey and Brookes (1971) is not possible as their information was based on all organisms >202 μ . The abundance of euphausiids, most of which are found in the >1000 μ size range, may, however, be compared with the data in the literature. Toward the end of January, 1969, Deevey and Brookes found approximately .12 euphausiids/m³ in the 500-1000m interval and

FIGURE 19: ABUNDANCE OF MAJOR GROUPS IN THE 1000-10,000 μ SIZE FRACTION

none in the 0-500m interval. The average for a 1000m water column would have been .06 euphausiids/m³. Our estimates of euphausiid abundance were slightly higher on the average, ranging from .016-.17/m³.

Other organisms present in the 1000-10,000μ size fraction, in approximate order of abundance, included chaetognaths, amphipods, ostracods, medusae, fish larvae, and eggs. All of these major groups were present in very small numbers, generally less than 1/100m³.

3. Dry Weight, Carbon and Nitrogen in the Major Groups

Fresh sorting was undertaken to determine the contribution of each major group to the standing stocks of dry weight, carbon and nitrogen. Table 6 shows the dry weight, carbon and nitrogen/organism in the major groups of each size fraction.

In the 79-202μ size fraction copepods contain .0017 μgN/organism, the greatest amount per organism in any of the major groups of this size fraction. Copepods are thus the most significant group in numerical abundance and in nitrogen standing stock.

In the 202-1000μ size fraction, copepods contain an average of .56 μgN/organism and ostracods an average of .48 μgN/organism. Copepods are thus the most significant group in numerical abundance and in nitrogen content.

In the 1000-10,000μ size fraction, the nitrogen/organism averaged 2,000 μgN/amphipod; 512 μgN/fish larvae; 130 μgN/euphausiid;

TABLE 6
 DRY WEIGHT, CARBON, AND NITROGEN/ORGANISM IN MAJOR GROUPS

STA. #	SIZE FRACTION	ORGANISM	mgN/ ORGANISM	mgC/ ORGANISM	mgDW/ ORGANISM
10A	202- 1000 μ	Copepods	.0001	.0005	.013
		Ostracods	.0004	.0023	.009
11	1000- 10,000 μ	Euphausiids	.3902	1.410	3.600
		Copepods	.033	.015	.048
		Chaetognaths	.0425	.177	.487
		Amphipods	.0354	.187	.833
		Decapods	.0061	.048	.205
24B	202- 1000 μ	Copepods	.0003	.0014	.0082
		Ostracods	.0003	.0022	.0066
		Pteropods	.0001	.0033	.0300
25	1000- 10,000 μ	Euphausiids	.1203	.485	1.238
		Fish Larvae	.4380	2.114	4.538
		Chaetognaths	.0230	.119	.236
		Siphonophores	.0024	.0085	.030
		Copepods	.0371	.192	.399
41A	202- 1000 μ	Copepods	.0004	.0016	.0047
		Ostracods	.0005	.0028	.0097
		Pteropods	.0002	.0037	.0344

TABLE 6 (continued)

STA. #	SIZE FRACTION	ORGANISM	mgN/ ORGANISM	mgC/ ORGANISM	mgDW/ ORGANISM
42	1000- 10,000 μ	Euphausiids	.115	.463	1.205
		Fish Larvae	.683	4.197	8.088
		Amphipods	.218	1.165	3.833
		Decapods	.200	1.955	4.295
		Copepods	.038	.165	.346
		Siphonophores	.007	.029	.080
63A	202- 1000 μ	Copepods	.0002	.0012	.0042
		Ostracods	.0004	.0022	.0108
64	1000- 10,000 μ	Euphausiids	.129	.485	1.0830
		Fish Larvae	.129	.510	1.190
		Copepods	.044	.249	.475
		Siphonophores	.004	.015	.049
107A	202- 1000 μ	Copepods	.0003	.0013	.0045
		Ostracods	.0004	.0019	.0074
108	1000- 10,000 μ	Euphausiids	.127	.500	1.153
		Fish Larvae	.729	2.904	7.142
		Amphipods	.407	1.966	5.427
		Chaetognaths	.077	-	.720
		Copepods	.030	.120	.279
		Siphonophores	.003	.010	.051

TABLE 6 (continued)

STA. #	SIZE FRACTION	ORGANISM	mgN/ ORGANISM	mgC/ ORGANISM	mgDW/ ORGANISM
118A	202- 1000 μ	Copepods	.0008	.0041	.0092
		Ostracods	.0010	.0052	.0143
119	1000- 10,000 μ	Euphausiids	.083	.310	.740
		Fish Larvae	.482	2.060	4.344
		Copepods	.069	.278	.600
129A	202- 1000 μ	Copepods	.0014	.0065	.0130
130	1000- 10,000 μ	Euphausiids	.104	.415	.888
		Fish Larvae	.550	2.535	5.493
		Amphipods	.097	.401	1.170
		Copepods	.032	.171	.333
Com- bi- ned (15,542)	79- 202 μ	Copepods	1.7×10^{-6}	8.9×10^{-6}	35×10^{-6}
(1,370)		Eggs	1.4×10^{-6}	9.5×10^{-6}	44×10^{-6}
(577)		Radiolaria	0.5×10^{-6}	9.0×10^{-6}	104×10^{-6}
(160)		Dinoflagellates	0.6×10^{-6}	12×10^{-6}	940×10^{-6}

51 $\mu\text{gN}/\text{chaetognath}$; 30 $\mu\text{gN}/\text{copepod}$; and 4 $\mu\text{gN}/\text{siphonophore}$. Using Station 20 as an example, the order of numerical abundance was copepods, siphonophores, euphausiids, amphipods, chaetognaths, and fish larvae. After application of the nitrogen/organism data, the order of importance in the biological nitrogen pool becomes amphipods, chaetognaths, euphausiids, copepods, fish larvae, and siphonophores (see Summary Data Form for AT-72-1-20; 1000-10,000 μ).

4. The Food Chain

The importance of the various zooplankton groups of each size fraction in the food chain, in terms of nitrogen content, has been clarified. It is clear, for example, that fish larvae and euphausiids, though present in much lower numbers than copepods and siphonophores, form a large nitrogen pool.

A food chain based on the size of the major group nitrogen pools and information from the literature (see CU-3826-22; Technical Progress Report for 11/1/70-10/31/71) will not be constructed because the quantitative determination of rations has not been made. Diets based on information in the literature would be speculative and, in the Bermuda ecosystem with its high percentage of omnivores, could lead to highly inaccurate conclusions.

5. Conclusions

Comparison with data in the literature indicates that typically low winter production conditions were encountered.

Daily changes were surprisingly large and indicate a significant population disturbance between January 28 and 30. Whether this disturbance was the result of stormy conditions prevailing at that time or advection of a different water mass or a combination of these factors cannot be determined at this time.

6. Data Collected

Ordered by size fraction: 79-202 μ , 202-1000 μ , and 1000-10,000 μ , and by station number within each size fraction.

Each Summary Data Form contains the dry weight, carbon and nitrogen per cubic meter, averaged for double samples, and the taxonomic and numerical abundance data for samples on which counts were made.

SUMMARY DATA FORM

CRUISE: AT-72-1SIZE FRACTION: 79-202 μ MONTH: 1/22NET: 79 μ STATION: 6A, BDEPTH: 990 mChemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/M ³	CARBON/M ³	NITROGEN/M ³	PROTEIN/M ³
.3674 mg	.1419 mg	.02409 mg	.151 mg

☐ Check if data above is average of two samplesTaxonomy: AT-72-1-6A

ORGANISM	TOTAL	NO/M ³	% OF TOTAL	VARIANCE	C/M ³	N/M ³
Copepods	98,325	646.88				
Eggs	7,663	50.41				
Forams	3,496	23.00				
Radiolaria	2,871	18.91				
Dinoflags	1,437	9.45				
Tintinnids	1,197	7.88				
Ostracods	1,054	6.93				
Pteropods	1,006	6.62				

SUMMARY DATA FORM

CRUISE: AT-72-1

SIZE FRACTION: 79-202 μ

MONTH: 1/23

NET: 79 11

STATION: 9A, B

DEPTH: 1,000 m

Chemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/M ³	CARBON/M ³	NITROGEN/M ³	PROTEIN/M ³
.4407 mg	.17155 mg	.03103 mg	.194 mg

✓7 Check if data above is average of two samples

Taxonomy

[illegible]

SUMMARY DATA FORM

CRUISE: AT-72-1

SIZE FRACTION: 79-202 11

MONTH: 1/26

NET: 79 *W*

STATION: 30AE

DEPTH: 1150 m

Chemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/M ³	CARBON/M ³	NITROGEN/M ³	PROTEIN/M ³
.4013 mg	.15675 mg	.029105 mg	.182 mg

☐ Check if data above is average of two samples

Taxonomy

[illegible]

SUMMARY DATA FORM

CRUISE: AT-72-1

SIZE FRACTION: 79-202 μ

MONTH: 1/29

NET: 79 in

STATION: 54 A. B.

DEPTH: 4150m

Chemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/M ³	CARBON/M ³	NITROGEN/M ³	PROTEIN/M ³
.3112 mg	.12965 mg	.024855 mg	.155 mg

✓ Check if data above is average of two samples

Taxonomy

[illegible]

SUMMARY DATA FORM

CRUISE: AT-72-1

SIZE FRACTION: 79-202 11

MONTH: 2/1

NET: 79 11

STATION: 70A R

DEPTH: 1100 m

Chemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/M ³	CARBON/M ³	NITROGEN/M ³	PROTEIN/M ³
.39345 mg	.1634 mg	.03096 mg	.194 mg

✓ Check if data above is average of two samples

Taxonomy

[illegible]

DEPTH: 96.0 m

[illegible]

SUMMARY DATA FORM

CRUISE: AT-72-1

SIZE FRACTION: 202-1,000 μ

MONTH: 1/29

NET: 202 μ

STATION: 55 A B

DEPTH: 1000 m

Chemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/M ³	CARBON/M ³	NITROGEN/M ³	PROTEIN/M ³
.7219 mg	.28075 mg	.0592 mg	.370 mg

✓ Check if data above is average of two samples

Taxonomy

[illegible]

SUMMARY DATA FORM

CRUISE: AT-72-1SIZE FRACTION: 1,000-10,000 μ MONTH: 1/24NET: 1,000 μ STATION: 20DEPTH: 990 mChemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/ M^3	CARBON/ M^3	NITROGEN/ M^3	PROTEIN/ M^3
1.4601 mg	.4630 mg	.10703 mg	.669 mg

☐ Check if data above is average of two samplesTaxonomy

ORGANISM	TOTAL	NO/ M^3	% OF TOTAL	VARIANCE	C/ M^3	N/ M^3
Copepods	508	.53473				.0160
Siphonophores	468	.49263				.0020
Euphausiids	164	.17263				.0224
Amphipods	124	.13052				.02610
Chaetognaths	100	.10526				.0537
Fish	28	.02947				.0151
Medusae	20	.02105				
Ostracods	20	.02105				
Eggs	12	.01263				

SUMMARY DATA FORM

CRUISE: AT-72-1SIZE FRACTION: 1,000-10,000 μ MONTH: 1/25NET: 1,000 μ STATION: 25DEPTH: 970 mChemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/ M^3	CARBON/ M^3	NITROGEN/ M^3	PROTEIN/ M^3
1.5490 mg	.3515 mg	.08225 mg	.514 mg

☐ Check if data above is average of two samplesTaxonomy

ORGANISM	TOTAL	NO/ M^3	% OF TOTAL	VARIANCE	C/ M^3	N/ M^3
Copepods	652	.6743	37.3			
Siphonophores	360	.3723	20.6			
Chaetognaths	116	.1200	6.6			
Euphausiids	92	.0951	5.2			
Fish	64	.0662	3.6			
Amphipods	56	.0579	3.2			
Ostracods	56	.0579	3.2			
Medusae	44	.0455	2.5			
Eggs	8	.0083	0.4			

SUMMARY DATA FORM

CRUISE: AT-72-1

SIZE FRACTION: 1,000-10,000 μ

MONTH: 1128

NET: 1,000.00

STATION: 49

DEPTH: 1,000 m

Chemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/M ³	CARBON/M ³	NITROGEN/M ³	PROTEIN/M ³
.9678 mg	.2754 mg	.06417 mg	.401 mg

☐ Check if data above is average of two samples

Taxonomy

[illegible]

SUMMARY DATA FORM

CRUISE: AT-72-1 SIZE FRACTION: 1,000-10,000 μ
 MONTH: 2/1 NET: 1,000 μ
 STATION: 69 DEPTH: 910

Chemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/M ³	CARBON/M ³	NITROGEN/M ³	PROTEIN/M ³
<u>.9154mg</u>	<u>.2832mg</u>	<u>.06985mg</u>	<u>.437mg</u>

☐ Check if data above is average of two samples

Taxonomy

ORGANISM	TOTAL	NO/M ³	% OF TOTAL	VARIANCE	C/M ³	N/M ³
<u>Copepods</u>	<u>412</u>	<u>.35732</u>				
<u>Siphonophore</u>	<u>236</u>	<u>.20463</u>				
<u>Chaetognaths</u>	<u>90</u>	<u>.07805</u>				
<u>Euphausiids</u>	<u>60</u>	<u>.05203</u>				
<u>Amphipods</u>	<u>56</u>	<u>.04856</u>				
<u>Fish</u>	<u>48</u>	<u>.04163</u>				
<u>Ostracods</u>	<u>26</u>	<u>.02254</u>				
<u>Eggs</u>	<u>20</u>	<u>.01734</u>				
<u>Medusae</u>	<u>16</u>	<u>.01387</u>				

SUMMARY DATA FORM

CRUISE: AT-72-1SIZE FRACTION: 4,000-10,000 μ MONTH: 2/6NET: 4,000 μ STATION: 85DEPTH: 1000 mChemistry

DRY WEIGHT, TOTAL	CARBON, TOTAL	NITROGEN, TOTAL	PROTEIN, TOTAL
DRY WEIGHT/ M^3	CARBON/ M^3	NITROGEN/ M^3	PROTEIN/ M^3
<u>2.3025 mg</u>	<u>.6927 mg</u>	<u>.17893 mg</u>	<u>1.118 mg</u>

☐ Check if data above is average of two samplesTaxonomy

ORGANISM	TOTAL	NO/ M^3	% OF TOTAL	VARIANCE	C/ M^3	N/ M^3
<u>Siphonophores</u>	<u>356</u>	<u>.31310</u>	<u>30.1</u>			
<u>Copepods</u>	<u>340</u>	<u>.29903</u>	<u>28.7</u>			
<u>Chaetognaths</u>	<u>116</u>	<u>.10202</u>	<u>9.8</u>			
<u>Amphipods</u>	<u>54</u>	<u>.04749</u>	<u>4.5</u>			
<u>Eggs</u>	<u>38</u>	<u>.03342</u>	<u>3.2</u>			
<u>Fish</u>	<u>38</u>	<u>.03342</u>	<u>3.2</u>			
<u>Medusae</u>	<u>24</u>	<u>.02111</u>	<u>2.0</u>			
<u>Euphausiids</u>	<u>18</u>	<u>.01583</u>	<u>1.5</u>			
<u>Ostracods</u>	<u>10</u>	<u>.00880</u>	<u>0.8</u>			

D. ^{15}N Experiments

Tables 7, 8 and 9 contain all observed data in each of the experiments (Experiments 1, 2, and 3 took place on February 11, 12, and 13, respectively).

The data obtained from the three experiments are summarized in the first three columns of Table 7. The fourth column is used to tabulate the ^{15}N as a percentage of the total nitrogen for each sample taken.

The observed values of phytoplankton densities and volumes are presented in Table 8.

In Table 9, the total number of cells in the carboy at the beginning and end of each experiment is tabulated in the first two rows. In the third row, the difference between these two cell counts (cells consumed) is recorded and the fourth row contains the duration of each experiment.

The percentage nitrogen incorporation efficiency by zooplankton is calculated according to the procedure outlined in the footnote to Table 10.

Table 11 presents the rate of nitrogen uptake by the zooplankton. This rate was calculated from the rate of ^{15}N uptake by the zooplankton after correction had been made for the fact that the phytoplankton inoculum contained less than 100% ^{15}N . Since each experiment had a different duration, the rate for each experiment was computed on a 24-hour basis to allow comparison among the experimental results.

TABLE 7

Sample	Cells/ Filter	Kjeldahl Nitrogen ($\mu\text{g N}$)	^{15}N Content ($\mu\text{g } ^{15}\text{N}$) *	$^{15}\text{N}\%$ of Total Nitrogen**
Phytoplankton Inoculum, Exp. 3 ***	1.7×10^7	12.5	11.1	88.4
Phytoplankton Filter #1, Exp. 1	1.4×10^7	117.8	17.4	14.8
Phytoplankton Filter #2, Exp. 1	1.4×10^7	93.4	12.7	13.6
Phytoplankton Filter #3, Exp. 1	1.4×10^7	102.3	13.9	13.6
Average of three	(1.4×10^7)	(104.5)	(14.6)	(14.0)
Phytoplankton Filter #1, Exp. 2	1.3×10^7	42.4	17.0	40.1
Phytoplankton Filter #2, Exp. 2	1.3×10^7	38.1	16.9	44.4
Phytoplankton Filter #3, Exp. 2	1.3×10^7	32.5	14.9	45.9
Average of three	(1.3×10^7)	(37.6)	(16.2)	(43.4)
Phytoplankton Filter #1, Exp. 3	6.4×10^7	120.2	77.3	64.2
Phytoplankton Filter #2, Exp. 3	6.4×10^7	125.7	86.7	69.0
Phytoplankton Filter #3, Exp. 3	6.4×10^7	117.6	80.3	68.2
Average of three	(6.4×10^7)	(121.2)	(81.4)	(67.2)
Zooplankton Filter, Exp. 1	-	3685.1	99.1	2.6
Zooplankton Filter, Exp. 2	-	3236.6	79.4	2.4
Zooplankton Filter, Exp. 3	-	13247.6	99.0	0.8
Carboy Filtrate, Exp. 1	-	2.7	-	-
Carboy Filtrate, Exp. 2	-	0.5	-	-
Carboy Filtrate, Exp. 3	-	4.1	-	-

* "Carboy Filtrate" samples were not analyzed for ^{15}N content since total N content was below the minimum required for mass spectrometric analysis.

** $^{15}\text{N}\%$ of cellular N = ($^{15}\text{N}/\text{total Kjeldahl N}$) $\times$ 100.

*** We do not have data on "Phytoplankton Inoculum" samples for experiments 1 and 2 as the sample for Exp. 1 was lost in shipment and that for Exp. 2 was lost during Kjeldahl digestion. Nevertheless, the experiments are still valid as all calculations can be based on data obtained for the phytoplankton samples taken at the end of the experiments.

TABLE 8

	Experiment 1	Experiment 2	Experiment 3
Density of cells in phytoplankton inoculum culture (cells/ml)	1.5×10^6	8.7×10^5	1.7×10^6
Volume of phytoplankton inoculum culture added to experimental carboy (ml)	490	480	480
Experimental volume in carboy (ml)	20,000	20,000	10,000
Density of phytoplankton cells in carboy at beginning of experiment (cells/ml)	3.7×10^4	2.1×10^4	8.2×10^4
Density of phytoplankton cells in carboy at end of experiment (cells/ml)	1.4×10^4	1.3×10^4	6.4×10^4

*These densities of Coccolithus huxleyi are higher than the natural density of C. huxleyi found to be 2700 cells/liter at the surface waters in the Sargasso Sea off Bermuda in January 1958 by Hulburt et al. (1960). The selection of C. huxleyi as the phytoplankton species to be fed to the zooplankton was based on our findings in previous years that this is the predominant phytoplankton species in the surface waters at the Bermuda station. Higher than naturally occurring phytoplankton densities were used in the ^{15}N carboy experiments to ensure enough transfer of ^{15}N from the phytoplankton to the zooplankton to enable mass spectrometric analysis.

TABLE 9

	Experiment 1	Experiment 2	Experiment 3
Phytoplankton total cell count at beginning of experiment (cells) *	7.4×10^8	4.2×10^8	8.2×10^8
Phytoplankton total cell count at end of experiment (cells)	2.8×10^8	2.6×10^8	6.4×10^8
Phytoplankton total cell count removed by zooplankton (cells) **	4.6×10^8	1.6×10^8	1.8×10^8
Duration of experiment (hours)	33	22	7

* See Table for supplementary data on cell counts.

** Phytoplankton total cell count removed by zooplankton is equal to the phytoplankton total cell count at the beginning of the experiment minus the phytoplankton total cell count at the end of the experiment.

TABLE 10

	Experiment 1	Experiment 2	Experiment 3
% ^{15}N incorporation by zooplankton*	20.5	39.6	43.2

- * % ^{15}N incorporation by zooplankton for each experiment was obtained by
- (1) Calculating the $\mu\text{g } ^{15}\text{N}$ per phytoplankton cell for each experiment. (The averaged phytoplankton filter data for each experiment given in Table was used for this calculation).
 - (2) Calculating the $\mu\text{g } ^{15}\text{N}$ removed by the zooplankton during the duration of the experiment by multiplying the $\mu\text{g } ^{15}\text{N}$ per phytoplankton cell (calculated in 1) by the phytoplankton total cell count removed by the zooplankton on during the duration of the experiment (Table).
 - (3) Taking the ratio of the $\mu\text{g } ^{15}\text{N}$ of the zooplankton sample of each experiment (Table) to the $\mu\text{g } ^{15}\text{N}$ removed by the zooplankton during the duration of the experiment (calculated in 2).
 - (4) Expressing this ratio as a percentage.

NITROGEN RETENTION BY ZOOPLANKTON			
EXPERIMENT 1	EXPERIMENT 2	EXPERIMENT 3	
plankton N/24 hours.....	0.036	0.042	0.034
ug phytoplankton N/ug zoo-			

TABLE 11

E. Synthesis of Data

1. Statistical Analysis

(a) Flowmeter

(i) Efficiency-Mean, SD and range for all nets and combinations

The filtration efficiency (e) of all nets in each size fraction was calculated by expressing the inner flowmeter reading as a percentage of the outer flowmeter reading. These percentages were totalled and divided by the total number of tows (n) to find the mean efficiency ($\bar{e}$) for both nets in each size fraction.

$$e = \left(\frac{\text{inner flowmeter reading}^*}{\text{outer flowmeter reading}^*} \right) \times 100$$

$$\bar{e} = \frac{\sum e}{n} \quad \text{[*after correction for calibration factor]}$$

The individual mean efficiencies were also calculated for each net in each size fraction.

The standard deviation (SD) of the filtration efficiency of both nets in each size fraction and each net in each size fraction was calculated in the usual way.

$$SD(e) = \sqrt{\frac{\sum (e - \bar{e})^2}{n - 1}}$$

The 90% confidence limits of the range (R) for each filtration efficiency were calculated by multiplying the SD(e) by the appropriate "t" factor found from student t tables based on a sample of n.

$$R(e) = \pm SD(e) \times t_{n, 90\%}$$

(ii) Flow-Mean, SD and range for all nets
and combinations

A comparison of the flows in the two nets was made by expressing the flow in either net as a percentage of the mean flow (fa & fb). The mean is of course 100 and the standard deviation (SD [f]) and range (R [f]) were calculated as in A above for each net pair in each size fraction:

$$fa \text{ or } fb = \frac{\text{flow in net a (or b)} \times 200}{\text{flow in net a} + \text{flow in net b}}$$

$$SD (f) = \sqrt{\frac{2\sum (fa - 100)^2}{n - 1}}$$

Since

$$2\sum (fa - 100)^2 = \sum (fa - 100)^2 + \sum (fb - 100)^2$$

Additionally, to isolate the tendency of any flowmeter to read high or low (systematic error), and to estimate its precision (random error), the procedure outlined below, was followed. The relative flows and errors are not absolute but do indicate relative tendencies. The flows of the inner and outer flowmeters on both nets were expressed as a percentage of the mean for each tow in each size fraction. The mean percentage flow (fa_i , fa_o , fb_i and fb_o) for the inner and outer flowmeters on each net, the standard deviations (SD (fa_i) etc.) and the ranges (R (fa_i) etc.) were calculated as in A above.

(b) Nitrogen Sampled

(i) Net-to-net comparison

Nitrogen sampled by nets a & b were compared in the same way as flow between the two nets in each size fraction.

(ii) Daily variation

Daily variation of all nitrogen caught in all nets on a given day was measured as follows. All nets in a given size range towed on the same day were compared by expressing the individual nitrogen contents of the catches as a percentage of the mean for that day. The deviations of the individual catches from the mean were then used to calculate the standard deviation and range at the 90% confidence level within a day. This was done to estimate the significance of daily changes in relation to the standard error of the net-to-net comparisons. No significance could be attached to observed daily changes.

(iii) Dissolved inorganic nitrogen

The dissolved inorganic nitrogen in the top 100 meters of the water column was calculated by integrating the nitrate, nitrite and ammonia measured at standard hydrographic depths. The error in this figure was estimated based on the measured error in the individual chemical analyses alone and takes no account of sampling errors.

(c) Regression Analysis of Nitrogen Pools vs. Time

The daily variations in the various size fractions were not significant in terms of the standard deviation of duplicate net tow nitrogen catches from their mean. Thus the regression coefficient of the mean nitrogen sampled in each size fraction on each day vs. time was calculated to establish any long term trends. The standard deviation of the regression coefficient and the 95% confidence limits were calculated to estimate the significance of these coefficients. Results are presented in III,E,2,c.

Filtration Efficiency90% Confidence Limits of Nets

79 μ	(a & b)	101.2 $\pm$ 5.0%
79 μ	(a alone)	101.3 $\pm$ 4.7%
79 μ	(b alone)	101.1 $\pm$ 5.5%
202 μ	(a & b)	99.4 $\pm$ 12.0%
202 μ	(a alone)	101.1 $\pm$ 3.7%
202 μ	(b alone)	97.8 $\pm$ 11.0%

1000 μ net had a filtration efficiency of at least 98% (Tranter and Herron, 1968; Unesco Monograph on Zooplankton Sampling).

Flow

Variation of nets a and b about mean at 90% confidence limits.

79 μ	$\pm 3.7\%$
202 μ	$\pm 11.0\%$
1000 μ	only single tows made

Individual flowmeter means and 90% confidence limits based on mean of each tow.

79 μ net a inner	100.9 $\pm$ 2.1%
79 μ net a outer	99.6 $\pm$ 1.9%
79 μ net b inner	100.3 $\pm$ 2.8%
79 μ net b outer	99.3 $\pm$ 1.4%
202 μ net a inner	101.3 $\pm$ 3.4%
202 μ net a outer	100.3 $\pm$ 3.0%
202 μ net b inner	97.7 $\pm$ 8.0%
202 μ net b outer	100.7 $\pm$ 2.3%

Nitrogen Sampled

Variation of nets a and b about mean at 90% confidence limits.

79μ ± 14.7%

202μ ± 21.7%

1000μ only single tows made

Daily variations of all nets in single size range.

79μ ± 22.1%

202μ ± 27.7%

1000μ ± 76.4%

Dissolved Inorganic Nitrogen

Standard deviation of individual analysis at 95% confidence limits ±0.25 μg-at N/liter. 95% confidence limits of N in 100m x 1 m² water column = ±520 mg.

2. Nitrogen Flux

(a) Magnitude of Nitrogen Standing Stocks

Nitrogen Pools

(i) Magnitude of the biological and detrital nitrogen pools

The biological and detrital nitrogen pools are the sum of particulate nitrogen in the four size fractions described previously. In reality, the biological nitrogen pool includes organisms greater than 10,000 μ , but they are not abundant and have an insignificant effect on the magnitude of the total biological nitrogen pool off Bermuda (CU-3826-17, Technical Progress Report for 11/1/69-10/31/70).

The nitrogen in the 0.45-79 μ size fraction was found in the greatest concentration, 3.87 mg/m³ mean, in the upper 100 m (section III,A,2). From 100-1000 m the mean concentration of 0.45-79 μ nitrogen was 1.05 mg/m³. Summing over the water column, the material in the 0.45-79 μ size fraction contained 1334 mgN of which 387 mg was in the upper 100 m. As the Secchi disc readings indicated that the photic zone extended to about 120 m, most of the living nitrogen above that depth was almost certainly phytoplankton, while below, it was most likely heterotrophic flagellates and other protozoans (Hulburt, Ryther and Guillard, 1960).

Detritus undoubtedly accounted for a large part of the 0.45-79 μ nitrogen in both the photic and aphotic zones (Beers

and Stewart, 1969; Zhailov and Finenko, 1968).

The mean total biological nitrogen in a 1000 meter water column in the 79-202 μ size fraction was 40 mg, in the 202-1000 μ size fraction was 82 mg, and in the 1000-10,000 μ size fraction was 74 mg. Detritus formed an insignificant fraction (2%) of the zooplankton nitrogen (CU-3826-22, Technical Program Report for November 1, 1970 - October 31, 1971).

Table 12 shows the magnitude of the biological nitrogen pool and the contributions of the respective components.

(ii) The magnitude of the nitrogen pools in the model of the annual nitrogen cycle

During the time samples were taken, standing stock of dissolved inorganic nitrogen, including nitrate, nitrite, and ammonia, in the upper 100 meters (the photic zone) remained below 6.4 $\mu\text{g-at N/liter}$ (8960 mg N/m²/100 m) and averaged 2.5 $\mu\text{g-at N/liter}$ (3,430 mgN/m²/100 m) over the 23-day sampling period. In the 100 - 1000 meter water column (the aphotic zone), the maximum dissolved inorganic nitrogen was 16.3 $\mu\text{g-at N/liter}$ (205,000 mg N/m²/900 m) and the average over the 23-day sampling period was 12.7 $\mu\text{g-at N/liter}$ (160,000 mgN/m²/900 m).

The magnitude of the standing stocks of the biological nitrogen pool was discussed in the previous section, and is summarized in Table 12.

Figure 20 shows the magnitude of all nitrogen, applied to the model of the annual nitrogen cycle.

TABLE 12

MAGNITUDE OF BIOLOGICAL NITROGEN POOL

.45-79 μ , photic	387 mgN/m ² /100m
.45-79 μ , aphotic	947 mgN/m ² /900m
79-202 μ , 0-1000m	40 mgN/m ² /1000m
202-1000 μ , 0-1000m	82 mgN/m ² /1000m
1000-10,000 μ , 0-1000m	74 mgN/m ² /1000m
TOTAL	1530 mgN/m ² /1000m

FIGURE 20

MAGNITUDE OF THE NITROGEN POOLS

Note: We are aware that the majority of the biological nitrogen is in the photic zone, but as the depth distribution of the nitrogen in the zooplankton fractions was not measured, the biological nitrogen pool cannot be divided into the photic and aphotic fractions.

Clearly, there are large dissolved inorganic nitrogen supplies in the photic zone supporting a relatively small living biological population. These same dissolved inorganic nitrogen supplies must also be supporting an unmeasured detrital pool above the thermocline and unknown amounts of dissolved organic nitrogen. It is apparent also, that the biological nitrogen pool was not limited by the quantity of nitrogen available to it. Limiting factors must, therefore, be the rates of nitrogen transfer into and out of the biological nitrogen pool. The biological nitrogen pool can increase in total nitrogen content only if the rate of input surpasses the rate of output.

In the following section, changes in the biological nitrogen pool over a 23-day span will be examined to determine the amount of nitrogen transferred within the components of this pool and its response to changes in the supplies of dissolved inorganic nitrogen.

(b) Nitrogen Size Fractions vs. Time

We have seen in the previous section that the nitrogen pools in the model of the annual nitrogen cycle may be divided into photic and aphotic nitrogen resources. However, for the purpose of comparing the responses of the various components of the biological pool and the dissolved inorganic nitrogen pool, only the portions showing a response were considered. Thus, in Figure 21 only the changes in the 0-100 m dissolved inorganic nitrogen and in the 0.45-79 μ

FIGURE 21: THE ERROR IN DAILY DETERMINATIONS OF NITROGEN

nitrogen are presented. As the three larger size fractions, regardless of their depth distribution, must receive the majority of their nitrogen supply from the upper 100 meters, the daily nitrogen standing stocks of these size fractions are presented for the 0-1000 m water column.

The nitrogen pools of the dissolved inorganic nitrogen and the four particulate size fractions show considerable fluctuation over short time periods (see Figure 21). The maxima and minima within the three zooplankton nitrogen fractions, however, have been shown to fall within the limits of the coefficient of variance at the 95% confidence level (see section E,1,b). For this reason, daily fluctuations in the nitrogen pools of these fractions are insignificant, and cannot be interpreted.

The 0.45-79 μ phytoplankton fraction also shows some short-term changes. The error of these determinations, however, was not estimated as replicate samples were not taken.

The daily dissolved inorganic nitrogen fluctuations exceed the error limits of an estimated $\pm 520 \text{ mgN/m}^2/100\text{m}$, except for abrupt increases of the dissolved inorganic nitrogen observed in the upper 100 m of the water column which seem to be associated with storms and winds from the southwest, indicating that either advection or local vertical mixing occurred. The decreases in dissolved inorganic nitrogen following storm periods were associated with an increase in the 0.45-79 μ fraction in one instance (Jan. 27-30), but not in the other (Jan. 6-7).

It is possible that on Jan. 6-7, when an increase in $0.45\text{-}79\mu$ nitrogen was not seen, an increase did occur but was not detected due to inability to sample at that time (COO-3222-01, Cruise Report AT-72-1).

Since daily changes in the biological nitrogen pool are not significant at the 90% confidence level, regression analyses were undertaken to determine if there were statistically significant trends over the 23-day sampling period (see section E,2,c). The results are given below.

(c) Long-Term Trends

(i) Significance of trends

The results of the regression analysis described in section E,1,c, are presented in Table 13. The dissolved inorganic nitrogen in 1 m^2 of the top 100 m of the water column gained 2.4 mg of nitrogen per day with a standard deviation of $\pm 3580\text{ mgN/day}$ at the 95% confidence limits. For all practical purposes, with a mean of $3430\text{ mgN/m}^2/100\text{m}$, the small increase in nitrogen per day can be considered insignificant, especially with a standard deviation greater than the mean total in the water column. The high standard deviation results from large short-term changes and the absence of any clear long-term trends.

The $0.45\text{-}79\mu$ nitrogen fraction lost 9.2 mg of nitrogen per day with a standard deviation of 14 mgN/day at 95% confidence limits. This analysis was, however, based on seven data

TABLE 13
LONG TERM CHANGES OR TRENDS (and associated error)
IN THE SEVERAL SIZE FRACTIONS

Size Fraction	Depth of Water Column Considered (Meters)	Mean mgN/m ² /water column	σ at 90% CL	Trend (slope)	Significance at 95% CL
Dissolved	0-100 m	3430	±520	+2.4	±3580
0.45-79 μ	0-100 m	387	-	-9.2	±14
79-202 μ	0-1000 m	40	±8.9	+0.84	±0.37
202-1000 μ	0-1000 m	82	±22.7	+1.83	±0.83
1000-10,000 μ	0-1000 m	74	±56.5	+5.94	±5.4

points with intervals as large as five days between samples (Table 12), and as a consequence, the trend is not significant.

The 79-202 μ nitrogen fraction, composed primarily of small herbivores (see section III,C) gained .84 mg of nitrogen per day with a standard deviation of $\pm .37$ mgN/day at 95% confidence limits.

The 202-1000 μ nitrogen fraction, composed primarily of larger herbivores and omnivores (see section III,C), gained 1.83 mg of nitrogen per day with a standard deviation of $\pm .83$ mgN/day at 95% confidence limits.

The 1000-10,000 μ nitrogen fraction, composed primarily of omnivores and carnivores (see section III,C), gained 5.94 mg of nitrogen per day with a standard deviation of ± 5.4 mgN/day at the 95% confidence limit.

However, as there were significant trends in only two of the nitrogen size-fractions measured, the 79-202 μ nitrogen fraction and the 202-1000 μ nitrogen fraction, no estimate of the quantity or efficiency of nitrogen transfer from the phytoplankton fraction to the zooplankton fraction can be made at the 95% confidence level.

(ii) Interpretation of trends

At 60% confidence limits, the trends in the four fractions of the biological nitrogen pool are all significant. The interpretation at this confidence limit is entirely speculative, however, as the trends stand only a slightly better than even chance of being representative of the actual situation.

Table 14 shows the errors at 60% confidence limits and the total changes of the nitrogen pools over 21 days. The total loss of nitrogen from the 0.45-79 μ (phytoplankton) fraction was 193 mg. The sum of the total gains of nitrogen in the 79-202 μ , 202-1000 μ , and 1000-10,000 μ (zooplankton) fractions was 181 mg of nitrogen. It would appear from these data that increases in the zooplankton nitrogen standing stocks resulted from zooplankton grazing on the 0.45-79 μ (phytoplankton) fraction. Although calculation of the efficiency of nitrogen transfer from the <79 μ fraction to the >79 μ fraction would be a tempting exercise, the efficiency of 94% obtained must be viewed with extreme caution. The statistical significance of this figure is low as the errors in the changes in nitrogen content in the <79 μ and >79 μ pools are scarcely significant. Secondly, this figure precludes excretion, predation or mortality in the >79 μ fraction. The figure is also two and one-half times the efficiency found by other workers and reported in the literature (Butler, Corner and Marshall, 1969), and that found in our own ^{15}N experiment to measure nitrogen efficiency from the <79 μ to the 79-202 μ size fractions (~40%).

TABLE 14
LONG TERM NITROGEN CHANGES
(and associated error at the 60% confidence level)
OVER THE 21 DAY SAMPLING PERIOD FOR THE SEVERAL SIZE FRACTIONS

Size Fraction	Depth of Water Column Considered (Meters)	Mean mgN/m^2 /water column	σ at 90% CL	Trend (slope)	Significance at 60% CL	$\Delta 21$ days
Dissolved	0-100 m	3430	± 520	+2.4	± 1408	+50
0.45-79 μ	0-100 m	387	-	-9.2	± 5.5	-193 -193 ± 115
79-202 μ	0-1000 m	40	± 8.9	+0.84	$\pm .15$	+17.6
202-1000 μ	0-1000 m	82	± 22.7	+1.83	$\pm .35$	+38.4
1000-10,000 μ	0-1000 m	74	± 56.5	+5.94	± 2.11	+125

(d) ^{15}N Experiments

In Experiment 1, the zooplankton collected contained many dead organisms. This was probably caused by the long duration of the net tow used to harvest the zooplankton. The collection method was improved for the other experiments by using repeated net tows of 5 minutes duration. Thus, the results obtained for the first and subsequent two experiments are not completely comparable.

The percentage nitrogen incorporation efficiency by zooplankton is reported in Table 10. These figures represent a measure of the nitrogen transfer efficiency between phytoplankton and zooplankton. Good agreement was found between the percentage of nitrogen incorporated by zooplankton in Experiments 2 and 3 (39.6 and 43.2%, respectively). The lower efficiency (20.5%) in the first experiment may result from (1) changes in metabolic processes due to the greater trauma caused by the zooplankton collecting method we employed, or (2) the excretion of ^{15}N -containing catabolites to the environment during the longer incubation period.

The rate of nitrogen uptake by the zooplankton has been expressed as μg of phytoplankton nitrogen incorporated by zooplankton per μg of zooplankton nitrogen per 24 hours (Table 11). There is excellent agreement between the rates in the three experiments. This agreement with the first experiment was not expected because a significant number of the zooplankters in Experiment 1 appeared to be dead and, therefore, non-assimilating.

A comparison of the rate of change of nitrogen in the 79-202 μ zooplankton fraction for the net tow samples over the 23-day sampling period (section III,E,2,c) to the rates of incorporation of nitrogen by this fraction found in the ^{15}N carboy experiments was made. The net tow samples in the 79-202 μ size fraction taken on the 11, 12, and 13th of February had a mean nitrogen content of 49 mg/m²/1000 m. The mean rate of assimilation obtained from the ^{15}N carboy experiments on the same days was 0.037 μg of phytoplankton N/ μg of zooplankton N /24 hours, which corresponds to a daily rate of increase of 1.8 mgN incorporated/day/m²/1000 m water column. This figure from the ^{15}N carboy experiments is in excellent agreement with the results obtained from the net tow samples. The results of the net tow samples showed a rate/day of 0.82 ± 0.37 mgN incorporated/day/m²/1000 m water column, as calculated in the regression analysis of the 79-202 μ nitrogen pool vs. time (see section III,E,2,c).

The rate of nitrogen incorporation obtained for the net tow samples is not identical with the rate obtained for the ^{15}N experiments as (1) the rate for the net tow samples was based on 23 days of sampling whereas the rate for the ^{15}N experiments was determined on the last three days of sampling; (2) the naturally occurring phytoplankton densities would be far less than those in the ^{15}N carboy experiments; and (3) the nitrogen incorporation rate for the net tow samples does not take account of zooplankton nitrogen loss due to predation by

larger organisms and mortality. Predation was not expected to be an important cause of zooplankton nitrogen loss in the ^{15}N experiments as larger organisms were excluded.

IV CONCLUSIONS

A—The expected initial stage of the vernal bloom was not seen because the winter weather was relatively mild (see section III,A) and mixing did not extend below the seasonal thermocline. The last stages of a fall bloom (see section III,B) may have been observed. Equally likely, the situation may have represented typically low winter production limits. The ecosystem sampled appeared to be approaching semi-steady state, and, given time, the particle grazers may have reduced their rations to the point where their standing stock could no longer be supported. At that time, particle grazer population would have fallen off, and, in the absence of grazing pressure the phytoplankton standing stock would have increased if nutrients were still available. This conclusion assumes that the decrease in $0.45\text{-}79\mu$ nitrogen standing stock calculated by regression analysis actually occurred.

B—The increase in the nitrogen content of the $79\text{-}202\mu$ and $202\text{-}1000\mu$ size fractions has been determined within acceptable error limits at the 95% confidence limit. Additionally, the daily rate of nitrogen incorporation by the $79\text{-}202\mu$ fraction has been determined by ^{15}N tracer methods. The separate determinations agreed surprisingly well, $.84\text{ mgN } (\pm .37\text{ mgN})$ incorporated/day/ m^2 /1000m and 1.8 mgN retained/day/ m^2 /1000m, for the

nitrogen content/size fraction and ^{15}N methods, respectively. The higher rate of incorporation determined by the ^{15}N method was probably the result of concentrations of organisms in the culture vessel far greater than natural population density.

C—To understand the nitrogen flux in an ecosystem, ideally, both the standing stock and ^{15}N methods should be employed. The standing stock method is at the lower limits of its sensitivity in conditions where production and changes in standing stock are small. The ^{15}N method may, however, be used more successfully under such conditions.

D—In the future, studies of nitrogen flux will be continued in the Sargasso Sea off Bermuda, using a combination of both the standing stock and ^{15}N methods. Sampling will be done during the main stage of the vernal bloom as changes in standing stock at that time are expected to be greater than the error in measurements. Rates of nitrogen flux will be measured by in situ and/or simulated in situ experiments using the ^{15}N method. The preliminary ^{15}N experiments done in February, 1972, indicate that, if the mechanical problems of handling and sampling from large volume ($>1\text{ m}^3$) containers can be solved, it may be feasible--using ^{15}N as a tracer--to follow nitrogen flux from the dissolved form through the phytoplankton and hence to particle grazers and detritus.

Detailed descriptions of our planned future work are presented in the "Plan of Work" section of our proposal for the period February 1, 1973 to January 31, 1974.

V BIBLIOGRAPHY

- Beers, J.R., 1966. Studies on the chemical composition of the major zooplankton groups in the Sargasso Sea off Bermuda. *Limnol. Oceanog.* 11:520-528.
- Beers, J.R. and Stewart, G.L., 1969. Microzooplankton and its abundance relative to the larger zooplankton and other seston components. *Mar. Biol.* 4:182-189.
- Butler, E.I., Corner, E.D.S. and Marshall, S.M., 1969. On the nutrition and metabolism of zooplankton. VII: Feeding efficiency of Calanus in terms of nitrogen and phosphorus. *J. mar. biol. Assn. U.K.* 49:977-1001.
- Deevey, G.B. and Brookes, A.L., 1971. The annual cycle in quantity and composition of the zooplankton of the Sargasso Sea off Bermuda. II: The surface to 2,000m¹. *Limnol. Oceanog.* 16(6):927-943.
- Finenko, Z.Z. and Zaika, V.E., 1968. Particulate organic matter and the role of productivity of the sea. Marine Food Chains, J.H. Steele (ed.), Univ. Calif. Press, 1970.

Guillard, R.R.L. and Ryther, J.H., 1962. Studies on marine planktonic diatoms, I: Cyclotella nana Hustedt and Detonula confervacea (Cleve) Gran. Can. J. Microbiol. 8:229-239.

Hulburt, E.M., Ryther, J.H. and Guillard, R.R.L., 1960. The phytoplankton of the Sargasso Sea off Bermuda. J. Cons. Int. Explor. Mer 25:115-128.

Menzel, D.W. and Ryther, J.H., 1961. Zooplankton in the Sargasso Sea off Bermuda and its relation to organic production. J. Cons. Int. Explor. Mer 26:250-258.

Menzel, D.W. and Ryther, J.H., 1961. Annual variations in primary production of the Sargasso Sea off Bermuda. Deep-Sea Res. 7:282-288.

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Marine Biology Division

Cruise Report: ATLANTIC TWIN-72-1

COO-3222-01

Submitted by J. Hillegas
C. Garside

May 8, 1972

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VESSEL: R/V ATLANTIC TWIN
FROM/TO: January 17, 1972-February 19, 1972
OPERATING AREA: 9-1/2 mi. E. of Gibbs Hill Light, Bermuda

PERSONNEL:	J. Currie, B.S.	Phytoplankton Ecology
	C. Garside, Ph.D. (Chief Scientist)	Hydrography
	A. Hagen	Engineering
	V. Harris (Graduate Student)	Zooplankton Analysis
	J. Hillegas, B.S.	Zooplankton Ecology
	W. S. Hoover (Student)	
	R. Levine (Graduate Student)	
	S. Williams, Ph.D.	Hydrographic Analysis

STATIONS OCCUPIED

<u>Station #</u>	<u>Date</u>	<u>Time</u>	<u>Description</u>
<u>AT-72-1-01</u>	1/22	1020	B.T. cast
-02	1/22	1040	B.T. cast
-03	1/22	1110	Surface temperature bucket
-04	1/22	1125	Hydrocast for nutrients and phytoplankton
-05	1/22	1510	202 μ double net tow
-06	1/22	1901	79 μ double net tow
-07	1/23	0540	B.T. cast
-08	1/23	0620	Hydrocast for phytoplankton and nutrients
-09	1/23	0950	79 μ double net tow
-10	1/23	1335	202 μ double net tow
-11	1/23	1421	1,000 μ single net tow
	1/23	1515	Return to St. Georges
-12	1/24	0906	B.T. cast
-13	1/24	0908	Surface temperature bucket
-14	1/24	0930	Hydrocast for nutrients and phytoplankton
-15	1/24	1128	79 μ double net tow
-16	1/24	1314	202 μ double net tow
-17	1/24	1450	1,000 μ single net tow
-18	1/24	1610	79 μ double net tow
-19	1/24	1717	202 μ double net tow
-20	1/24	1912	1,000 μ single net tow

<u>Station #</u>	<u>Date</u>	<u>Time</u>	<u>Description</u>
<u>AT-72-1-21</u>	1/25	0540	B.T. cast
-22	1/25	0600	Hydrocast for phytoplankton and nutrients
-23	1/25	0847	79μ double net tow
-24	1/25	1000	202μ double net tow
-25	1/25	1138	1,000μ single net tow
	1/25	1230	Return to St. Georges
-26	1/26	1030	B.T. cast
-27	1/26	1054	Surface temperature bucket
-28	1/26	1100	Hydrocast for nutrients and phytoplankton
-29	1/26	1408	1,000μ single net tow
-30	1/26	1530	79μ double net tow
-31	1/26	1645	202μ double net tow
-32	1/26	1915	1,000μ double net tow
-33	1/26	2023	79μ double net tow
-34	1/26	2128	202μ double net tow
-35	1/27	0630	B.T. cast
-36	1/27	0632	Surface temperature bucket
-37	1/27	0645	Hydrocast for phytoplankton and nutrients
-38	1/27	0730	Secchi disc
-39	1/27	0745	Geochem. Random sample
-40	1/27	0828	79μ double net tow
-41	1/27	0924	202μ double net tow
-42	1/27	1015	1,000μ single net tow

<u>Station #</u>	<u>Date</u>	<u>Time</u>	<u>Description</u>
AT-72-1-	1/27	1100	Return to St. Georges
-43	1/28	0930	B.T. cast
-44	1/28	0940	Surface temperature bucket
-45	1/28	0950	Hydrocast for nutrients and phytoplankton
-46	1/28	1134	1,000μ single net tow
-47	1/28	1305	79μ double net tow
-48	1/28	1410	202μ double net tow
-49	1/28	1455	1,000μ single net tow
-50	1/28	1548	79μ double net tow
	1/28	1630	Return to St. Georges: wind 20-25, 40 knots in gusts.
-51	1/29	1130	B.T. cast
-52	1/29	1150	Hydrocast for nutrients and phytoplankton
-53	1/29	1335	1,000μ single net tow
-54	1/29	1508	79μ double net tow
-55	1/29	1630	202μ double net tow
-56	1/29	1737	1,000μ single net tow
-57	1/29	1916	202μ double net tow
-58	1/29	2015	79μ double net tow
-59	1/30	0600	B.T. cast
-60	1/30	0615	Hydrocast for phytoplankton and nutrients
-61	1/30	0845	79μ double net tow
-62	1/30	0900	Geochem. Radon sample

<u>Station #</u>	<u>Date</u>	<u>Time</u>	<u>Description</u>
AT-72-1-63	1/30	0951	202μ double net tow
-64	1/30	1046	1,000μ single net tow
	1/30	1145	Return to St. Georges
	1/31	1200	Seas 6-10 feet; wind 30, gusting to 40 knots. Cancelled sampling.
-65	2/1	1000	B.T. cast
-66	2/1	1037	Hydrocast for nutrients and phytoplankton
-67	2/1	1434	79μ double net tow
-68	2/1	1530	202μ double net tow
-69	2/1	1635	1,000μ single net tow
-70	2/1	1830	79μ double net tow
-71	2/1	1948	202μ double net tow
-72	2/1	2043	1,000μ single net tow
-73	2/2	0600	B.T. cast
-74	2/2	0610	Hydrocast for phytoplankton and nutrients
-75	2/2	0915	79μ double net tow
	2/2	1030	Return to St. Georges. Seas 10-12 feet; wind 25-30 knots; gales forecast.
	2/3		Winds 25-30 knots in harbor. Cancelled sampling. General maintenance.
-76	2/4	1203	B.T. cast
-77	2/4	1219	Hydrocast for nutrients and phytoplankton
-78	2/4	1346	1,000μ surface tow

<u>Station #</u>	<u>Date</u>	<u>Time</u>	<u>Description</u>
<u>AT-72-1-79</u>	2/4	1400	Secchi disc
-80	2/4	1430	Geochem. Radon sample
	2/4	1500	Return to St. Georges. Seas 8-10 feet; wind gusting to 30 knots.
	2/5		Seas 10-14 feet; wind 25-30, gusting to 40 knots. Cancelled sampling.
-81	2/6	0915	B.T. cast
-82	2/6	0930	Hydrocast for nutrients and phytoplankton
-83	2/6	1115	79 μ double net tow
-84	2/6	1215	202 μ double net tow
-85	2/6	1310	1,000 μ single net tow
-86	2/6	1400	79 μ double net tow
-87	2/6	1455	202 μ double net tow
-88	2/6	1540	1,000 μ single net tow. Winch trouble
-89	2/6	1810	1,000 μ single net tow, repeat.
-90	2/7	0600	B.T. cast, winch trouble.
-91	2/7	0645	Hydrocast for phytoplankton and nutrients to 200m.
-92	2/7	0800	Hydrocast for phytoplankton and nutrients, 200-1,000m. Winch only pulling 200 lbs.
-93	2/7	1035	202 μ surface net tow
-94	2/7	1052	1,000 μ surface net tow
	2/7	1130	Return to St. Georges. Broken injector in winch.

<u>Station #</u>	<u>Date</u>	<u>Time</u>	<u>Description</u>
AT-72-1-95	2/8	1020	B.T. cast, poor trace
-96	2/8	1035	B.T. cast repeat, winch trouble
-97	2/8	1130	Hydrocast for nutrients and phytoplankton; shortened. Repaired injector broken.
-98	2/8	1255	202 μ surface tow
-99	2/8	1315	1,000 μ surface tow
-100	2/8	1325	Geochem. Radon sample
	2/8	1400	Return to St. Georges
	2/9	1645	Replacement injector arrived from N.Y.
			Winds 25-30 knots in harbor, forecast for gusts to 40 knots. Cancelled sampling.
	2/10		Seas 12-14 feet; winds 30-35, gusting to 45 knots. Cancelled sampling.
-101	2/11	0810	Surface bucket for Chl. <u>a</u>
-102	2/11	0820	B.T. cast
-103	2/11	0827	Surface bucket for Chl. <u>a</u>
-104	2/11	0833	Hydrocast for nutrients and phytoplankton
-105	2/11	0920	Surface bucket for Chl. <u>a</u>
-106	2/11	1000	79 μ double net tow
-107	2/11	1052	202 μ double net tow
-108	2/11	1137	Surface bucket for Chl. <u>a</u>
-109	2/11	1145	1,000 μ single net tow
-110	2/11	1300	202 μ net tow for A. Be'.

<u>Station #</u>	<u>Date</u>	<u>Time</u>	<u>Description</u>
AT-72-1-111	2/11	1428	202μ surface net tow
-112	2/11	1440	79μ surface net tow for N_{15}
-113	2/11	1454	1,000μ surface net tow
-114	2/11	1500	Geochem. Radon sample
	2/11	1515	Return to St. Georges
-115	2/12	0820	B.T. cast
-116	2/12	0831	Hydrocast for nutrients and phytoplankton
-117	2/12	1020	79μ double net tow
-117a	2/12	1045	Geochem. Radon sample
-118	2/12	1130	202μ double net tow
-119	2/12	1216	1,000μ single net tow
-120	2/12	1310	79μ surface net tow for N_{15}
-121	2/12	1310	79μ surface net tow for N_{15}
-122	2/12	1321	202μ net tow for A. Be'.
-123	2/12	1428	1,000μ surface net tow
-124	2/12	1446	202μ surface net tow
	2/12	1452	Return to St. Georges
-125	2/13	0610	B.T. cast
-126	2/13	0625	Hydrocast for phytoplankton and nutrients
-127	2/13	0846	79μ double net tow
-128	2/13	0850	Surface bucket for N_{15}
-129	2/13	0949	202μ double net tow
-130	2/13	1046	1,000μ single net tow

<u>Station #</u>	<u>Date</u>	<u>Time</u>	<u>Description</u>
AT-72-1-131	2/13	1140	202μ net tow for A. Be'.
-132	2/13	1224	79μ surface net tow for ¹⁵ N
-133	2/13	1250	1,000μ surface net tow
-134	2/13	1320	Return to St. George. Start packing equipment.

I. THE SAMPLING PROGRAM

The goal of this program was to take a series of samples in the Sargasso Sea off Bermuda to determine the dry weight, carbon and nitrogen dynamics of the food web at the start of the vernal bloom. It was expected that nutrient mixing, phytoplankton growth, and herbivore growth would be observed, and that through frequent measurement of the standing stock of the various "nitrogen pools", rates of flux could be determined.

A. Location

Bermuda was chosen as the base for the sampling program for four reasons. 1) The shore facilities at the Bermuda Biological Station would allow rapid analysis of hydrographic samples and sorting of fresh zooplankton samples for later nitrogen analysis. 2) This station (34° 14' N, 64° 37' W) was occupied on our previous cruises. The dates and station numbers occupied at the Bermuda station for each cruise are respectively: 5/16/68, stations 66-75 (All-68-2); 10/26/68 to 10/28/68, stations 1-16 (Gib-68-1); 1/18/69 to 1/20/69, stations 114-135 (Gib-69-1); 9/7/69 to 9/10/69, stations 57-96 (Roc-69-1); 12/7/69 to 12/10/69, stations 1-16 (Miz-69-1); 1/6/70 to 1/8/70, stations 26-44 (Roc-70-1). 3) The food web in the Sargasso Sea is relatively simple and does not show great fluctuations. 4) Much biological and hydrographic work has been done in the Bermuda area and is reported in the literature.

B. Time of Sampling

From a survey of the previously reported work undertaken in the Bermuda area, it was expected that production would begin to increase during the last week of January. Our sampling program was begun just prior to that time.

C. Depth of Sampling

Samples were taken to 1,000 meters. From previous studies it was determined that the water mass is relatively unmixed below 1,000 meters and that the major part of the biological population is above 1,000 m.

D. Schedule

The program was based on a two day schedule with a day and a half at sea and an evening in port to return samples to the Bermuda Biological Station and for general maintenance.

Two Day Sampling Schedule

Day 1

Sunrise	Leave St. George Harbor
0830	On Station
0830	B.T. cast
0900	Hydrocast
1100	79 μ net tow
1200	202 μ net tow
1300	1,000 μ net tow
1400	79 μ net tow

1500 202 μ net tow
1600 1,000 μ net tow

Day 2

0600 B.T. cast
0630 Hydro cast
0830 79 μ net tow
0930 202 μ net tow
1030 1,000 μ net tow
1300 Arrive in St. George, drop samples.

The above schedule is the ideal, achieved in only the calmest weather. Frequently problems with ship's motion, equipment and extra sampling extended the time required to accomplish the station work.

II. HYDROGRAPHY

C. Garside, Ph.D., S. Williams, Ph.D.

A. Methodology

A B.T. cast was made to 200 meters on each day that the station was occupied. On Day 1, samples were taken at standard hydrographic depths for nitrate, nitrite, ammonia, silicate, phosphate, dissolved oxygen, pH, alkalinity, salinity, and temperature with 1.7 liter Niskin bottles equipped with reversing thermometers. On Day 2, only nutrients were sampled. Samples were kept in glass bottles for phosphate, nitrate, and ammonia, and in polyethylene bottles for silicate and nitrite, and analyzed within a few hours of reaching shore at the Bermuda Biological Station. Nutrient determinations were made using a

Technicon three channel Auto-Analyzer II. Dissolved oxygen was determined using a modified Winkler method (Strickland and Parsons, 1968). Salinity was determined with a Hytech Model 621 Salinity Conductivity meter. Alkalinity and pH were determined using a Corning Model 12 pH meter.

B. Results

Eighteen nutrient profiles were made, eleven of which, included all parameters. Data will be presented in the Technical Progress Report for 1972.

III. PHYTOPLANKTON ECOLOGY J. Currie, B.S.

A. Methodology

1. Dry weight, Carbon, Nitrogen

On Day 2, samples were taken at standard hydrographic depths with 12 liter Niskin bottles. 3.5 liters from each depth was then prefiltered through a 79 μ mesh, and then filtered through a 0.45 μ , 47 mm diameter preweighed Millipore filter for later dry weight determination. 6 liters from each bottle was filtered through a 0.33 μ , 47 mm glass fiber filter, after pre-filtering through a 79 μ mesh net, for later carbon and nitrogen determinations. All samples were frozen immediately.

2. Taxonomy

On Day 2, samples were taken at standard hydrographic depths for taxonomic determinations.

150 ml were filtered through a 0.45 μ , 25 mm Millipore filter, after prefiltration through a 20 μ mesh, for later examination by electron microscopy. On Day 1 and on Day 2, 500 ml of water taken at standard hydrographic depths were prefiltered through 79 μ mesh and preserved in 2% buffered glutaraldehyde for later examination by light microscope. The samples on the Millipore filters were preserved by drying in a dessicator and glutaraldehyde-preserved samples were stored at 45° F.

B. Results

Seven profiles for dry weight, carbon, nitrogen, and 0.45-20 μ taxonomy and eighteen profiles for 20-79 μ taxonomy were made. Data will be presented in the Technical Progress Report for 1972.

IV. ZOOPLANKTON ECOLOGY

J. Hillegas, B.S., V. Harris, Graduate Student

A. Methodology

1. Dry Weight, Carbon, Nitrogen and Taxonomy

Three nets were used: a double 79 μ mesh net with flared 79-202 μ cod end sieves and paired inner-outer flowmeters, a double 202 μ mesh net with flared 202-1000 μ cod end sieves and paired inner-outer flowmeters, and a single 1000 μ mesh net with flared 1000 μ cod end sieve and an inner flowmeter. Design specifics will be presented in the Technical Progress Report for 1972.

All tows were made vertically at 60 meters/minute from 1000 meters. A Benthos Time Depth Recorder was attached below the weight.

The sample from each net was split with a Folsom Splitter. One half of the sample was preserved in 500 ml of 4% buffered sea water/formaldehyde solution, and the other half was washed with 20 ml of 40% sodium sulfate solution and 20 ml of deionized water to remove salts, and then frozen on a mesh disc corresponding to the mesh of the net.

2. Fresh Sorting

To obtain true measurements of dry weight, carbon, and nitrogen in zooplankton samples in the $> 202\mu$ size ranges, fresh samples were sorted into the most abundant major taxonomic groups.

On Day 2 of the sampling cycle, samples were taken from 1/4 splits of the 202-1000 μ and 1000-10,000 μ size fractions and kept in 900 ml of filtered sea water at ambient temperature and light. The samples were transferred from the ship to the Bermuda Biological Station within four hours of the time they were taken. The 202-1000 μ size fraction was aerated immediately and the 1000-10,000 μ size fraction, being the most perishable, was sorted first.

The sorted major groups from both size fractions were placed on mesh discs corresponding to the mesh size of the nets and washed with sodium sulfate solution and deionized water. The discs were then placed in 2 oz. vials and frozen for later analysis at Lamont-Doherty Geological Observatory.

3. Zooplankton Culturing

The goal of the zooplankton culturing program was to find a herbivore, an omnivore, and a carnivore from the open ocean environment that could survive under laboratory conditions.

Culture specimens were originally taken from 1/4 splits of the $> 202\mu$ size fractions, but few organisms in good condition were found, so short surface tows specifically for culture material were added to the sampling program.

B. Results

1. Dry Weight, Carbon, Nitrogen, and Taxonomy

A total of 96 samples were taken. Daily coverage for the first third of the cruise (1/22 through 1/30) was obtained. Coverage during the remaining part of the cruise was not as complete due to weather and mechanical problems; sampling dates for this period include 2/1, 2/6, 2/11, 2/12, and 2/13. The nets performed according to design specifications.

2. Fresh Sorting

A total of 14 samples of the 79-202 μ and 10³-10⁴ μ net tows were collected from stations 10, 11, 24, 25, 41, 42, 63, 64, 107, 109, 118, 119, 129, and 130, and these were fresh sorted into the most abundant major groups. Approximately 200 organisms were separated from each 79-202 μ sample; the fresh sorted organisms of this size consisted almost totally of copepods and ostracods. With the 10³-10⁴ μ fraction from 50 to 150 organisms were sorted. Eight different major groups were segregated from this fraction - with copepods being the most abundant.

3. Shipboard Cultures

61 cultures, each consisting of approximately 10 inoculating organisms, were started, but mortality was high and less than a third were shipped in viable condition to Lamont. No organisms survived for more than two months after their return to Lamont.

V. ¹⁵N UPTAKE EXPERIMENTS

Preliminary experiments were done to determine the feasibility of measuring in situ rates of nitrogen flux in a large sampling bag.

Coccolithus huxleyi was grown with ¹⁵N-labeled NaNO₃ as the only nitrogen source. Approximately 500 ml of culture at 4 x 10⁷ cells/l were transferred at ambient temperature and

light to 20 liters of sea water which had been previously filtered through 0.3 μ glass fiber filters. Zooplankters were collected at stations 112, 120, 121, and 132 by 5-minute surface tows with a double or single 79 μ net and 79-202 μ cod end sieves. These zooplankters were added to the filtered sea water at the same time.

The ^{15}N -labeled phytoplankton/zooplankton mixture was incubated for 12-18 hours under aeration at ambient temperature and light in the laboratory at the Bermuda Biological Station.

After incubation the entire 20 liters was poured through a 79 μ filter and then through a 0.33 μ glass fiber filter. The samples on both filters were frozen for later ^{15}N analysis at Lamont.

B. Results

Three ^{15}N uptake experiments were done. Detailed results will be presented in the Technical Progress Report for 1972.

ACKNOWLEDGEMENTS

We are grateful for the interest and cooperation of the scientists and staff of the Bermuda Biological Station and the Captain and crew of the R/V ATLANTIC TWIN without whose help none of this work would have been possible.

**LAMONT-DOHERTY GEOLOGICAL OBSERVATORY
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PALISADES, NEW YORK

AN EVALUATION OF THE PLANKTON NETS USED ON AT-72-1

Julian Hillegas

Introduction

Comparison of inner and outer flowmeter records of 72 plankton tows made on ALL-68-2, GIB-68-1, GIB-69-1, ROC-69-1, and ROC-70-1 with 75 μ , 202 μ , and 1000 μ mesh nets with .25m², .25m², and 1m² mouth areas, respectively, indicated that over half the tows were not quantitative (that the volume sampled was less than 85% of the volume of the water column). The oblique tows made on the first two cruises resulted in a higher percentage of quantitatively unacceptable samples than did the vertical tows made on the last three cruises. Even though the standard error of volume sampled by the paired nets used on the last three cruises was 9%, comparison of inner and outer flowmeter records showed that almost 40% of these tows were quantitatively unacceptable.

Clogging of the mesh was undoubtedly the chief cause of unacceptable tows, but flowmeter malfunction and unsuitable net design were also considered contributing factors.

Design Specifications

New nets were designed to overcome the problem of clogging and to provide reserve filtration area (National Academy of Sciences, 1969) for sampling in areas of high population density.

This aim was achieved through the use of high open area to mouth area ratios. A circular mouth opening was incorporated to insure uniform flow around the nets (Tranter and Smith, 1968). A cylinder-cone shape

was chosen for the increased open area possible for a given length (Tranter and Smith, 1968). Mouth areas of $.125\text{m}^2$, $.125\text{m}^2$, and 1m^2 for 79μ , 202μ , and 1050μ mesh nets, respectively, were chosen for the large open area possible without the sacrifice of manageability (National Academy of Sciences, 1969). The meshes were the highest porosity available in the area of 76μ , 202μ , and 1000μ .

Figures 1 and 2 show the specifications and construction details of the nets.

Sampling Procedure

A paired towing arrangement (Figure 3) was used for the $.125\text{m}^2$ nets and a single towing arrangement (Figure 4) was used for the 1m^2 net.

Volume sampled was measured with an inner and an outer TSK flowmeter on the $.125\text{m}^2$ nets and with an inner TSK flowmeter on the 1m^2 net. Inner flowmeters on all nets were located one half the distance between the edge and the center of the net mouth such that they were unobstructed by the towing bridle. The same flowmeter pairs were used on the net pairs of both mesh sizes. Factory flowmeter calibration factors were used to compute volume sampled.

Flared cod-end sieves were used on all nets (Roels, et al., 1969), and a Benthos, Inc. time depth recorder was attached below the weight on all tows.

All samples were taken vertically from 1000 meters at a towing velocity of 60m/min.

Results

A total of 97 plankton samples, consisting of 39 paired tows with .125m² nets and 19 single tows with the 1m² net, were taken on AT-72-1 between January 22 and February 13, 1972 at a single station 9-1/2 miles east of Gibbs Hill Light, Bermuda (Cruise Report: AT-72-1, COO-3222-01, 1972).

Manageability: Even though the nets were lifted in and out of the water with a "cherry picker" type crane, they were on the borderline of manageability for three people when the wind was 35 knots and the seas 10 feet. No tows were attempted under more extreme conditions as it was felt that harm to either nets or personnel would have been inevitable. Under favorable conditions, the nets were relatively easy to manage.

While these nets could be cast by hand, a boom or a crane would be essential on a vessel with low freeboard to permit washing the sample into the cod-end bucket.

Durability: The .125m² nets withstood the rigors of almost daily use very well. A few small abrasion holes appeared in the upper portion of the nets after two weeks of use.

Design faults were found in the 1m² net. The frame, made of 1/2" diameter stainless steel rod, was badly bent during a tow made under poor weather conditions. During the same tow, the net material, a non-locked weave, separated from the mouth collar. The cause was a snarled bridle wire resulting in uneven vertical stress.

The faults could be corrected by using 5/8" diameter stainless steel rod for the frame, and by quadruple stitching a 4" over-lap of net material and mouth collar material.

Filtration Efficiency: The design of the 1m^2 net was based on that of the WP-3 net, which has a filtration efficiency of 98% (Tranter and Heron, 1968), and was, therefore, assumed to have an equal filtration efficiency.

The filtration efficiency of the $.125\text{m}^2$ nets was estimated by dividing the inner flowmeter reading by the outer flowmeter reading after correction by individual flowmeter calibration factors. The resulting figures represent the percentage of a $.125\text{m}^2$ water column sampled by the nets, and in the absence of clogging, may be considered as filtration efficiency.

Table 1 shows that mean filtration efficiencies ranged from 97.789% to 101.294%. The means of the 79μ mesh nets and the 202μ mesh nets were 101.189% and 99.421% respectively, indicating that mesh size had ^{an} insignificant effect on filtration efficiency. The mean filtration efficiencies of nets a and b in both size fractions indicated comparable performance except in net b, 202μ mesh, which had a mean filtration efficiency of 97.789%. Flowmeter pairs a and b performed comparably, at 101.167% and 99.487%, respectively. The slightly lower value of flowmeter pair b is probably a reflection of the lower efficiency of net b, 202μ mesh.

Variability in Performance

The standard deviation of filtration efficiencies was calculated in the usual way.

$$S.D. = \sqrt{\frac{\sum (f - \bar{f})^2}{n-1}}$$

Table 2 shows that while all standard deviations were small, ± 2.96 and ± 4.17 for the 79μ and 202μ mesh nets, respectively, 202μ mesh net b was at least twice as variable (± 6.20) as the other three nets.

The variability of flow between net pairs was calculated by determination of standard deviation using an assumed mean flow between nets of 100.

$$f_a \text{ (or } f_b) = \frac{\text{flow in a (or b)} \times 200}{\text{flow in a} + \text{flow in b}}$$

$$S.D. = \sqrt{\frac{2\sum (f_a - 100)^2}{n-1}}$$

$$\text{Since: } 2\sum (f_a - 100)^2 = \sum (f_a - 100)^2 + \sum (f_b - 100)^2$$

Table 2 shows that the variability was greater in the 202μ mesh net pairs, ± 6.52 and ± 3.32 for inner and outer flow, respectively, than in the 79μ mesh net pairs, ± 2.19 and ± 1.12 for inner and outer flow respectively. Inner flow was, as expected, more variable than outer flow, but the higher variability of 202μ net pair outer flow as compared to 79μ net pair outer flow, was unexpected.

Flowmeter Variability

The standard deviation all four flowmeters used on a double net was calculated for both mesh sizes using an assumed mean of 100 as above. The results, shown in

Table 3, are not absolute values since each net in a net pair filtered a different amount of water and since the filtration efficiency was not exactly 100%, but they do indicate the relative tendencies of each flowmeter.

Inner flowmeter b was the most variable, ± 2.7849 for the 79μ mesh net and ± 7.9977 for the 202μ mesh net. The mean for the 202μ mesh net (97.7223%) was lower than the means of the other nets, indicating that it was recording low values. Table 3 also shows that variability is greater for the 202μ nets than for the 79μ nets. Further, the variability ratios for each size fraction show that inner b was affected disproportionately by the 202μ mesh net.

Rejection of Samples

Flow data may be rejected on the basis of inner/outer comparisons and net a to net b comparisons. In the absence of clogging, inner flow/outer flow should be 100% and the net a to net b ratio should be 1:1. Any deviation from these means indicates that a non-representative sample has been taken. Critical values can be found in student's t-distribution tables. In general, assuming more than 15 samples, any piece of data falling outside 3 standard deviations from the mean can safely be rejected.

Two samples from the 202μ nets could be rejected on the basis of unacceptable inner/outer deviation by the criteria described above.

Conclusions

I. Precision of Sampling

The nets of both mesh sizes performed well, with filtration efficiencies in the area of 100% and inner/outer flow variation of about 2% at one standard deviation. These field determinations should, however, be compared with testing tank or wind tunnel tests.

There is no explanation at this time for the larger flowmeter variability of the 202 μ nets. The only difference between the design of the 79 μ nets and that of the 202 μ nets was the greater porosity of the 202 μ mesh. The greater porosity should not, however, cause greater flow variation. Likewise, there is no explanation for the disproportionate variability of inner flowmeter b.

Flowmeter performance, therefore, remains the weak link in high precision measurements of zooplankton populations, regardless of the accuracy of sampling.

II. Accuracy of Sampling

The accuracy of sampling is a matter of avoidance, escapement, and sampling procedure. Avoidance can be controlled by using nets of large diameter. Escapement is not a problem if a series of nets with different mesh sizes is used. If more than one net tow is made, patchiness can be estimated.

The nets described above may have one weakness in accuracy of sampling: the relatively small mouth area

of the 79 μ and 202 μ nets. However, it was felt that the high reserve filtration area and the resultant absence of clogging offset the gains that might have been achieved with a larger mouth area. In any case, a larger mouth area with the same open area ratio would have resulted in practically unmanageable nets. Manageability could be improved only by reducing the length of the net and, thus, the reserve filtration area.

Vertical tows were favored over oblique tows because whereas oblique tows sample more water and, therefore, tend to even out patchiness, vertical tows reflect patchiness. A double vertical tow filters half again as much water as a single oblique tow and the average of the paired samples has more value than the figure obtained from a single oblique tow. It could be argued that paired oblique tows would provide more representative samples. This may, in fact, result in a truer estimate of the mean, but population variance, a highly important factor in descriptions of a population, might well be masked.

The author is most indebted to Dr. C.A. Garside for his recommendations on statistical methods.

FIGURE 1

SPECIFICATIONS FOR HIGH OPEN AREA 79u AND 202u NETS

TYPE: Cylinder-Cone

MOUTH AREA: $.125\text{m}^2$ DIA: 40 cm

LENGTH: 3.95m (Cyl: 2m, Cone: 1.75m)

AREA OF MESH: 3.6m^2

POROSITY, 79u MESH: 42%

OPEN AREA RATIO: 12:1

POROSITY, 202u MESH: 47%

OPEN AREA RATIO: 13.5:1

MATERIAL

Mouth collar and cod end collar:
6.5oz. Dacron sailcloth.

Seam tape: 9/16" Nylon binding
tape.

Mesh: 79u mesh Nitex Heavy Duty
Screen Cloth or 202u Nitex Monofilament
Bolting Cloth.

Grommets: 3/16" I.D., Plain lock.

FIGURE 2

SPECIFICATIONS FOR HIGH OPEN AREA
1050u-1m² NET

TYPE: Modified WP-3; Cylinder-Cone

MOUTH AREA: 1m² DIA: 113cm

LENGTH: 4.0m (Cyl: 2m, Cone: 2m)

AREA OF MESH: 10.6m²

POROSITY: 59%

OPEN AREA RATIO: 6.25:1

MATERIAL

Mouth collar and cod end collar:
6.5oz. Dacron sailcloth.

Seam tape: 9/16" Nylon binding
tape.

Tape ties: 9/16" Nylon binding
tape. Placed every 6" around cir-
cumference of cylinder base and
down seam tape at 90 intervals.

Mesh: 1050u Nitex Heavy Duty
Screen Cloth.

FIGURE 3

TABLE 1

Efficiency of $.125\text{m}^2$ Plankton Nets

Total tows - 78
Flowmeter failure - 3

Efficiency (%)			
n = 37	Inner/Outer,	79 μ mesh, mean -	101.189
n = 17	"	79 μ net a, "	- 101.294
n = 20	"	79 μ net b, "	- 101.100
n = 38	"	202 μ mesh, "	- 99.421
n = 19	"	202 μ net a, "	- 101.053
n = 19	"	202 μ net b, "	- 97.789
n = 36	"	all a, "	- 101.167
n = 39	"	all b, "	- 99.487

TABLE 2
 Variability of .125m² Plankton Net Tows

Inner/Outer, 79μ mesh, all	±2.96
79μ, net a	±2.69
79μ, net b	±3.20
202μ mesh, all	±4.17
202μ, net a	±2.13
202μ, net b	±6.20
Net a: net b, Inner, 79μ mesh	±2.19
202μ mesh	±6.52
Outer, 79μ mesh	±1.12
202μ mesh	±3.32

TABLE 3

Flowmeter Variation

I. 79 μ mesh, .125m² net tows, standard deviation $\bar{x}$ = 100.8580 Inner a - ± 2.0599 $\bar{x}$ = 100.2701 Inner b - ± 2.7849 $\bar{x}$ = 99.6038 Outer a - ± 1.9324 $\bar{x}$ = 99.3272 Outer b - ± 1.4141

Ia	:	Ib	:	Oa	:	Ob
1.46	:	1.97	:	1.37	:	1

II. 202 μ mesh, .125m² net tows, standard deviation* $\bar{x}$ = 101.3150 Inner a - ± 3.4606 $\bar{x}$ = 97.7223 Inner b - ± 7.9977 $\bar{x}$ = 100.2799 Outer a - ± 2.9753 $\bar{x}$ = 100.6823 Outer b - ± 2.3301

Ia	:	Ib	:	Oa	:	Ob
1.49	:	3.43	:	1.28	:	1

* 1 sample rejected due to flowmeter blockage or improper resetting

LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

OF COLUMBIA UNIVERSITY

PALISADES, NEW YORK

LIST OF RESEARCH DOCUMENTS

- CU-3826-01 : Technical Progress Report, Feb. 1/67-Oct. 30/67.
- 02 : Technical Progress Report, Feb. 1/68-Oct. 30/68.
- 03 : Cruise Report, GIB-68-1.
- 04 : "Pteropods as indicators of water masses off Cape Hatteras, North Carolina".
- 05 : "Influence of the mode of nutrition on the digestive system of Ochromonas malhamensis".
- 06 : Operations Order, GIB-69-1.
- 07 : Technical Progress Report, Nov. 1/68-Sep. 30/69.
- 08 : Cruise Report, GIB-69-1.
- 09 : Operations Order, ROC-69-1.
- 10 : Cruise Report, ROC-69-1.
- 11 : Operations Order, MIZ-69-1.
- 12 : "Nitrogen metabolism of Ochromonas malhamensis: Urate breakdown and urea assimilation in O. malhamensis".
- 13 : "Artificial upwelling".
- 14 : Cruise Report, ROC-70-1.
- 15 : Cruise Report, MIZ-69-1.
- 16 : "A series of photographs".
- 17 : Technical Progress Report, Oct. 1/69-Oct. 30/70.
- 18 : "Fertilizing the sea by pumping nutrient-rich deep water to the surface".
- 19 : "Artificial upwelling - OTC-1179".
- 20 : "Deep ocean water as a resource for combined mariculture, power and fresh water production".
- 21 : "An improved method to determine glyoxylic acid".

LIST OF RESEARCH DOCUMENTS (continued):

22: Technical Progress Report, Nov. 1/70-Oct. 31/71.

23: "Nitrogen metabolism of aquatic organisms.
II: The assimilation of nitrate, nitrite
and ammonia by Biddulphia aurita."

24: "Cold, nutrient-rich water: the most abundant
resource of the deep sea."

Contract Number Changed by Chicago Operations Office:

COO-3222-01: Cruise Report, ATLANTIC TWIN-72-1

02: Technical Progress Report, Nov. 1/71-Oct. 31/72.