**Title**
MARINE SCIENCES GROUP ANNUAL REPORT - 1980



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**Publication Date**
1981-11-01

LBL-13579
UC-64

# Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

## EARTH SCIENCES DIVISION



MARINE SCIENCES GROUP ANNUAL REPORT - 1980

Marine Sciences Group

November 1981





Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

## DISCLAIMER

LBL 13579

# MARINE SCIENCES GROUP

# ANNUAL REPORT - 1980

Marine Sciences Group

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Berkeley, California 94720

November 1981

This work was prepared for the Assistant Secretary for Conservation and Renewable Energy, Office of Solar Power Applications, Division of Ocean Energy Systems, of the U.S. Department of Energy under Contract W-7405-ENG-48.

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## INTRODUCTION

Environmental aspects of using the oceans as an energy source are being coordinated for the Department of Energy by the Marine Sciences Group of the Earth Sciences Division. The technologies being considered are Ocean Thermal Energy Conversion (OTEC), salinity gradients, wave power, tidal power, and ocean currents. At present (November 1980) only OTEC is being funded to a pilot plant level with the other technologies remaining at the feasibility study level. The Marine Sciences Group acts as lead laboratory for environmental studies, specifically for the OTEC program. As such, LBL has reponsibility for fundamental research investigations in the tropical oceans for management of other environmental research groups in the private and public sectors to provide integration of the environmental data, insuring compliance with environmental regulations. The basic research requirements of the OTEC program include collection, analyses, and evaluation of serial fundamental physical, chemical, biological and geological oceanographic site and regional data to characterize the natural variability. The applied use of such studies is to estimate the extractable energy resource allowable with minimal or non-detectable environmental change to provide designers and engineers with the specific environmental conditions required for safe and efficient technical extraction of the resource.

Thus far, site specific oceanographic data has been collected in the Gulf of Mexico (two sites) Puerto Rico, Hawaii (two sites), and a regional study in the equatorial South Atlantic. Potential additional ner-term sites are Key West, Guam and the Virgin Islands (Figure 1). Formal environmenal assessments have been issues for (1) generic OTEC-1 megawatt plant, (2) programmatic OTEC, and (3) generic OTEC 10/40 megawatt plant.

## BIOLOGICAL OCEANOGRAPHIC RESEARCH

During the past year the Marine Sciences Group, OTEC Biological Oceanography Program was oriented along three avenues of research. These are presented below.

1. OTEC site descriptions:

This was a field effort aimed at providing a biological description of the water masses at potential OTEC sites. The purpose of these studies is to provide information useful to design engineers, environmental engineers, and the scientific oceanographic community. This work was performed by subcontractors to specifications designed by the Marine Sciences Group.

A. Zooplankton distributions in the upper 1000 m of tropical oceans at OTEC sites vary greatly (Fig. 2). Generally, there is a decrease in zooplankton abundance with depth. In Hawaii, however, there is generally a subsurface zooplankton abundance maximum. This

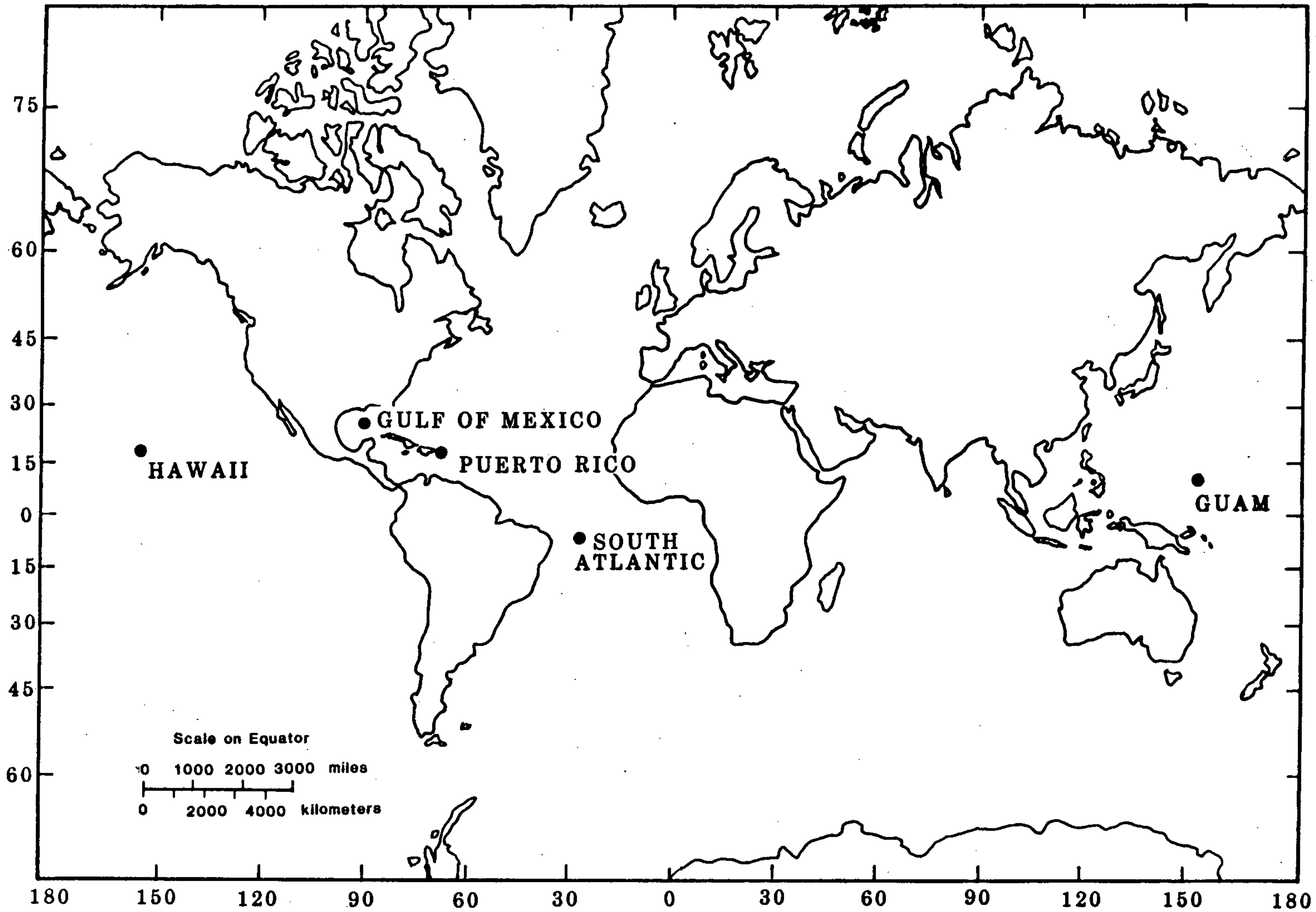


FIGURE 1 **LOCATION OF SELECTED SITES OF INTEREST** XBL 8012-13520

TOTAL ZOOPLANKTON DEPTH DISTRIBUTION AT FOUR OTEC SITES

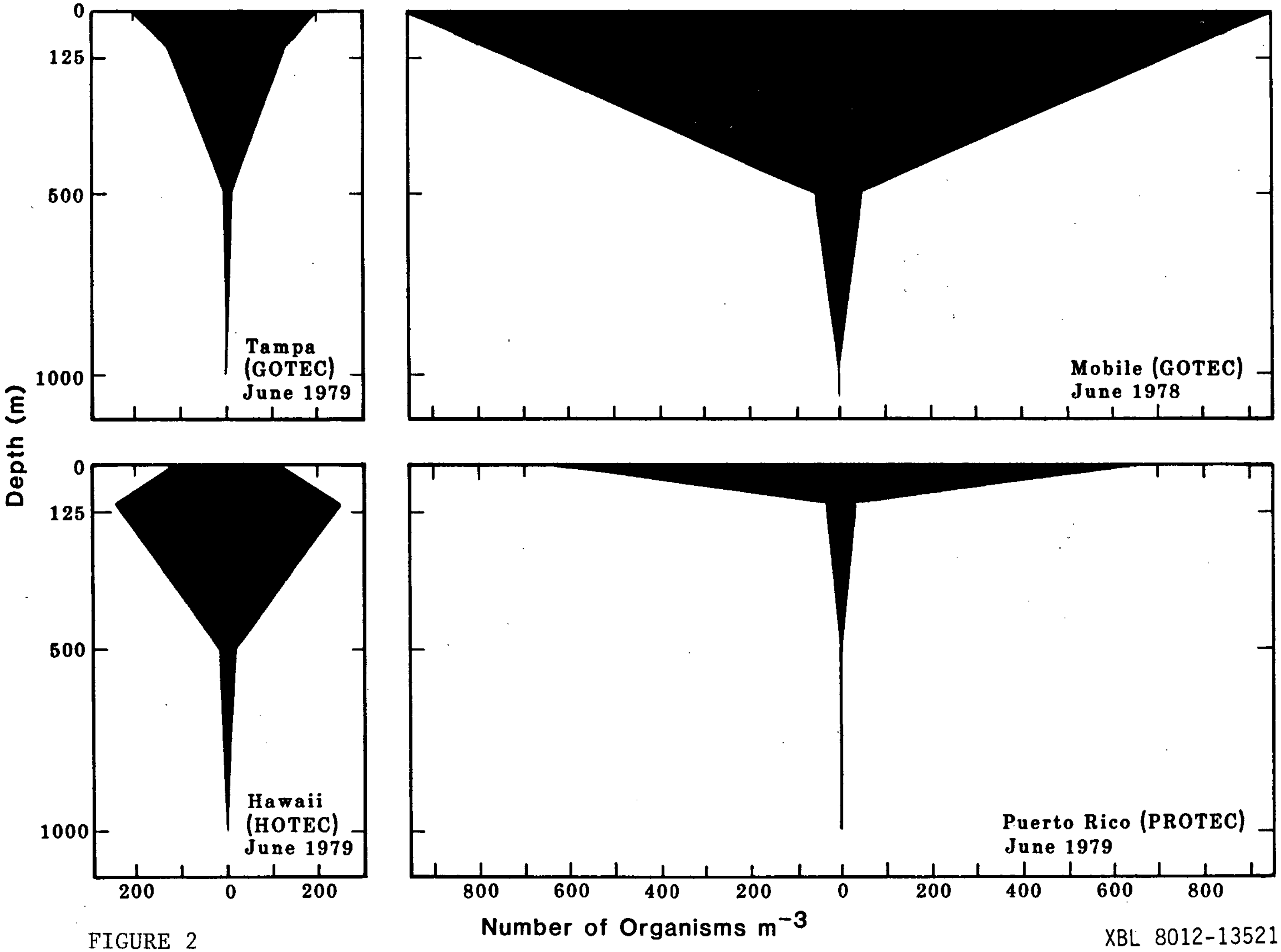


FIGURE 2

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subsurface maximum is duplicated in the biomass indicator data (Fig. 3A, 3B, Chlorophyll a, Phaeophytin and ATP). However, we presently have no conclusive proof that the distributions are correlated. This is partially due to the fact that in the upper water layers, where organisms are concentrated, their distribution is patchy and their abundance highly variable. These problems may be overcome analytically by extensive sampling over time.

OTEC warm water intakes will entrain the biological community in the upper 25m. This water mass contains a high biomass which varies temporally and spatially. Many zooplankters undergo a diel vertical migration yielding both a high variability temporally as well as spatially in the vertical direction. Horizontal variability is the result of the patchy distribution of zooplankton. These faunal distributions are related to inter- and intraspecific competitive pressures, e.g. predation, feeding, and reproduction. Sampling for zooplankton must, therefore, attempt to adequately sample this variability.

OTEC deep, cold water intakes are located at depths of (600 m-1000 m). These waters contain low densities of organisms. The distribution of these organisms have yet to be adequately defined because of the problems in sampling at great depths. Our data to date, indicate no diurnal variability and we hope to address longer term temporal variability as well as spatial variability.

B. The size of individual zooplankters and the taxonomic composition of the zooplankton community is being investigated to permit a post deployment assessment of OTEC on the zooplankton community. Table 1 shows the variability in taxonomic composition with depth and time of day at the Gulf Coast OTEC site off Tampa Bay (TAM).

C. Taxonomic and distributional studies of micronekton, and ichthyoplankton communities were initiated this year at the Puerto Rico OTEC site. The first vertically stratified samplings to 1000 m have been made (November, 1980) but are not yet analyzed.

D. The phytoplankton distributions were examined at the potential OTEC sites using chlorophyll a as the the living biomass indicator and phaeopigment as the detrital indicator. ATP (adenosine triphosphate) distributions of total living biomass were then compared to phytoplankton distributions. In Figures 3A and 3B the ATP maxima is above the chlorophyll a maxima. This relationship may be the result of changes in the chlorophyll a /ATP ratio in phytoplankton, the presence of a population containing ATP but no chlorophyll a or a combination of both.

2. In-house research efforts:

This research consisted of field, laboratory and theoretical efforts. The purpose of the research was to answer specific environmental questions normally not part of a site description.

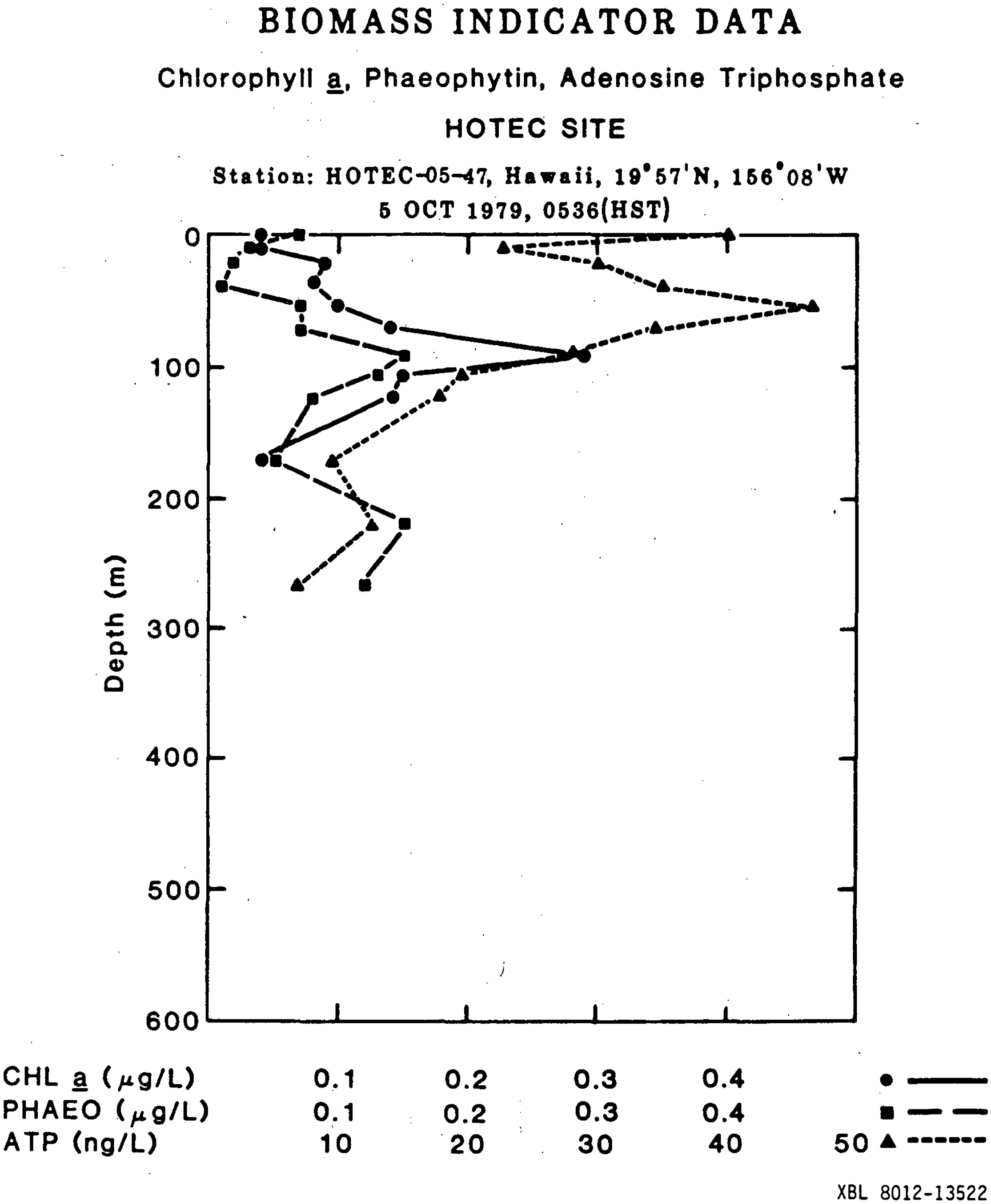
BIOMASS INDICATOR DATA
Chlorophyll a, Phaeophytin, Adenosine Triphosphate
HOTEC SITE
Station: HOTEC-05-47, Hawaii, 19°57'N, 156°08'W
5 OCT 1979, 0536(HST)
Depth (m)
0
100
200
300
400
500
600
CHL a (μg/L) 0.1 0.2 0.3 0.4
PHAEO (μg/L) 0.1 0.2 0.3 0.4
ATP (ng/L) 10 20 30 40 50
XBL 8012-13522

FIGURE 3A

# BIOMASS INDICATOR DATA

Chlorophyll a, Phaeophytin, Adenosine Triphosphate

HOTEC SITE

Station: HOTEC-05-41, Hawaii, 20°01'N, 156°04'W

4 OCT 1979, 1806(HST)

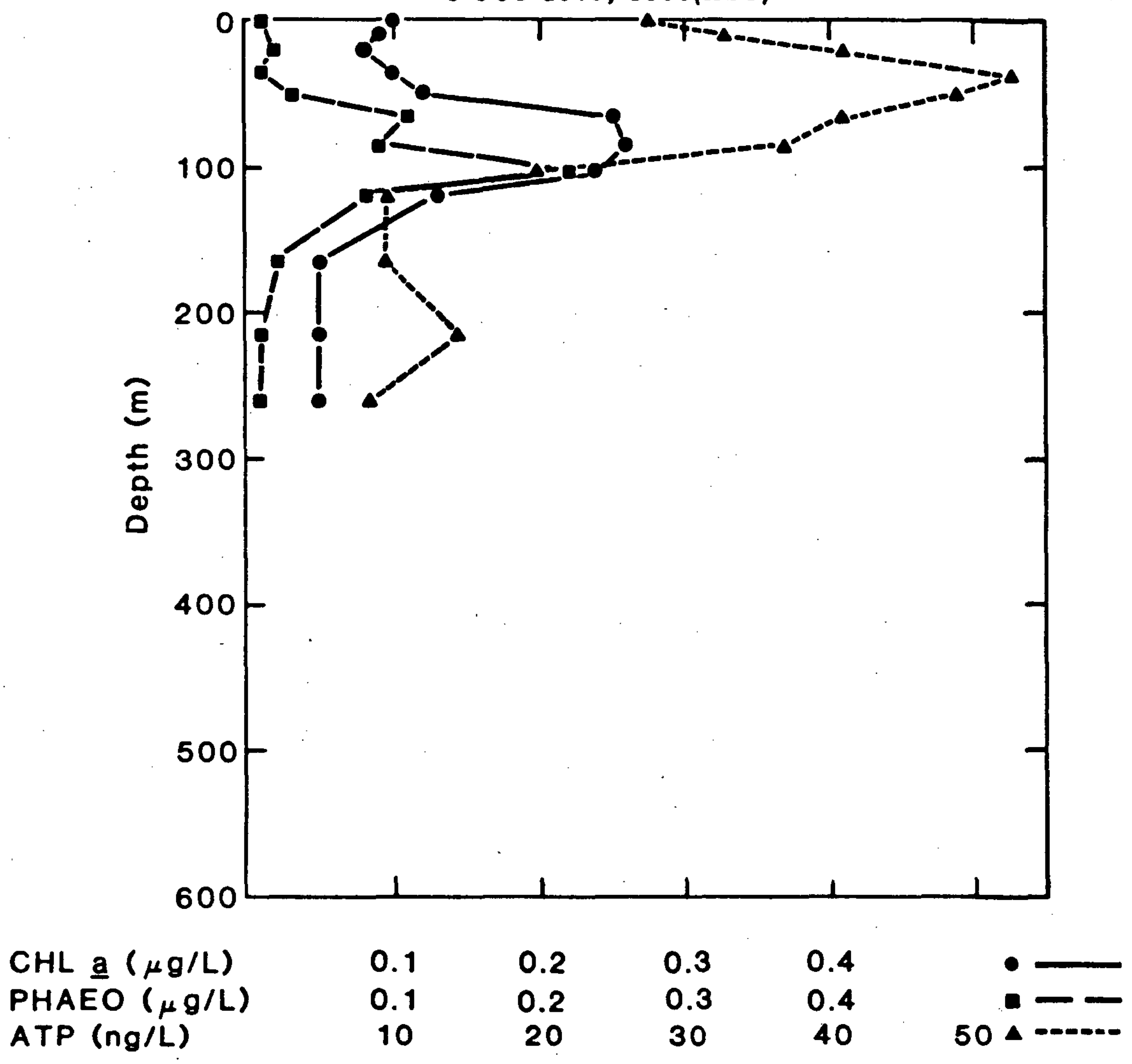


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FIGURE 3B

A. The fine structure distribution of zooplankton within the upper 25 m water column (OTEC warm water entrainment depths) is not known. We recently completed the first vertically stratified sampling at 5 m intervals from the surface to 25 m. A preliminary look at these samples revealed little difference between the various layers except the surface layer (neuston) which appeared to contain a higher biomass. Further taxonomic and distributional statistical analysis is being completed.

B. Methods for analyzing phytoplankton biomass (Estrella and Hartwig, 1980) plus phytoplankton numbers and taxonomy at potential OTEC sites were examined. The distribution and composition of taxonomic groups varied greatly. The major groups were diatoms, dinoflagellates, unidentified nannoplankton and unidentified other. The unidentified portion of the community comprised from 10% to 70% of the total phytoplankton community. With such a high percentage of unidentified phytoplankters it will not be possible to assess the effect of OTEC on total phytoplankton species distribution. However, OTEC's effect on taxonomic groups e.g., diatoms and dinoflagellates, and their size distribution can be assessed.

As a product phytoplankton studies MSG has been investigating preservation and counting methods. Glutaraldehyde, Lugols iodine, and chromacetic acid preservatives were tested. Chromacetic acid proved to be the poorest preservative in terms of both the quality of preservation (flagella removed, cells distorted) and quantity of cells preserved. Gluteraldehyde and Lugols iodine preserved equally well but due to the toxic nature of gluteraldehyde, Lugols iodine would be the preferred fixative.

Phytoplankton cells are counted using an inverted light microscope following settling of cells into counting chambers. Random fields of known area are counted and the number corrected for the total area. However, we have found that there is an edge effect in the chamber with reduced numbers present within two fields of view of the edge. This affect must be accounted for in the final area correction.

C. Bioassays were initiated in Hawaii to assess the impact of mixing deep, nutrient rich water with the near surface nutrient depleted waters. The bioassays also looked at the impact of an ammonia (OTEC working fluid) spill on surface waters. Figure 4 shows that the addition of ammonia to water collected at 25 m produces an initial increase in the rate of $H^{14}CO_3^-$ uptake and that the ammonia is preferentially taken up until the ammonia level is reduced below approximately 1.0 ug-at $l^{-1}$. When nitrate rich 800 m water is mixed with 25 meter 100 m water the same basic response is observed and nitrate is utilized (Fig. 5).

D. OTEC generating stations propose to use chlorine as a biofouling control agent. With the large amounts of chlorine needed it is of value to have an understanding of the ultimate fate of this chemical in the marine environment.

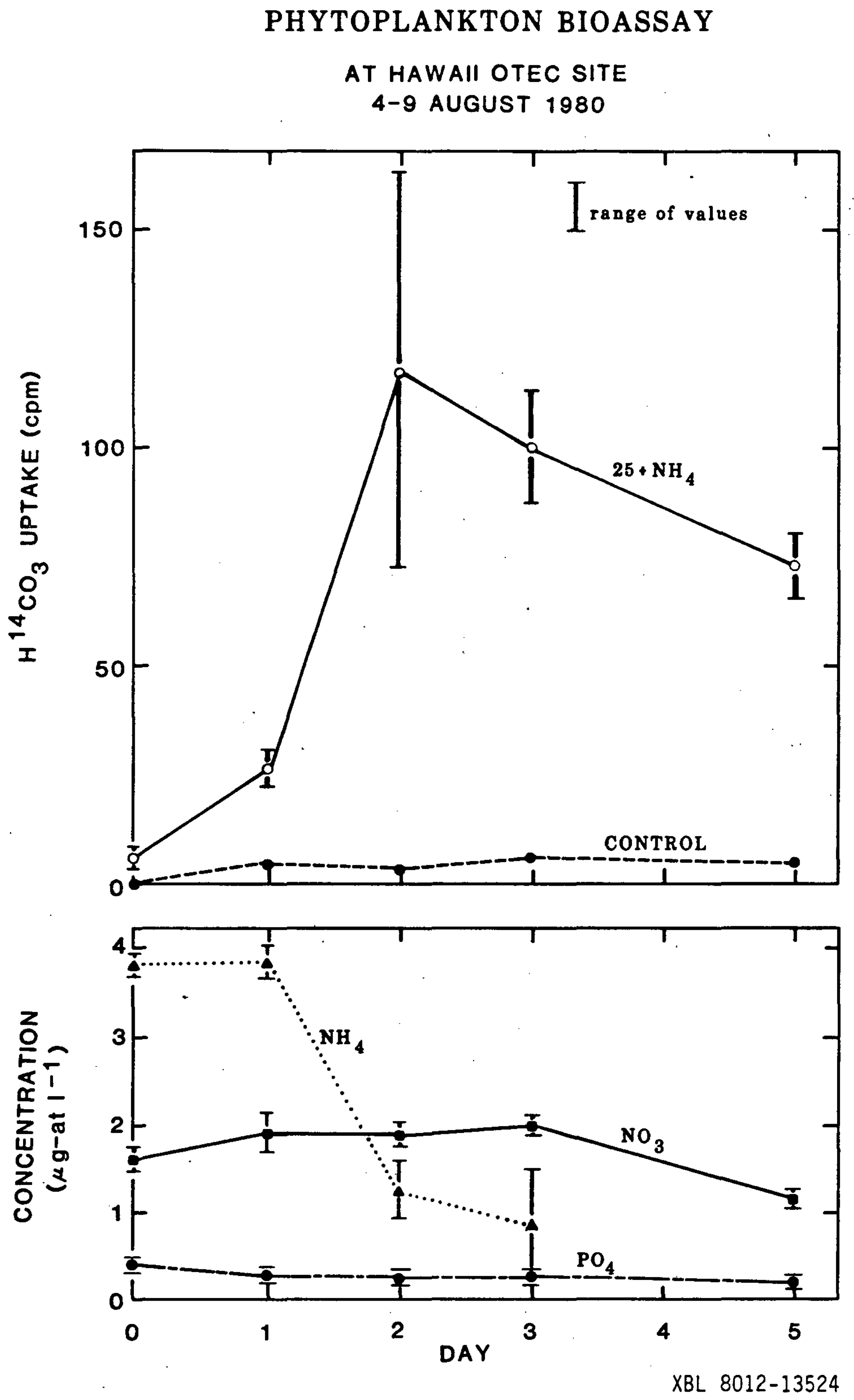
PHYTOPLANKTON BIOASSAY
AT HAWAII OTEC SITE
4-9 AUGUST 1980
range of values
150
100
50
0
H 14CO3 UPTAKE (cpm)
25+NH4
CONTROL
4
3
2
1
0
CONCENTRATION (μg-at l-1)
NH4
NO3
PO4
0
1
2
3
4
5
DAY
XBL 8012-13524

FIGURE 4

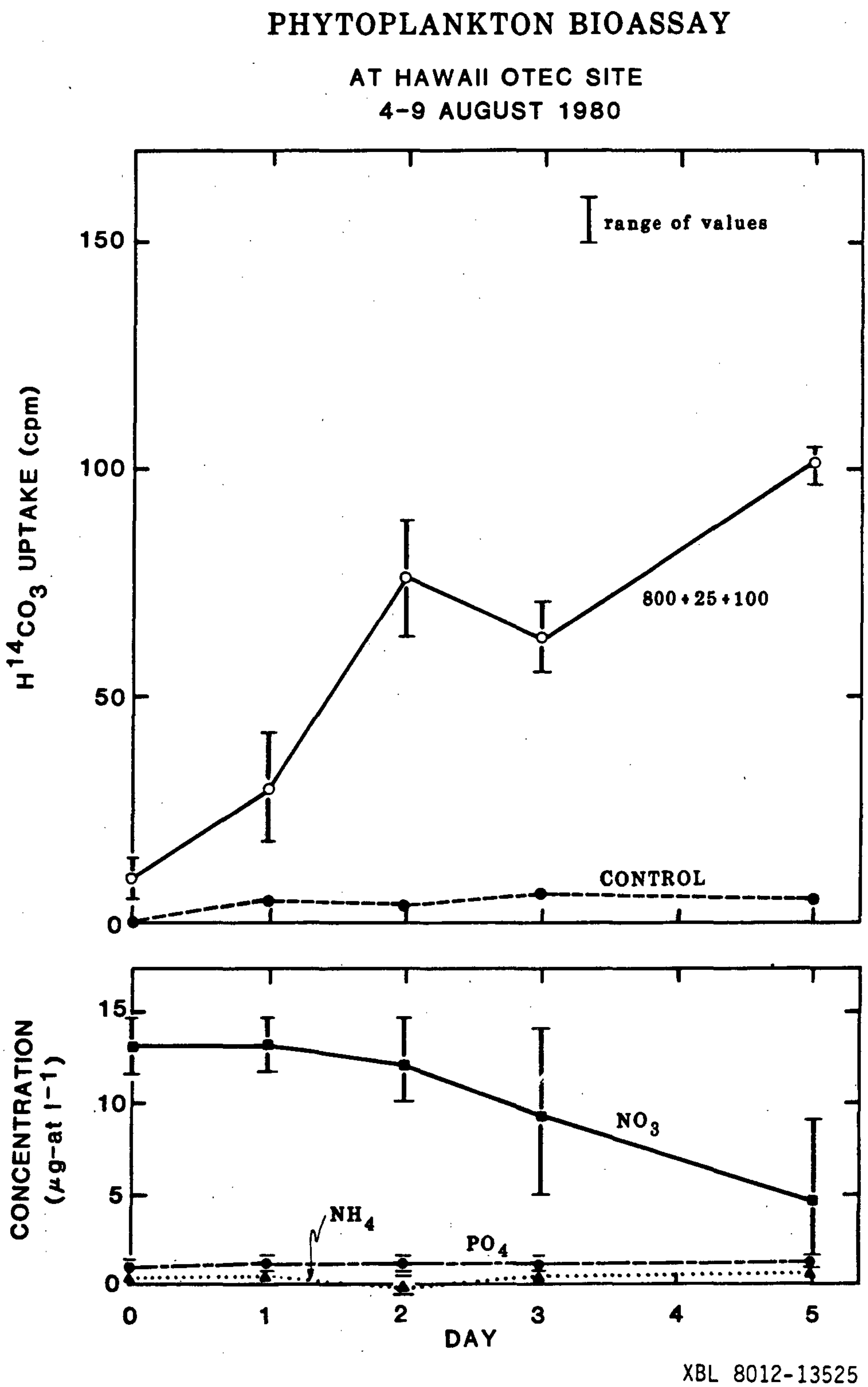
PHYTOPLANKTON BIOASSAY
AT HAWAII OTEC SITE
4-9 AUGUST 1980
range of values
150
100
50
0
$H^{14}CO_3$ UPTAKE (cpm)
800+25+100
CONTROL
15
10
5
0
CONCENTRATION
(μg-at $l^{-1}$)
$NO_3$
$NH_4$
$PO_4$
0
1
2
3
4
5
DAY
XBL 8012-13525

FIGURE 5

One type of possible degradation mechanism involves the reactions of chlorine (an oxidizing agent with reducing compounds, both organic and inorganic. In the marine environment bromide is an inorganic reducing agent found at significant concentrations. The formation of chloramines (mono-, di-, and tri-substituted) from the reaction of chlorine with ammonia (OTEC working fluid) and organic amines are fates of chlorine which present special toxicity problems. Chloramines have been found to react with bromides at a rate observed to following expression:

$$r = K\ [Br]\ [H^{+}]\ [NH_2Cl].$$

Total oxidant decomposition was shown to involve perhaps several intermediates. This work was concurrently verified by Trofe, Johnson and Inman at the University of North Carolina.

Organic amines have been found to react similarly although not consistent with the above expression in all instances. The total oxidant concentration in a seawater-chlorinated effluent mixture decays at an instantaneous rate given by:

$$r = \{K_1\ [Br^-] + K_2\}\ C$$

where

$K_1$ = bromide reation rate constant
$K_2$ = non-bromide reaction constant
$C$ = Total oxidant concentration

E. The nekton, actively swimming organisms such as fish, squid, and marine mammals, at tropical OTEC sites are being investigated with respect to what organisms are likely to interact with a power plant and the known natural history information about the permanent or seasonal residents (Jones, 1980; Ryan and Jones, 1980; Ryan, 1980).

Through searching the marine literature and records of commercial fishermen, derived faunal lists can initiate study to describe the organisms and their detailed habitat. The long-term record of commercial fishermen, maintained by local government agencies, can indicate temporal fluctuations in fishing stocks. The record of fish landings from Hawaii began in 1948 while the record from Puerto Rico began in 1967. The data shown in Figures 6 and 7 indicate the highly variable nature of commercial fish landings temporally as well as spatially at a site. This variability makes assessing the impact of an OTEC plant on nekton difficult. The economic importance to the local community of these landings is, however, substantial (Fig. 8) and must be considered.

In addition to the above fisheries information MSG has conducted an extensive literature survey of marine mammals (Payne, 1980).

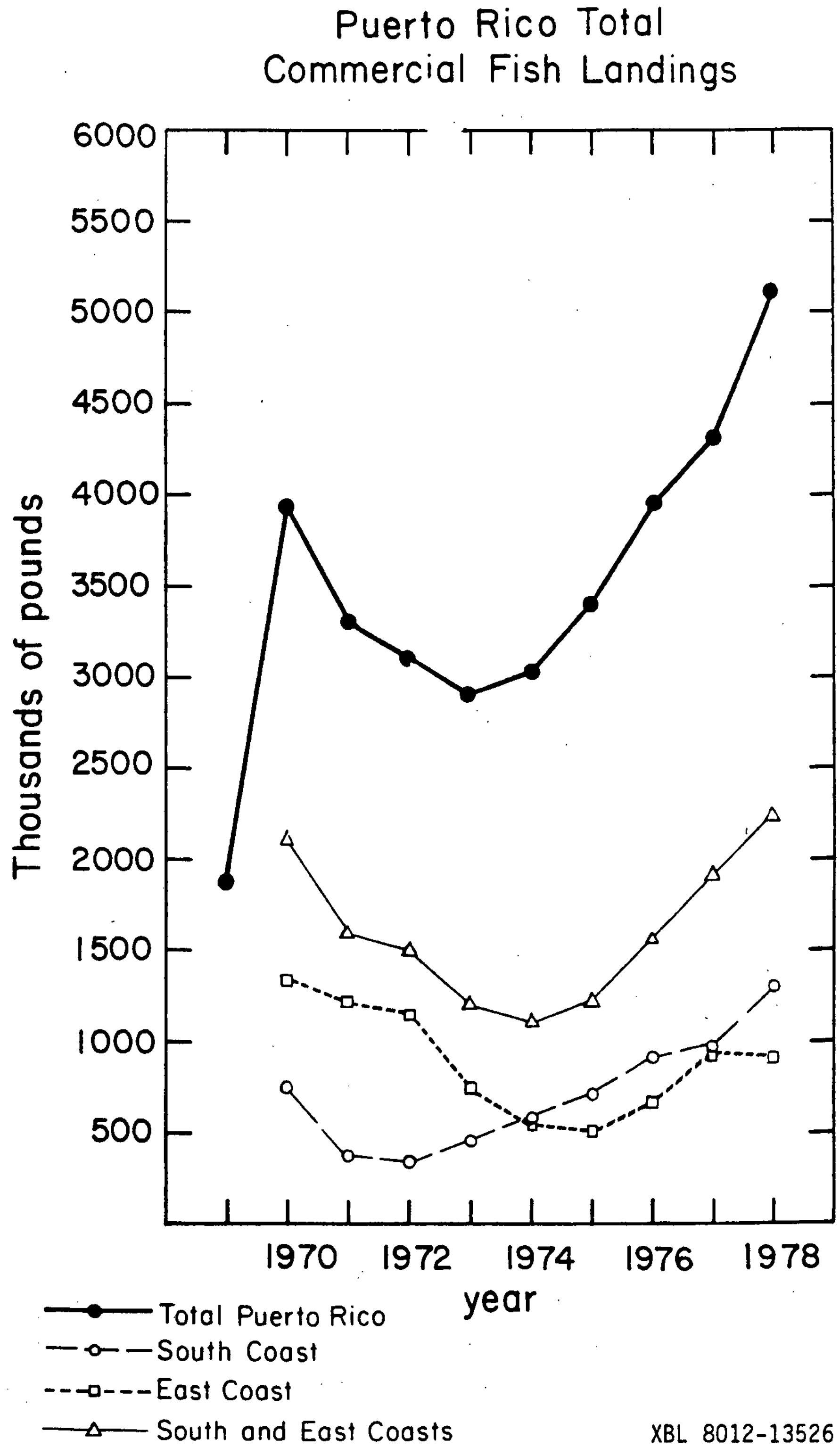
Puerto Rico Total
Commercial Fish Landings
Thousands of pounds
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
1970
1972
1974
1976
1978
year
Total Puerto Rico
South Coast
East Coast
South and East Coasts
XBL 8012-13526

FIGURE 6

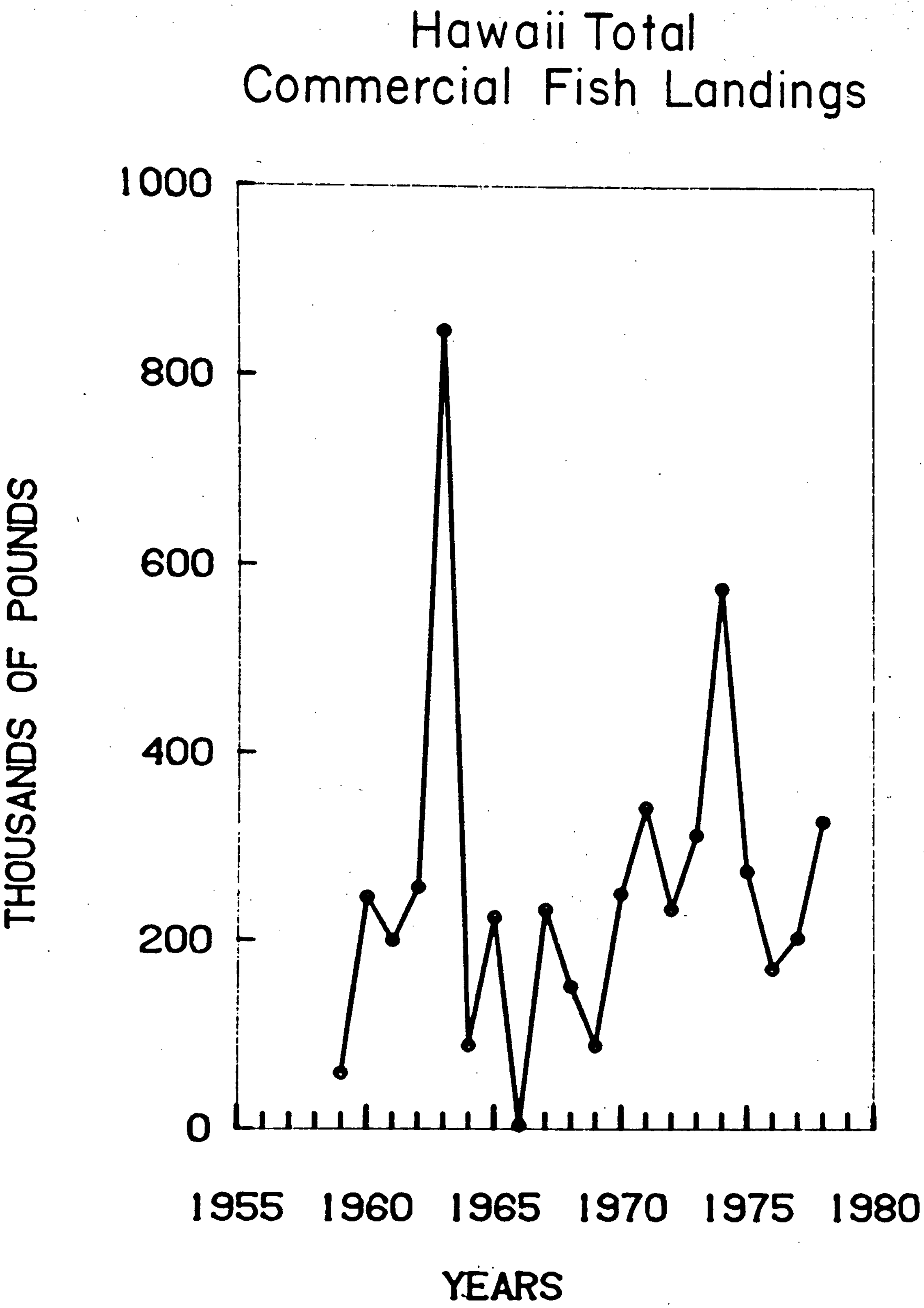


FIGURE 7

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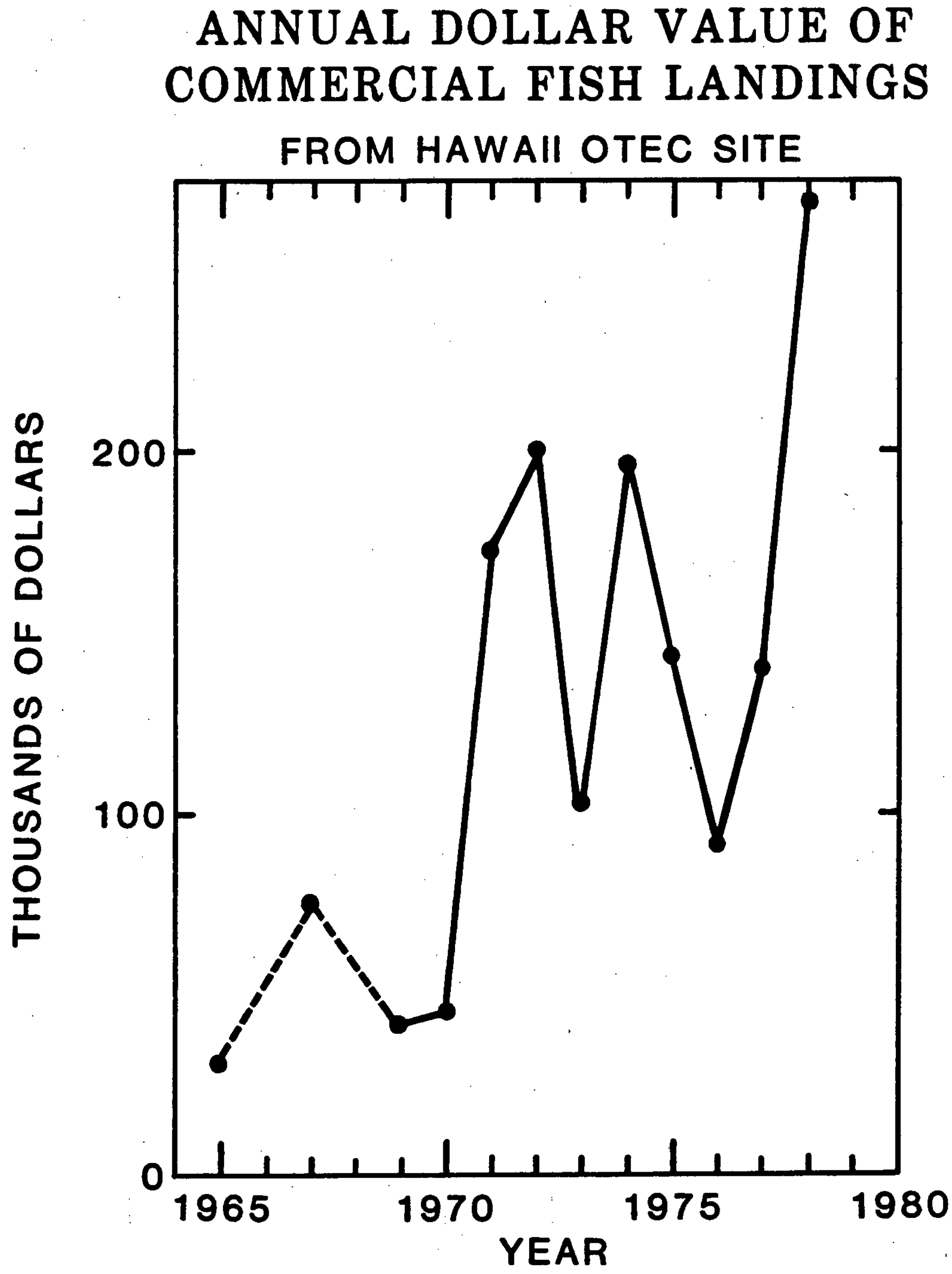


XBL 8012-13527

FIGURE 8

F. A simplified cod-end (Figure 9) for zooplankton nets was invented and field-tested with great success. Its simplicity of use and effectiveness reduce the time needed to complete a net-station. The invention was reported to the LBL Patents Office, who are proceeding with a patent application. Further simplifications in the manner in which the invention is used are being field-tested off the south-east coast of Puerto Rico.

3. Subcontracted research efforts:

This research consisted of laboratory and theoretical efforts. The purpose of this research was to answer specific environmental, design and operational questions of an OTEC plant which can best be performed by subcontractors.

A. Chlorine and ammonia toxicity.

This research is being conducted at the Gulf Coast Research Laboratory (GCRL) in Ocean Springs, Mississippi, under the direction of Dr. Venkataramiah.

Both chlorine and ammonia are known to be toxic to living organisms. Ammonia is the working fluid of proposed closed cycle OTEC plants. The effect of the leakage and catastrophic spillage of this toxic substance on marine organisms must be determined.

To operate efficiently, the evaporators and condensors of an OTEC plant must be free of biofouling. Chlorination is the prposed method of controlling biofouling. As with ammonia, the effects of chlorine discharge on marine organisms must be determined.

Research conducted on chlorine and ammonia toxicity has involved controlled laboratory bioassays on several organisms from the tropical oceans. These have included mullet (Mugil cephalus), Sargassum shrimp (Latreutes fucorum) and filefish (Monocanthus hispidus). The results have shown species specific size vs. toxicity relationships, as well as, behavioral changes in sublethal concentrations. Presently, bioassays are being initiated utilizing an oceanic copepod of the genus Eucalanus (Venkataramiah et al., 1980).

B. Food web inter-relationships:

This research is being conducted at the University of South Florida and at the GCRL under the direction of Dr. Hopkins and Dr. Gunter or Dr. Steen, respectively. Dr. Hopkins' group is examining the gut contents of micronekton. Their work is concentrated on a couple of well represented species to use as models for other similar organisms. The work at GCRL concentrates on upper water column zooplankton. The investigation at GCRL uses the literature, as well as, state-of-the-art techniques in scanning elecron microscopy, fluorescence microscopy, and histochemical techniques in order to assess the food of zooplankton.

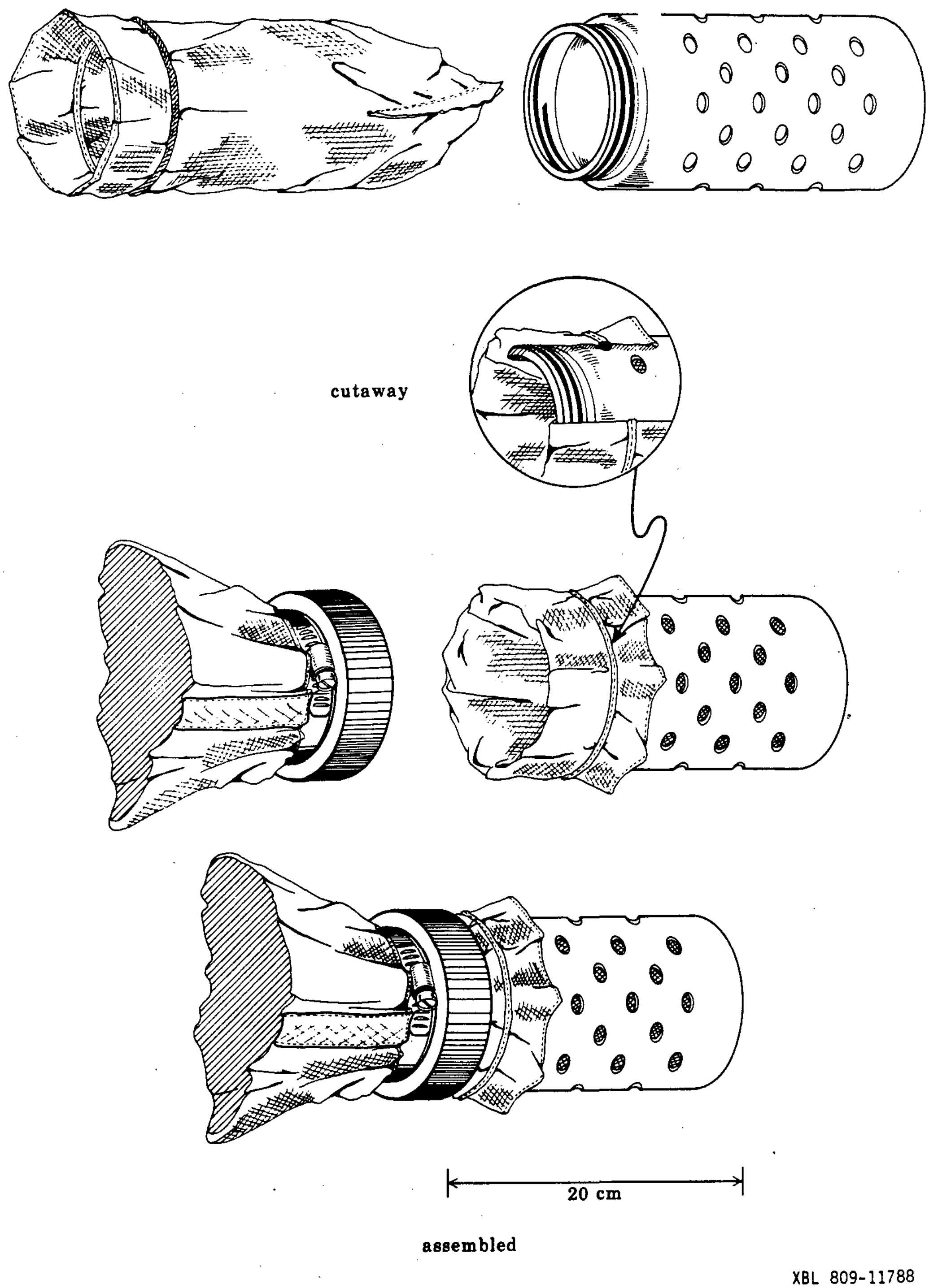


FIGURE 9

C. Diurnal variability:

This work is being performed at the GCRL under Dr. Gunter and Dr. Steen. For the study a series of replicate net tows collected through a 24 hour period were examined. The number of zooplankters and the taxonomic composition of the samples have been completed. The data is presently being statistically analyzed for diel variability.

D. Phytoplankton size vs. productivity and percent of total phytoplankton biomass:

This work was performed at the Oceanic Institute; Waimanalo, Hawaii, under the direction of Dr. Bienfang.

The data conclusively showed the importance of nannoplankton (< 5 um) biomass in the tropical waters off Hawaii. Additionally, there was a strong indication that production was nutrient limited and variations in productivity were not accounted for by variations in phytoplankton biomass. Correlations between dead phytoplankton and integrated ammonia concentrations and integrated primary production indicated that regenerated nutrients were primarily responsible for observed temporal variability in photosynthesis (Bienfang and Szyper, 1980).

TABLE 1. Taxonomic composition of dominant copepod genera at one Gulf Coast OTEC site

-

| Sample # | Dominant Genera (% of total copepods) | | % Composition by Order | | Number of taxa* |
|---|---|---|---|---|---|
| **TAM 40 (e) | Oncaea | 28.6 | Calanoids | 61.9 | 30 |
| | Eucalanus | 22.6 | Cyclopoids | 35.7 | |
| | Pleuromamma | 17.3 | Harpacticoids | 0.0 | |
| | Rhincalanus | 6.0 | | | |
| | Conaea | 4.8 | | | |
| TAM 41 (d) | Eucalanus | 22.3 | Calanoids | 60.5 | 63 |
| | Oncaea | 19.8 | Cyclopoids | 35.7 | |
| | Conaea | 12.6 | Harpacticoids | 0.2 | |
| | Pleuromamma | 7.7 | | | |
| | Clausocalanus | 4.8 | | | |
| TAM 42 (c) | Clausocalanus | 21.9 | Calanoids | 62.3 | 57 |
| | Oncaea | 21.2 | Cyclopoids | 37.0 | |
| | Oithona | 7.0 | Harpacticoids | 0.5 | |
| | Farranula | 6.2 | | | |
| | Temora | 5.7 | | | |
| TAM 43 (b) | Oncaea | 20.3 | Calanoids | 48.3 | 42 |
| | Clausocalanus | 18.7 | Cyclopoids | 43.0 | |
| | Temora | 14.9 | Harpacticoids | 0.5 | |
| | Farranula | 10.4 | | | |
| | Oithona | 7.0 | | | |
| TAM 45 (a) | Temora | 26.8 | Calanoids | 75.7 | 53 |
| | Farranula | 11.9 | Cyclopoids | 23.6 | |
| | Clausocalanus | 10.7 | Harpacticoids | 0.5 | |
| | Oncaea | 8.9 | | | |
| | Undinula | 6.8 | | | |

*Represents number of species identified plus genera not identified to species level.
**TAM: Gulf Coast OTEC site off Tampa Bay, Florida.

[a] 25-0 m night
[b] 25-0 m day
[c] 200-0 m day
[d] 800-200 m day
[e] 1000-800 m day

## CHEMICAL OCEANOGRAPHIC RESEARCH

The chemistry program of the Marine Sciences Group participated in OTEC site characterization, a nutrient preservation study, and initiated a radioactive tracer development program and a program examining the partitioning of trace metals in the water column. The relationship of the distribution of trace elements in the water column with other oceanographic parameters was examined to explore the possibility of using such a relationship to predict trace element concentrations.

Site Characterization. A year's study at the benchmark OTEC site off the Kona Coast of Hawaii was completed. Four hydrocasts were taken on each of six bimonthly cruises. Two casts to 1000m were taken at approximately noon and midnight showed the distribution of various parameters over the water column of interest to OTEC. Several chemical parameters, including the nutrients - reactive phosphate, nitrate, silicate and ammonia and dissolved oxygen were determined. Typical profiles of phosphate, nitrate, silicate and dissolved oxygen with depth are shown in Figure 10. Distributions observed were typical of the tropical Pacific Ocean. Two additional hydrocasts to 300m provided more detailed information on the euphotic zone. In addition to the chemical parameters measured on the deep hydrocasts samples were collected for chlorophyll a, phaeophytin and adenosine triphosphate as well as water to be used for $^{14}C$ uptake experiments for primary productivity. Figures 3A and 3B shows typical distributions of the biomass indicators with depth at the Kona Coast (HOTEC) site. Determination of the biomass indicators and primary productivity provides information on the standing stock and photosynthetic activity of the natural phytoplankton. Natural phytoplankton are considered to be extremely sensitive to perturbation and may show an early impact of the operation of an OTEC plant.

Nutrient Preservation Study. Although the analysis of nutrients is considered routine, (Strickland and Parsons, 1972; Grasshoff, 1976) samples must be analysed rapidly or they degrade. Because it is frequently impossible to analyze samples immediately, a number of preservation techniques have been devised (Fitzgerald and Faust, 1967; Rigler, 1964; Standard Methods 1975; Gilmartin 1967; Jenkins 1968; Maynard and Hokins, 1973; Degobbis 1973; Horne and Holley, 1969). A study was conducted to determine which of the more common preservation techniques was effective. Samples of deep and surface water was collected from the Gulf Stream, filtered immediately and delivered to the Rosensteil School of Marine and Atmospheric Science. One subsample of each type of water was analyzed immediately for nitrate plus nitrite, nitrite, ammonium, reactive phosphate, total dissolved phosphate, and silicate. Other subsamples were preserved for analysis after 7, 30 and 60 days using various techniques including three bottle types, glass, polyethylene, and teflon, two temperatures, frozen and refrigerated, and using either no preservative, acid, or poison - $HgCl_2$ for all nutrients but ammonium and alkaline phenol for ammonia.

No preservation method was found to be effective for all nutrients, in fact none were completely effective for any of the nutrients. For nitrate plus nitrite and reactive phosphate poisoning with $HgCl_2$ and freezing in glass bottles proved to be most effective. For total phosphate and silicate freezing with $HgCl_2$ in polyethylene worked best. Insufficient nitrite was found to complete the study and no method worked well for ammonium.

Radioactive Tracer Study. Radioactive tracer methods have been developed in order to study oceanic mixing rates at potential OTEC sites. 228-Ra was chosen for study because it enters the ocean water primarily from sediments; its half life of 5.7 years makes it ideal for studying natural mixing processes with a time constant of less than 25 years.

Trace Metal Partitioning Studies. This program developed and compared methods for sampling and analyzing for dissolved and particulate trace metals in the oceanic water column. The relative distribution of the trace metals in the dissolved and particulate phases as well as the particle flux are important factors for characterizing the oceanic ecosystem and the subsequent predicting of OTEC-related alterations of the marine environment.

Trace elements frequently are found in the marine environment in extremely low levels - concentrations of less than 1 ppb are not unusual. Because natural levels are so low, sampling must be conducted using ultra clean techniques. The past year has been spent examining methods of contamination free sampling which can be transported and used on small craft in areas of the world where clean lab conditions are generally unavailable.

An initial study in February 1980 was conducted at a potential OTEC site off St. Croix in the Virgin Islands. Sampling methods employed were a particle interceptor trap system developed by Dr. George Knauer of Moss Landing Marine Laboratory, large volume water samplers and plankton nets.

Samples for dissolved and filterable particles were collected in 30 L Teflon lined Go-Flo[R] bottles which had been acid cleaned and stored in plastic and wood containers until flushing with sea water and use. All metal fittings were removed or covered with clear plastic resin. During sampling bottles were attached to dacron sheathed hydrowire wrapped on a winch drum covered with polyethylene and passed through a stainless steel meter wheel. The bottles entered the water closed in order to avoid surface contamination. After collection samples were processed in a clean lab constructed out of polyethylene sheets. Samples were packaged and returned to shore for analysis. Atomic absorption (AAS) analyses were conducted at Moss Landing Marine Laboratory, neutron activation analyses (NAA) were conducted by Dr. Frank Asaro and Helen Michel of LBL x-ray fluorescence (XRF) measurements were performed by R.D. Giauque of LBL. Isotopic dilution mass spectrometry (IDMS) was performed at California Institute of Technology.

Surface water and plankton samples were collected from a rubber raft in acid cleaned polyethylene bottles and plankton nets at a sufficient distance from the ship to permit relatively uncontaminated samples.

The sampling methods being used were found to be largely

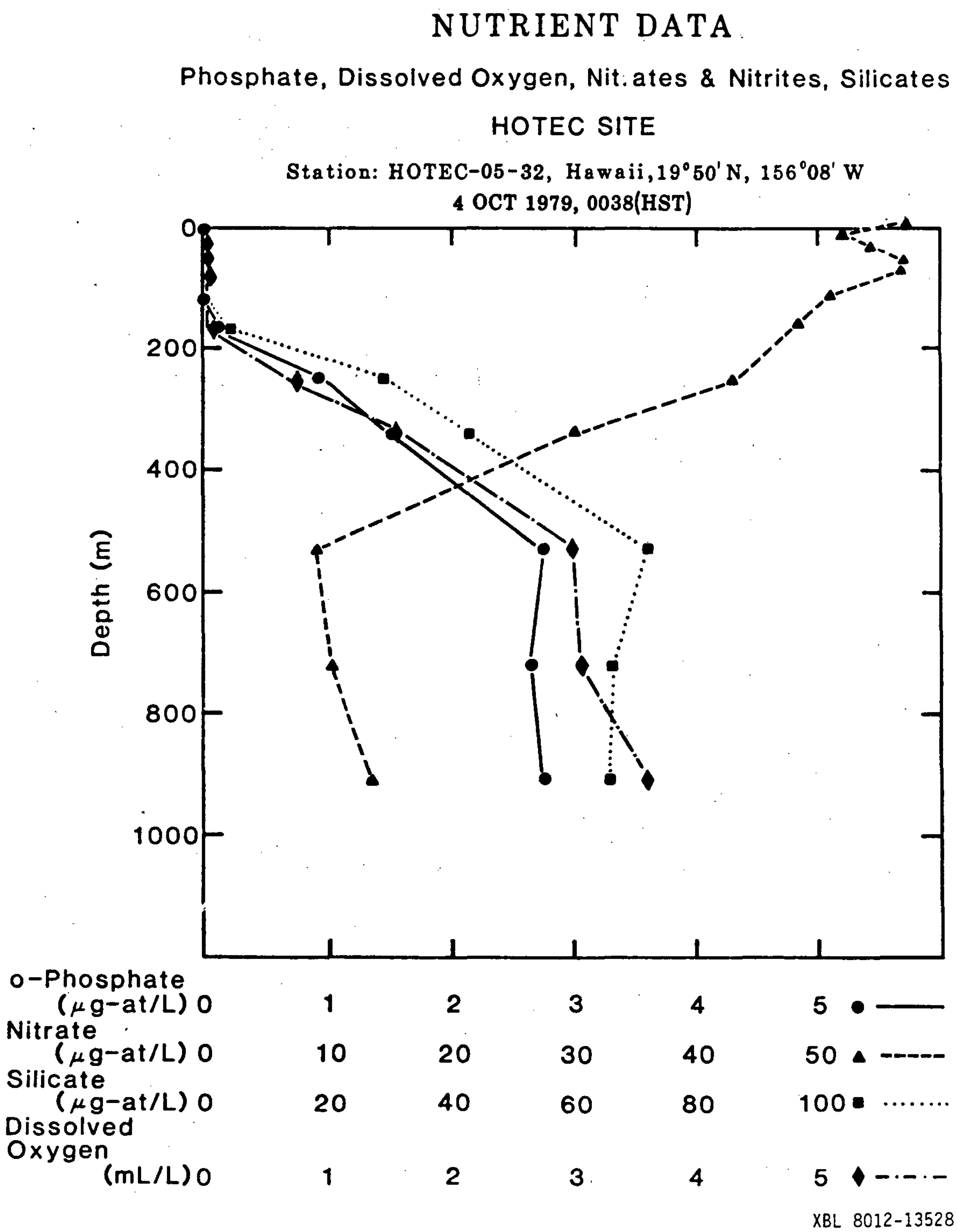
NUTRIENT DATA
Phosphate, Dissolved Oxygen, Nit.ates & Nitrites, Silicates
HOTEC SITE
Station: HOTEC-05-32, Hawaii, 19°50' N, 156°08' W
4 OCT 1979, 0038(HST)
Depth (m)
0
200
400
600
800
1000
o-Phosphate (μg-at/L) 0 1 2 3 4 5
Nitrate (μg-at/L) 0 10 20 30 40 50
Silicate (μg-at/L) 0 20 40 60 80 100
Dissolved Oxygen (mL/L) 0 1 2 3 4 5
XBL 8012-13528

FIGURE 10

contamination free, although a few samples were contaminated.

The four different methods of analysis were complementary providing sufficent overlap for quality assurance but each expanding the number of elements which could be determined.

The study was the first of its kind off St. Croix. The surface water was found to have some of the lowest values for cadmium (less than one part per trillion) in the world. The surface lead values (less than 8 parts per billion) are the lowest yet reported for the Atlantic. The manganese profile was found to be consistent with those reported for other regions.

As the water off St. Croix appears relatively clean and the reefs surrounding the island are an important natural resource, it will be of great importance to characterize this environment and protect it from any potential impact of an OTEC plant.

Trace Metal Correlation Study. In order to predict the possible impact of an operating OTEC plant on the local biological and chemical species composition, or on the efficiency of the OTEC plant, it is important to have a good understanding of the ambient water column.

The chemical composition throughout the water column must be known at each potential OTEC site. For some compounds, for example the nutrients, procedures for determination have been standardized (Strickland and Parsons, 1972, Grasshoff, 1976). For others, like the trace metals, as has been mentioned above, it can be an extremely expensive and difficult procedure, requiring sophisticated sampling and analysis procedures and highly skilled personnel (Patterson and Settle, 1976, Bruland *et al.*, 1979).

Traditionally, elements in sea water have been separated into two categories: the conservative and the non-conservative. Conservancy implies that the ratio of the elemental composition to salinity is constant over the normal oceanographic range (Brewer, 1975; Culkin, 1965; Dittmar, 1884). The major elements, sodium, potassium, chlorine, bromine etc. are conservative with salinity (Dittmar, 1884, Forchhammer, 1865, Cox, 1965, Culkin and Cox, 1966). The non-conservative elements are the gases, the nutrients and the non-nutrient trace elements. The profiles of the nutrients, biomass indicators, and dissolved oxygen are related to their biological activity. The concentrations of the non-nutrient gases are dependent largely upon their solubilities and the distribution of a large group of trace elements remained unexplained.

Recently, the concentrations of certain trace elements, whose distributions with depth were previously unexplained have been found to correlate with chlorinity (*i.e.* they are conservative) for example, uranium, vanadium and molybdenum.

In addition, a second conservancy or correlation -that of trace elements with biologically-controlled chemical species - also has been identified. The correlation can be a linear relationship between the trace element and another parameter, as is exhibited by cadmium and phosphate (Bruland, Knauer and Martin, 1978a). But often the relationship is more complex, the elemental concentration being linearly related to a combination of the concentrations of two or more parameters. For example, nickel correlates to a combination of silicate and phosphate (Bruland, 1980).

Recognizing these correlations, it is reasonable to propose that the concentration of a specific element might be predicted if its relationship to other parameters were known.

We have reviewed the literature reporting elemental distributions in sea water and identified the correlations exhibited with the idea of using those correlations to predict trace element concentrations at OTEC sites. For some elements, although detailed profiles have not been determined, a correlation category could be suggested based on the data available. For other elements, no prediction has been made. These were largely elements for which little or no data exists, which are found in only ultra-trace quantities with no reported evidence of biological importance in the context of OTEC operations.

Chemical References

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## GEOLOGICAL OCEANOGRAPHIC RESEARCH

The knowledge of the characteristics of the sea bed and sea floor are extremely important to the success of the ocean energy program not only from an engineering but also an environmental perspective. For example, all types of proposed Ocean Thermal Energy Converson platforms, except for grazing plant ships, have obvious direct requirements for bottom data for mooring, anchoring, cable and pipeways paths, etc. Plant ships can only operate in regions deeper than the cold water pipe depth so even for such operations a knowledge of bathymetry is required.

Archival and Previous Work. To insure that all pertinent data from previous investigations are available to engineers, designers and environmental scientists through archival studies should be done to avoid costly duplication of effort and mistakes in design and judgement based on non-familiarity with the professional literature.

For OTEC studies, this has been initiated with joint program between the Marine Sciences Group of the Lawrence Berkeley Laboratory and the Pacific Arctic Branch of Marine Geology at Menlo Park. The archival program is basically the production of regional marine geologic and oceanographic data sheets which serve as a planning bathymetric base plus an index to the marine geologic and oceanographic data for a particular region of OTEC interest (Table 2). To date the data sheet for the Hawaiian area ($18^{\circ}$-$23^{\circ}$N; $154^{\circ}$-$159^{\circ}$W) have been completed (Wilde and others, 1980), and the Purto Rico-Virgin Islands sheet ($17^{\circ}$-$19^{\circ}$N; $64^{\circ}68^{\circ}$W) is in final draft form.

TABLE 2.

CONTENTS OF REGIONAL DATA SHEETS FOR EACH REGION

Bathymetric Base Map - 100 meter contour interval

List of applicable navigation charts

Geographic features map

Map of geologic samples - repositories indexed

Map of earthquake epicenters

Map of gravity anomalies

Map of magnetic anomalies

Track lines of seismic reflection/refraction with cruises, year and data sources indexed

Monthly maps of sea surface temperature and current drift

Selected profiles of sub-bottom records

List of pertinent references classed by published papers and books, reports and theses

List of sources with addresses and contacts

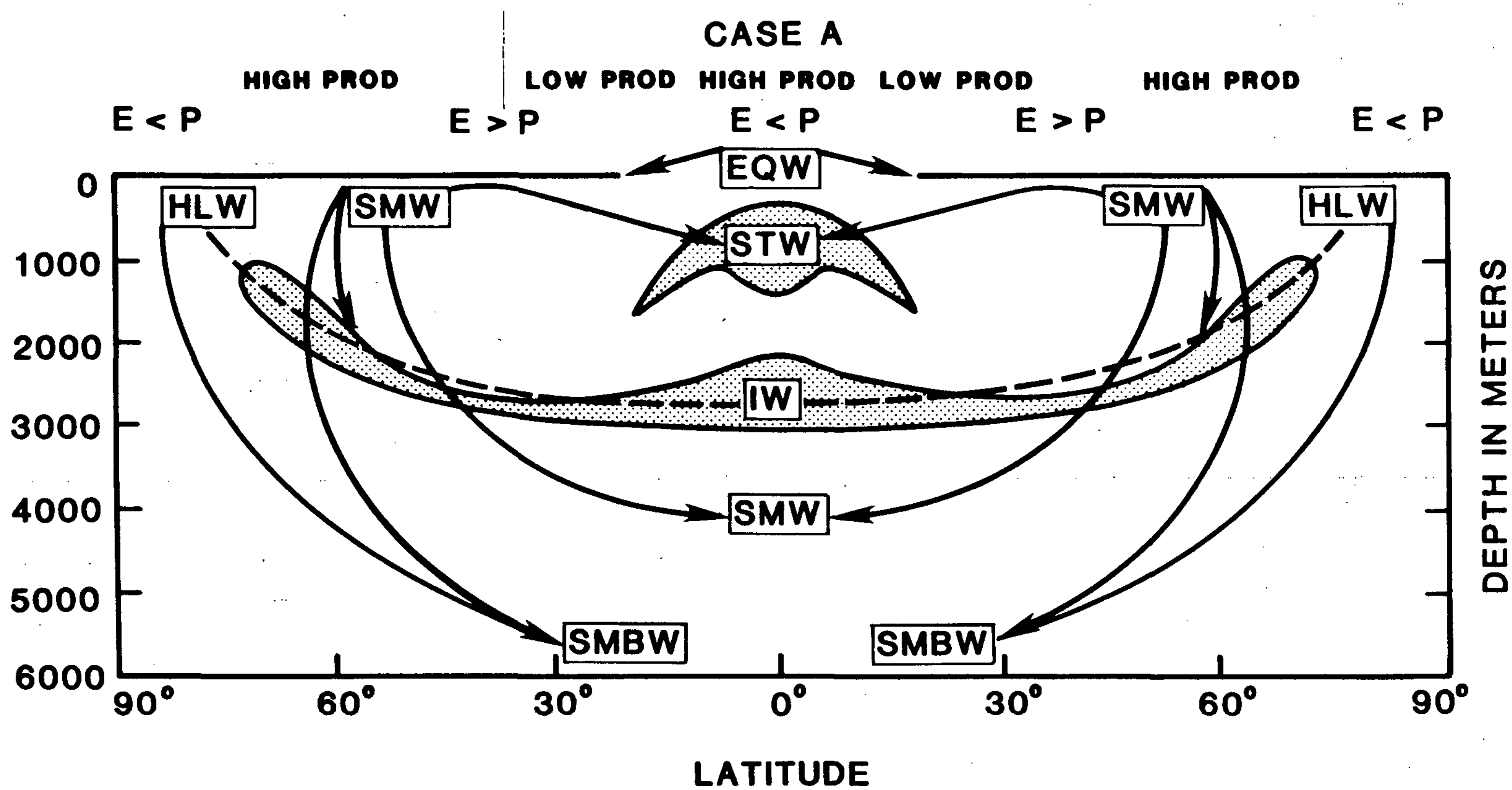
Additional material where applicable or available such as:

Wave and wind climate (monthly)

Temperature-salinity-density profis with water masses

Map of bottom sediment types and geotechnical data

Paleo-oceanographic models. In cooperation with the Paleontology Department at the University of California, Berkeley, models are being developed to explain the occurence of organic rich sediments at various times in the geologic record. The basis for the model is the progressive ventilation of the ocean by surface wind mixing and by density driven deep water during glacial episodes (Berry and Wilde, 1978) The intersection of the residual anoxic layer with the ocean floor provides a reducing environment for deposition of organic rich sediments. Wilde and Berry (1980) developed an extension of the 1978 model to explain the apparent return to anoxic conditions at midwater depths in the Cretaceous as seen in organic rich layers in cores from the deep-sea drilling project (Schlanger and Jenkyns, 1976; Thiede and Van Andel, 1977). The




XBL 809-11901

FIGURE 11

model predicts that after long non-glacial periods anoxic conditions could redevelop at mid-depths through a change in the deep water masses from cold oxygen rich high latitude water during glacial times to warmer oxygen-poorer higher salinity water formed at midlatitudes. Figure 11 shows the proposed oxygen depleted zones for the non-glacial case.

In order to evaluate the time history of the ventilation and calculate the oxygen demand for ventilation Berry and Wilde (1980) also are attempting to model the primitive ocean prior to the evolution of photosynthesis. This model suggests that carbon fixing by sulfur chemoautotrophes living in the primitive anoxic ocean provided the evolutionary stimulus for the eventual development of photosynthesis as the principle mechanism of primary production. Figure 2 shows the proposed sequence of events which lead to sufficient free oxygen in the atmosphere to initiate ventilation.

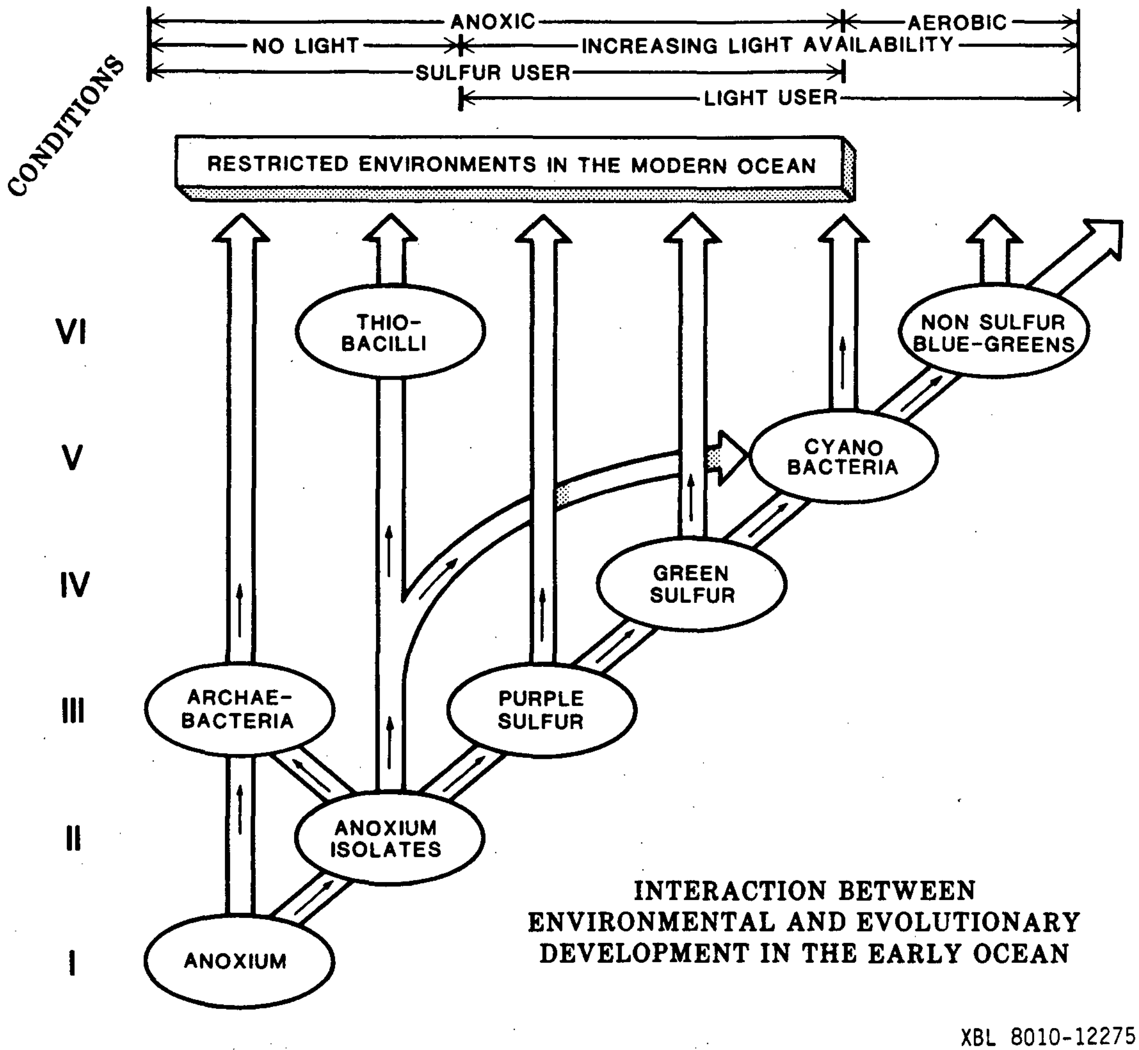

CONDITIONS
ANOXIC
AEROBIC
NO LIGHT
INCREASING LIGHT AVAILABILITY
SULFUR USER
LIGHT USER
RESTRICTED ENVIRONMENTS IN THE MODERN OCEAN
VI
V
IV
III
II
I
THIO-
BACILLI
NON SULFUR
BLUE-GREENS
CYANO
BACTERIA
GREEN
SULFUR
ARCHAE-
BACTERIA
PURPLE
SULFUR
ANOXIUM
ISOLATES
ANOXIUM
INTERACTION BETWEEN
ENVIRONMENTAL AND EVOLUTIONARY
DEVELOPMENT IN THE EARLY OCEAN
XBL 8010-12275

FIGURE 12

## Figure Captions

### Figure 11.

Longitudinal profile for Case A conditions with oxygen depleted zones shaded. Water designations as follows:

EQW = Equatorial water
SSW = Shelf sea water
STW = Sub-tropical water
SMW = Salinity maximum water
HWLa = High latitude water for Case A conditions
HWLb = High latitude water for Case B conditions
IW = Intermediate water
SMBW = Salinity maximum bottom water
MW = Mediterranean water

### Caption - Figure 12

Conditions

I. Outgassing of earth has provided an ocean of sufficient depth to permit fluid water at high temperatures. Atmosphere: High $CO_2$, Methane, and Ammonia, cloudy and hot near surface. Oceans: Low pH, High $CO_2$, anoxic with dissolved $H_2S$, $NH_3$, and rich in dissolved erosion products. Chemoautroph Anoxium evolves at outgassing submarine thermal springs.

II. $H_2S$. Carbon fixing by Anoxium begins. Carbon fixing proceeds - heterotrophes possible, however, autotrophes probably more efficient and carbon begins to be stored in geologic sinks. Amount of S and $CO_2$ is diminished in oceans and atmosphere as S and C goes into sinks. Cloudiness and temperature grdually reduced. $S_2O_3^{=}/S^{=}$ increases with expansion of autotrophes. Gradient of $S^{=}$ from vents puts environmental pressure on Anoxium isolates to use another energy source.

III. As carbon fixing and storage of C in sinks proceeds, quantity of light reaching ocean surface increases. Anoxium isolates at sea surface develop ability to use light to augment $S^{=}$, occupying niches similar to modern purple bacteria.

IV. Quality of light improves with reduced $CO_2$ and cloudiness so more low wave-length light available. Green bacterial niche available.

V. Continued scarcity of $S^{=}$ and improved quantity and quality of light gives advantage to near surface photic organisms. Transition from sulfur to photic organisms developed in cyanobacteria. Biogenic free $O_2$ appears in atmosphere.

VI. Oxidation of sulfur compounds by free $O_2$ eliminates anoxic environments near surface. Pure photic non-sulfur organisms become primary producers. Previous anoxic environments became restricted. Adaptation to existence at anoxic-aerated boundary developed by thiobacilli.

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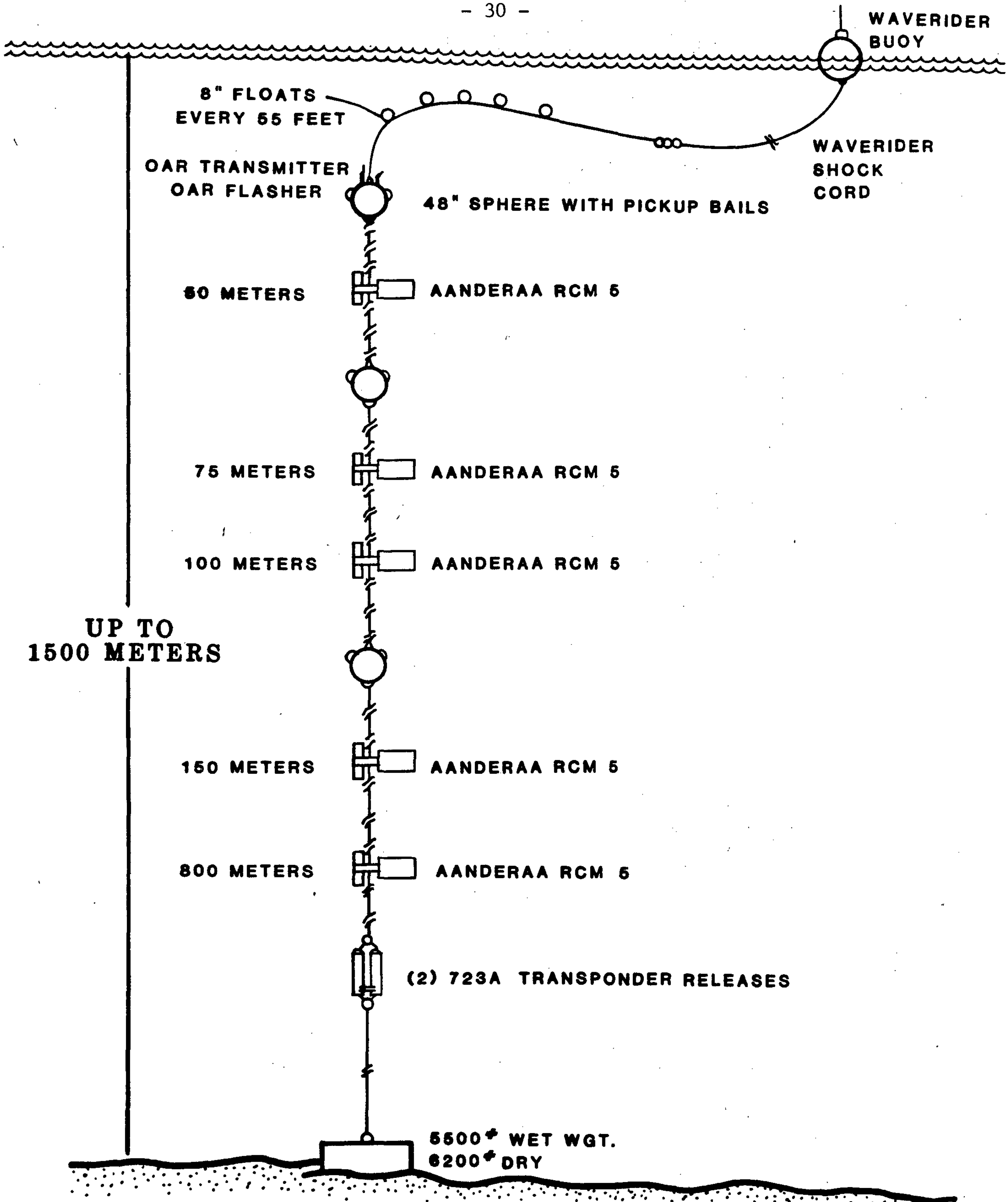
## PHYSICAL OCEANOGRAPHIC RESEARCH

Physical Oceanographic research performed in the Marine Sciences Group is directed at solving engineering and environmental questions for the OTEC resource. Results directly applicable to the program are disseminated rapidly to the OTEC community and results of wider interest arising out of the programmatic work are published in the professional literature.

The primary need for physical oceanographic data at OTEC sits is for current data so that stresses upon an OTEC plant and its moorings can be calculated, the flow of warm water to the plant can be determined, and to provide input to the computer models of downstream dispersal of discharge.

Current meter arrays. LBL's OTEC environmental program has installed current meter arrays at the following three sites: (i) the south coast of Puerto Rico, (ii) off the west coast of the island of Hawaii, and (iii) off the west coast of Oahu (Figure 13). These arrays have been installed in conjunction with thermal surveys. LBL has begun processing data from thes arrays, and the most significant results from the preliminary data are the high speeds seen at the OTEC-1 site off the




**MOORING DESIGN FOR OTEC-1**
**PRIMARY CURRENT METER MOORING**

FIGURE 13

XBL 8012-13529

west coast of the island of Hawaii. Speeds in excess of 100 cm/sec at a depth of 56 meters were seen for a duration of 10 days in an observational period of 28 days in August/September 1980. This is in agreement with the Coast Pilot for the region. At the Puerto Rico site the observed speeds have been less than 40 cm/sec, dominantly in a WSW direction.

World Ocean Currents. Duncan and Schladow (1980) have investigated the surface currents of the world ocean as deduced from the historical record of ships' drift observations on file at the National Oceanographic Data Center in Washington, D.C. (Figure 14).

Other research by the Physical Oceanography section. A research cruise to the South Atlantic aboard the NOAA Oceanographic Survey Ship O.S.S. Researcher was made in February-March 1980 (Figure 15). Both chemical and biological observations were made during the cruise. The chemistry of the Tropical Atlantic is intimately related to the complex, and as yet little-understood system of currents and countercurrents within ten degrees of the equator. The results of this cruise show definite correlations between the distribution of nutrient salts in the upper three hundred meters of the ocean and the velocity field. The reasons for these correlations are being investigated with the assistance of physical observations taken during the cruise by NOAA. The chemistry data has been send to the National Oceanographic Data Center by LBL.

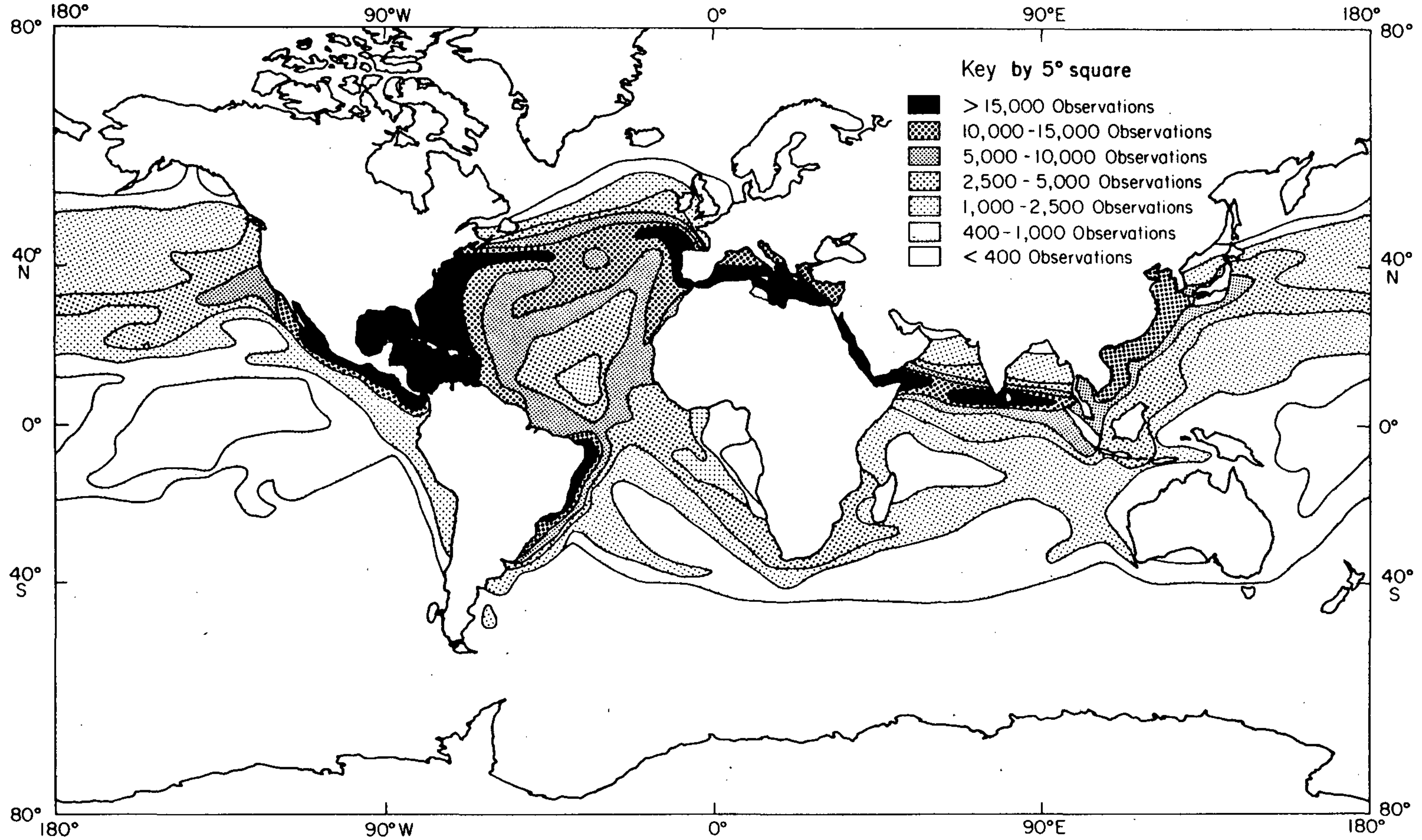


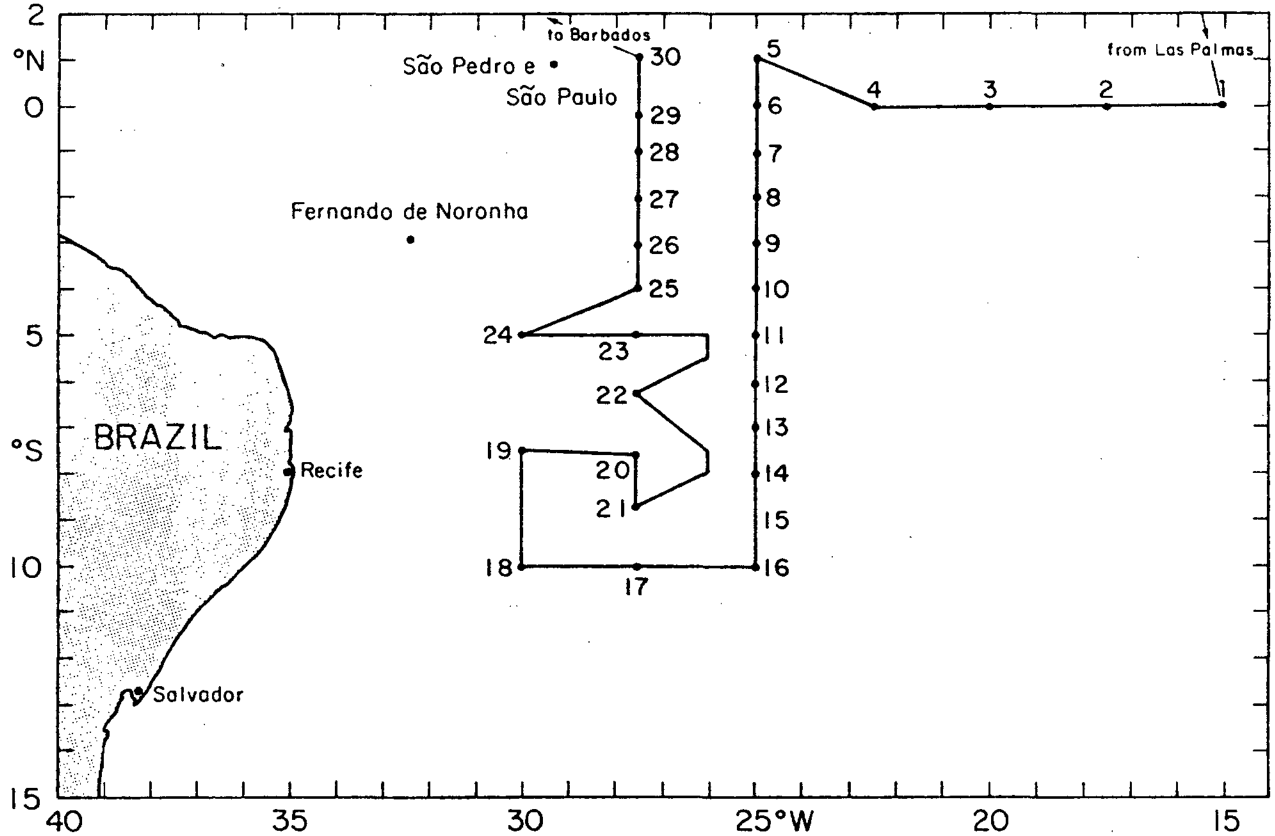

Figure 1: Frequency of ship's drift observations (total observations 4,175,325)

(From: NODC SCUDS file)

XBL 805-7087A

FIGURE 14

Track chart with station positions, cruise of R.V. Researcher, 21 Feb-7 Mar 1980




XBL 806-7096

FIGURE 15

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This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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