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OTEC ENVIRONMENTAL BIOLOGICAL OCEANOGRAPHIC PROGRAM

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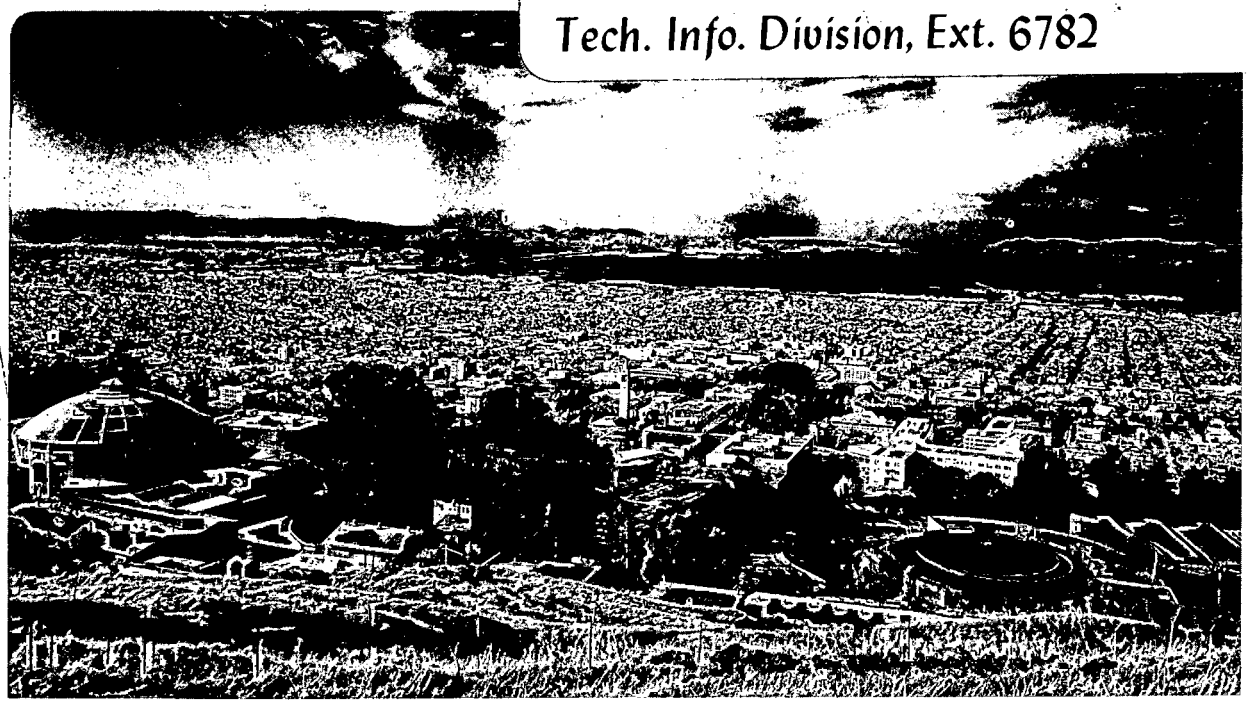

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OTEC ENVIRONMENTAL BIOLOGICAL OCEANOGRAPHIC PROGRAM

ABSTRACT

One of the major goals of the OTEC biological field measurement program is to assess the effect of OTEC operations on the environment. Prior understanding of the natural variability of the tropical oceanic plankton community is the most important method for determining changes due to operation of an OTEC plant.

The spatial and temporal patterns of the plankton community in terms of absolute number, biomass and species composition have been investigated at potential OTEC sites. Considerable data exists which document the changes with depth of all three measurements. Diel fluctuations in number and species composition have been studied at one site. While horizontal and seasonal patterns of variability likely exist at all sites, they are subtle and remain somewhat unclear. Attempts are now being made to determine the overall trophic structure of the plankton community at these sites using these data, gut content analysis, and information already in the literature.

1. Introduction

1.1 Goals of OTEC Biological Oceanographic Program

The goal of the OTEC biological oceanographic program is two-fold. First,to provide the engineer with data important to the design, operation, and maintenance of the OTEC plant, second, to provide an unbiased and accurate report of the impact of OTEC on the marine biological community. A biological impact is neither judgemental (i.e., good or bad) nor directional (i.e. increase or decrease). A biological impact is defined as a significant change in one or more selected biological parameters (e.g., abundance, productivity, biomass respiration etc.). This implies a statistical analysis of the biological parameter(s) selected a priori.

To evaluate the impact of OTEC on the marine biological community one must first select those components of the community most likely to be impacted. In addition an impact will be judged by the degree to which OTEC alters this community. To judge the degree of impact one must first know the extent or range of natural variability within the community. Without this information it is not possible to determine if the observations made during the impact assessment represent natural variability or a real change (impact). This paper will address the above two topics: 1) defining the biological community, and 2) determining the average condition and range of natural variability.

To an OTEC construction contractor and operator biological impact studies are important for three reasons. First are legal requirements needed to license the operation of the plant. Second, to provide insight into design considerations to maximum performance and minimize maintenance (e.g., screen, mesh size, intake location, etc.). Thirdly to identify possible economies derived from biological processes (e.g. biomass production, fishing enhancement, etc.)

The data presented in this report are the result of the efforts of several groups Participants in these studies have included AECOS Inc.; Ed Noda and Associates University of Hawaii, Look Laboratories and Hawaii Institute of Marine Biology, Oceanic Institute; Gulf Coast Research Laboratory, University of South Florida; Florida Institute of Oceanography University of Miami (Florida); and Marine Sciences Group/Lawrence Berkeley Laboratory

1.2 Define Biological Community

The biological community of interest consists of all living organisms potentially impacted by OTEC operations. These organisms can be divided into major ecological groups, including (Table 1) Benthic (living in or on the sediments); Nektonic (efficient swimmers capable of swimming against the current); and Planktonic (floating or feebly swimming organisms). Each of these groups consist of subgroups. Although there are further subdivisions possible, such as neritic (coastal) vs. oceanic (open ocean); littoral (sediments from shore to slope) vs. deep-sea (sediments from slope and deeper) etc., the subdivisions presented here are sufficient for this discussion

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1.3 Average Condition and Range of Natural Variability

The first step is to define the parameters of interest relevant to the community under investigation. Typically, these parameters have included abundance biomass, productivity etc. but should be selected for their relevancy to the particular community and site under investigation. The second step is to define where and how to best sample these parameters. This is dependent on the parameter, community and site. Such things as mesh size, volume of water to sample, near or far field samples, depth(s) to sample core type, sampling frequency, number of replicates, etc., all come to mind when considering this second step. The third and final step is to take and analyze the samples and calculate the mean value(s) and variance for each parameter.

2. Specific Biological Communities of Interest to OTEC

The ideal impact study would examine only those communities that are affected by OTEC. The first task is to focus the studies on those ecological groups with the highest probability of being impacted OTEC, depending upon the exact site and plant configuration, will impact all major ecological groups i.e., benthic, nektonic and planktonic organisms (Table 1)

2.1 Benthic

As the initial OTEC studies were concerned solely with deep ocean sites the environmental studies could concentrate solely on the nektonic and planktonic organisms This does not mean that the benthos at these oceanic sites could not be affected only that the impacts (e.g., transmission cable path) were projected to be minimal. If the site was changed to a neritic environment such as a shelf sitter or shore based the benthic group would be significantly impacted, and environmental studies would be initiated.

2.2 Nektonic

2.2.1 Marine Mammals

Of the organisms in the nektonic ecological group the least direct affect will be with the marine mammals. In this group (Table 1) there is no potential for otters to be affected. Although all the other groups can be impacted proper siting studies will alleviate environmental impacts. For example, the endangered Hawaiian monk seals are confined to a restricted area and simply by locating any OTEC site at a distance from this area impacts to this seal will be avoided. Whales, porpoises and dolphins present a different problem as they range over an extensive area. The major OTEC impact would be the disruption of mating, especially for species such as the endangered humpback whale. This again is a siting problem which could be eliminated by proper prior knowledge of the distribution and behavior of the animals.

2.2.2 Other Animals

All of the organisms listed under this ecological group (Table 1) will be impacted by OTEC The macronekton, although capable of avoiding entrainment are attracted to structures (e.g., OTEC) in the ocean thereby increasing the number subjected to the probability of entrainment and impingement. The effect on macronekton will be highly species dependent. Experience at OTEC-1 showed that although sharks (white tips) and large adult fish (yellow fin tuna, dolphin fish) were attracted to the structure none appeared to be impinged. However as impingement was not studied directly, smaller species may have been impacted.

Micronekton would be much more susceptible to entrainment and impingement. Visual sightings in the OTEC-1 moon pool revealed entrainment of micronekton. At the present time replicate stratified depth micronekton samples are being taken quarterly at the Puerto Rico OTEC (PROTEC) site. These samples are being analysed at the present time.

Preliminary data from the PROTEC site show that the micronekton migrate diurnally and is composed primarily of midwater shrimps and fishes (2 to 20 cm) which are dominant predators at the third to fifth trophic levels. These organisms although much less abundant than zooplankton, through predation play a major role in regulating zooplankton abundance and population structure. Significant impact to the micronekton due to entrainment and impingement can be avoided by proper intake design, such as reducing the velocity field around the intake mouth and the actual design of the intake structure (mesh opening size fish diversion system, etc.)

Attraction of fish and other nekton to the plant at the present time is impossible to prevent Any structure placed in the ocean attracts organisms for a number of reasons such as refuge from predators, a food source, mating, habitat, etc. The impact of attraction is regarded as beneficial but needs to be quantified, especially as regards the attraction of commercially important species and the impact of attraction on other populations. Fish abundance is discussed in more detail in the paper by Ryan and Jones in this conference.

Marine turtles occur in potential OTEC sites but are capable of avoiding the OTEC plants. Turtles are not known to be attracted to structures in the ocean.

2.3 Planktonic

The effect on planktonic organisms (Table 1) is potentially the greatest impact of OTEC. Plankton, which cannot effectively avoid an OTEC plant, are all subjected to the full range of OTEC operational effects. These include.

1) Entrainment
2) Impingement
3) Stimulation/Inhibition due to:
   a) Redistribution of water masses
   b) Working chemicals
   (This topic is discussed in the paper by Venkataramiah et al., in this conference.)
4) Redistribution of plankton
5) Attraction
6) Fouling

The degree of impact of each of these OTEC operational effects is highly species dependent. as well as, highly dependent upon the extant physical/chemical regime. A multitude of scenarios for each OTEC operational effect on the plankton can be constructed. These scenarios will not be discussed here, suffice it to say that numerous planktonic impacts are probable and to investigate and determine the extent of these impacts a scientist must have prior knowledge of both the taxonomic composition and the natural variability of the plankton.

2.3.1 Phytoplankton

Phytoplankton taxonomic work is aimed at accomplishing three tasks 1) identifying the phyletic group of the phytoplankter (pennate or centric diatom, athecate or thecate dinoflagellate, coccolithophorid, other flagellates, and other), 2) determining the size structure of the community and 3) determining the response of these populations to OTEC operations.

Analyses of community composition at the PROTEC site (Table 2) shows that monads and small flagellates (<5 um diameter) usually far outnumber all other phyletic groups. The typical rank order of phyletic groups, based upon numerical abundance shows monads and small flagellates, diatoms and coccolithophores (in relatively similar abundance to one another), followed by dinoflagellates and blue-greens. The taxonomic composition within each phyletic group characteristically displays very high diversity. Similar results have been shown for the island of Hawaii OTEC (HOTEC) site.

Analysis of the size structure of phytoplankton communities off Hawaii shows a vast predominance of biomass occurring in extremely small (< 5 um) cells. Size fractionation studies showed that about 80% of the phytoplankton biomass and nearly 90% of the photosynthesis occurs in the size fraction < 5 um (Figure 1 Table 3). This feature of subtropical phytoplankton communities is of conspicuous relevance to OTEC. The introduction of large quantities of deep water nutrients to a subtropical system may alter the existing size structure in favor of larger celled species, such as those which tend to dominate in regions of natural upwelling. Should this occur in response to OTEC operation, changes could be generated in the types of animals found at higher levels of the food chain including not only herbivores but higher level carnivores. The implication is that changes in the size structure of the primary trophic level may be transmitted throughout the entire food web of affected areas.

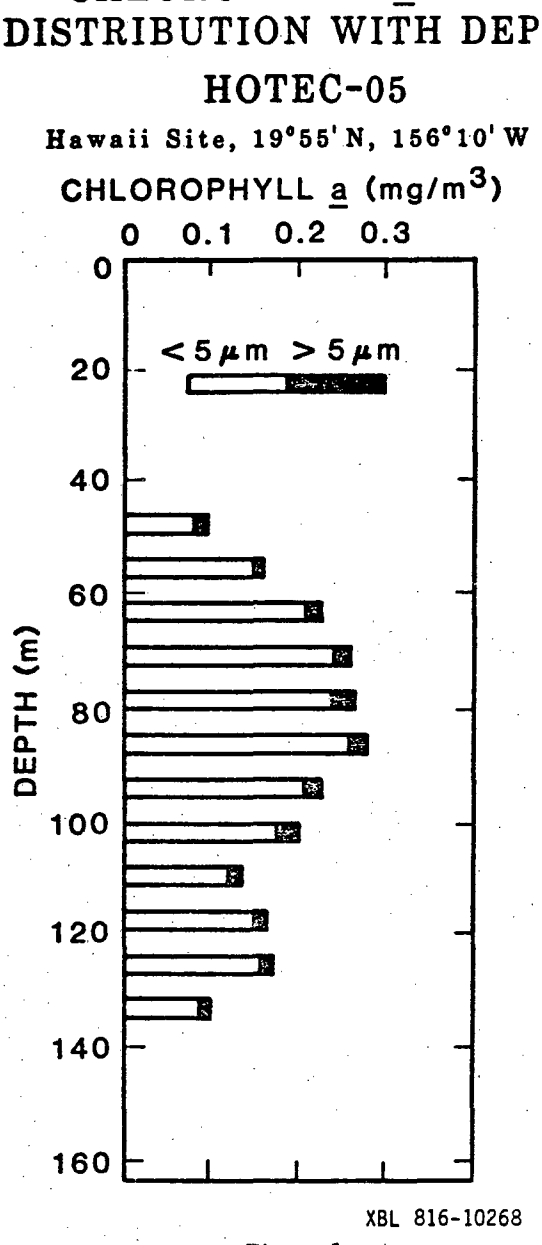

Figure 1.

The introduction of large quantities of deep water to the surface layer will have impacts to the metabolic rates of the affected phytoplankton communities. A series of deep water enrichment experiments were performed to examine the degree of biostimulationin response to the unique form of environmental perturbation represented by the OTEC discharge. Deep water is characterized by significantly higher nutrient concentrations. In Hawaii the following nutrient concentrations are representative of the surface and deep waters.

	Nitrate (μM)	Phosphate (μM)	Silicate (μM)
Surface water	0.3	0.2	2.1
Deep water	40.0	3.0	80.0

Examinations of the response of naturally occuring phytoplankton to a 3-16% deep water nutrient enrichment showed biostimulation of 9-149% over natural levels. The degree of stimulation was depth-dependent and showed considerable variation from time to time. The greatest stimulation occured in the upper light-saturated layer (about 40m) below this layer there was little biostimulation despite evidence of prevailing nutrient-limitation. These findings relate to the vertical extent of exported stimulation, and thus description of the total photic zone response. Enrichment experiments carried on for five days indicated that the stimulatory response progressed for 2-3 days before leveling off.

2.3.2 Animals

2.3.2.1 Microzooplankton

No systematic taxonomic examination has been performed. Some data are available from the island of Oahu, Hawaii OTEC (O'OTEC) site and are presented in Table 4.

2.3.2.2 Macrozooplankton

To date the greatest taxonomic effort has been directed towards identifying the copepod populations in the zooplankton community with recent efforts directed at the micronekton and phytoplankton. Total zooplankton abundance and biomass are easily measured parameters, however, they do not permit community or population dynamics to be examined. To do this one must know who (populations), by name (taxonomy), is a part of the whole (community). As taxonomic identification is time consuming (expensive), key or indicator species are singled out These species are chosen on many bases, one basis is abundance.

Tables 5-8 present the top five (5) copepod genera in the upper 25m based on ranked abundance of identified copepods. The top six (6) rankings are given if the lowest two genera are of equal rank. These tables also separate the day/night ranked abundance and give the percent copepod composition by taxonomic order.

Table 9 is a summary Table from all sites of the top 5 copepod genera in the upper 25m. Several genera appear to be dominant at all sites (Oithona, Oncea, Corycaeus, Calocalanus, and Mecynocera) while other dominant genera are characteristic of particular sites. For example Clausocalanus, Farranula, Temora and Paracalanus are dominant at PROTEC and GOTEC sites but not at the HOTEC site. Acartia is dominant at the HOTEC and the PROTEC sites but not at the Gulf of Mexico OTEC (GOTEC) sites (Table 10). Acartia is generally found closer to shore and the HOTEC and PROTEC sites are closer to shore than the GOTEC sites Dominance also varied in day vs. night samples but no consistant pattern is evident.

The percent composition by order for copepods in the upper 25 m is summarized in Table 11. Calanoid copepods are the most dominant order at all stations and times except during the day at the GOTEC Mobile site when Cyclopoid copepods were most numerous.

Due to variations in the taxonomic expertise of different investigators, consistency of the level of identification varies between sites and between investigators at the same sites For example at the O'OTEC site in Oahu, preliminary indications are that Clausocalanus is a dominant zooplankter which had most probably been lumped under unidentified microcalanoids at the HOTEC site. Copepods, identified to genera, provide a common, accessible goal for all investigators. Additionally, within a genera, the niche occupied by the included species would be restricted relative to a higher taxonomic group, such as within a copepod order. Therefore by identifying all copepods to at least the level of genera, a consistent site and time description of the copepod community can emerge.

2.3.2.3 Ichthyoplankton

The first larval fish (ichthyoplankton) samples were taken this year and the results are being analyzed.

2.3.2.4 Other Larval Animals

These are collected with macrozooplankton samples and are identified to larval type, e.g., gastropod veliger, pelecypod veliger, etc. This data is being analyzed.

3 Natural Variability

The basis against which one measures change in a parameter is the average value and the natural variability of that parameter. If following or during the occurence of some perturbation the average value and variability of the parameter has significantly changed then the investigator can determine that there has been a significant impact on that parameter due to that perturbation. Significance is generally tested at the 95% level, i.e., there is the risk that due to random chance alone one out of 20 times the acceptance of the conclusion that there was a significant impact will be incorrect. As important is to know the significance level of concluding there was no impact when in fact there was.

The first stages of the OTEC biological oceanographic field program was descriptive and looked mainly at the macrozooplankton community and phytoplankton community. This data was collected to obtain a general picture of the plankton at the various OTEC sites. This picture is composed of the general community composition biomass, depth variability, seasonal variability, etc. The second stage of the OTEC environmental field program is structured to produce a quantified analysis of the selected community parameters at specific sites. Most of the data collection for this stage was initiated this year and are still being analyzed. However, some preliminary quantitative data will be assessed. Results will be structured according to the Planktonic Ecological Group given in Table 1.

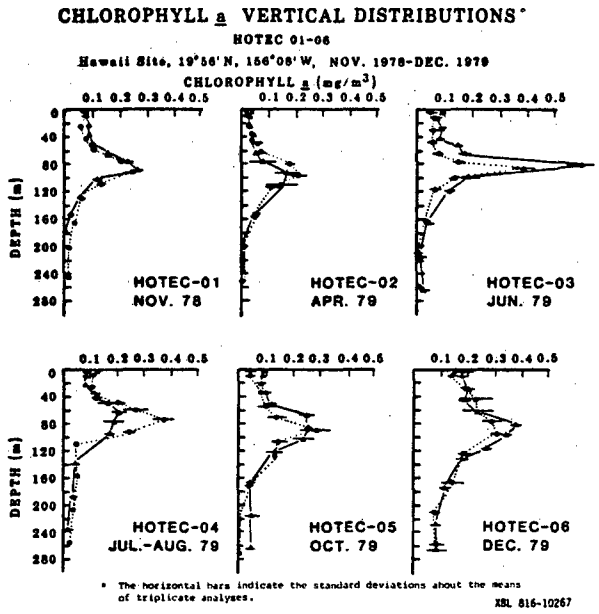

Figure 2.

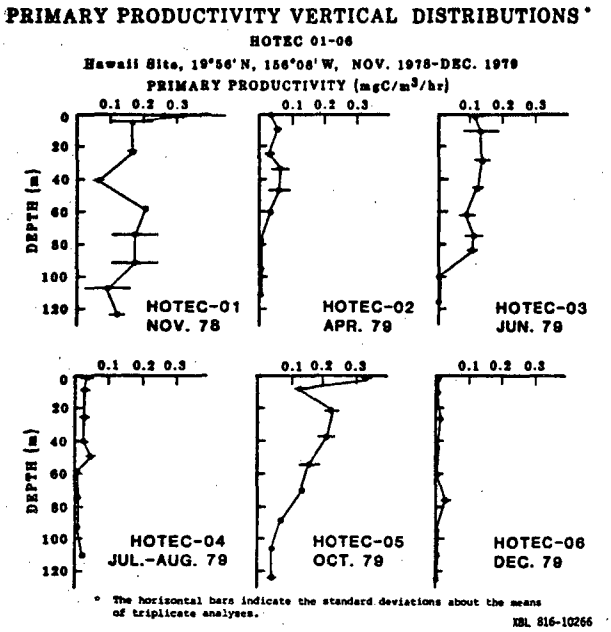

Figure 3.

3.1 Bacteria

No work has yet been initiated on this group of plankton. It is planned to initiate work on these organisms next year.

3.2 Phytoplankton

At the HOTEC site large temporal and vertical variations in phytoplankton biomass and primary productivity were observed. Over a year, phytoplankton biomass (chlorophyll a) varied threefold, and primary productivity, although always nutrient-limited varied more than 25-fold (Table 12). Vertically the profiles of phytoplankton biomass were similar over time (Figure 2) showing low and uniform levels in the upper 40-60m, with a chlorophyll a maxima centered at 85m. Photosynthetic rates were highly variable over time (Figure 3) and productivity: biomass ratios were consistently low and indicative of strong nutrient limitation. The large variation in photosynthetic activity was far in excess of the accompanying changes in the physical properties of the system, and could not be explained by variations in phytoplankton biomass or the prevailing nutrient gradients. Directing attention to factors which might affect the specific rates of activity, we found significant correlations ($P<0.01$) between depth-integrated phaeopigment stocks and primary production, and between phaeopigments and ammonium levels. Phaeopigments are produced by the digestion of chlorophyll. Variations in the supply of regenerated nutrients by grazers is believed to account for most of the observed temporal variability in photosynthesis.

3.3 Animals

3.3.1 Microzooplankton

Although this group has not been expressly sampled, six vertical net tow (35um mesh) samples taken at the (O'OTEC) site from 200 m to the surface have been analyzed for microzooplankton. The results are presented in Table 4. The replicate samples show a high variability in total abundance. However, copepod nauplii are consistantly dominate and exhibit a low variability as a percent of the total abundance (mean of 70.3% and range of 60.9% to 76.3%).

3.3.2 Macrozooplankton

The greatest amount of effort has been expended in the sampling and analysis of macrozooplankton from the several potential OTEC sites Operationally, these are plankton retained by a 200 um mesh net. Some results of these analyses are presented below.

The size distribution in abundance of macrozooplankton at the GOTEC site off Mobile, Alabama is skewed towards the smaller size classes (Table 13). The depth distribution of these size classes varies with time of day (Figure 4). The depth distribution of total zooplankton at this site showed a diel vertical migration pattern (Figure 5, Table 14). In the evenings and going into the night (1740 hrs to 2415 hrs) the zooplankton leave the shallow-water (0-50m) and migrate down to the 50m-100m layer where a peak abundance of 4938 m^{-3} was observed. During the night (2230 hrs to 0515

hrs) the zooplankton distribution remains the same As daylight approaches and into the day (0515 hrs to 1415 hrs) the zooplankton leave the near-surface water (50-100m) and move back into the surface, mid- and deep-water

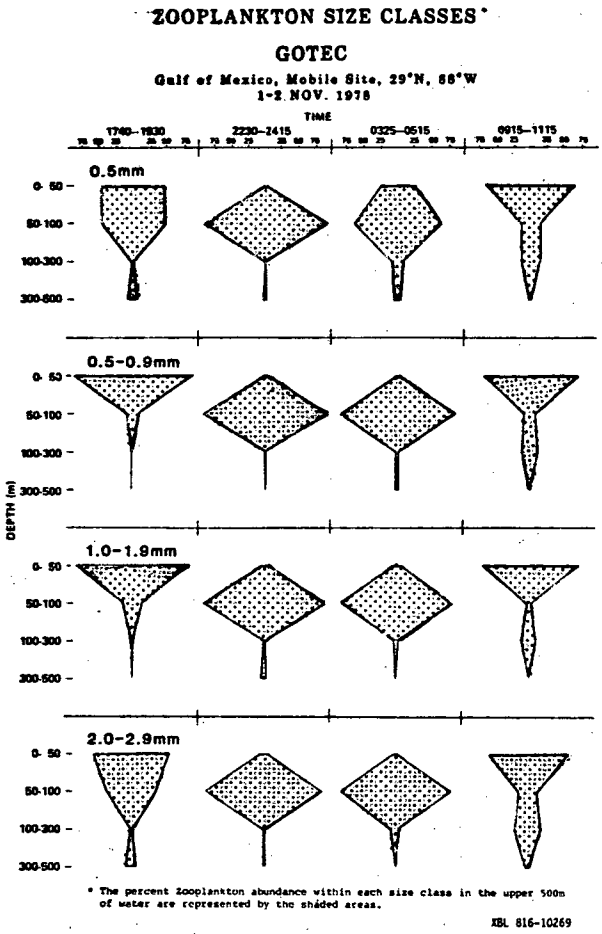

Figure 4.

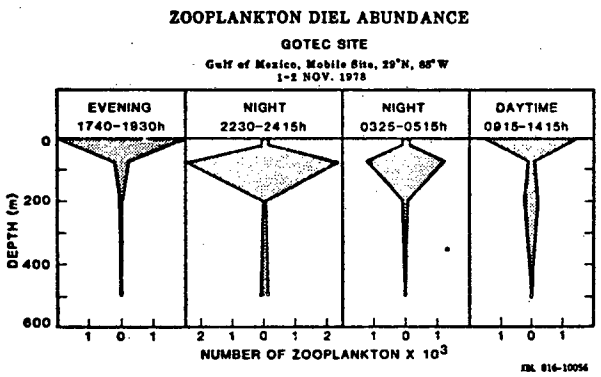

Figure 5.

The HOTEC site likewise shows a diel vertical migration pattern, with zooplankton migration into the surface waters during the night and back into the deeper waters during the day. Zooplankton samples from the GOTEC sites off Mobile and Tampa and the PROTEC site were obtained only during the day and reveal strictly the depth distribution of zooplankton

Figures 6-9 are summary graphs of day/night surface (0-25m) copepods abundance at four potential OTEC sites. It is apparent that one can not make the sweeping generalization that copepod abundance increases at night and decreases in the day Day/night copepods abundance distributions are site dependent, time dependent and depth dependent.

The diel variation with depth of zooplankton biomass in two size categories (0 2-0.5mm and greater than 0.5 mm) is depicted in Figure 10. HOTEC-05 showed evidence of diel vertical migration of biomass while HOTEC-06 did not. This is in contrast to the abundance data (Figure 8) where both cruises evidenced diel vertical migration. This points out the problem of parameter selection for examining events or impacts. An investigator must choose that (those) parameter(s) which most succinctly or simply explains the event or impact under study

On HOTEC-05, as also evidenced in the GOTEC Mobile site data (Figure 4) diel vertical migration occurred in smaller and larger zooplankton. The depth distribution of biomass at the HOTEC site (Figures 10 and 11), was similar for both size classes.

The depth distribution of the mean zooplankton abundance or biomass from all sites has the same basic characteristic of drastically reduced numbers or weight with increased depth. The variability of these parameters is likewise reduced with increasing depth. Therefore the greatest sampling effort for quantifying the zooplankton community should be exerted in the shallow waters and least in the deep waters. This general statement of sampling effort is reinforced by the fact that the impact of OTEC is projected to be greatest in the shallower waters.

The zooplankton data show significant sampling variability, diel variability, cruise to cruise variability depth variability and spatial variability. The largest components of the site-specific variability are generally associated with depth and time. Spatial variability can be large if one does not select similar sampling sites. Depth variability can be accounted for by performing stratified sampling. Variability at a single site and depth due to sampling, diel migrations and cruise dates are all components of time variability. The data, up to now, do not permit the best accounting for time variability. One of the purposes of the sampling programs presently underway is to permit us to develop the most cost effective sampling scheme to account for time variability. Preliminary indications are that OTEC zooplankton sampling should be done one of two ways:

1) Sample time intensively with low replicates within each time, e.g., sample once a month taking only replicates, or

2) Divide the year into 2 seasons and sample intensively within each season, e.g., replicate sample intensively in January (winter) and July (summer) only.

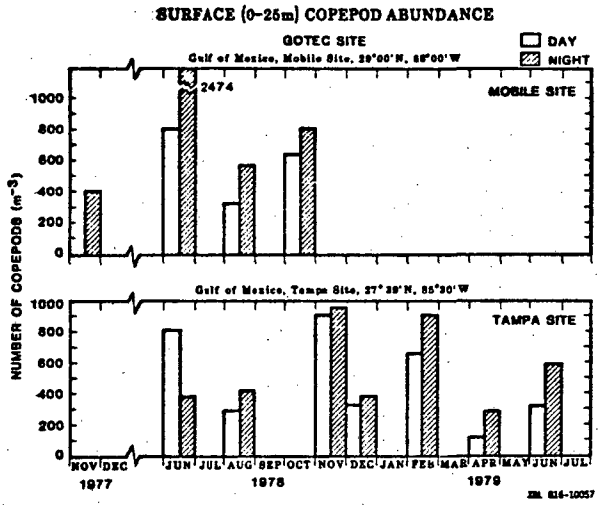

Figure 6.

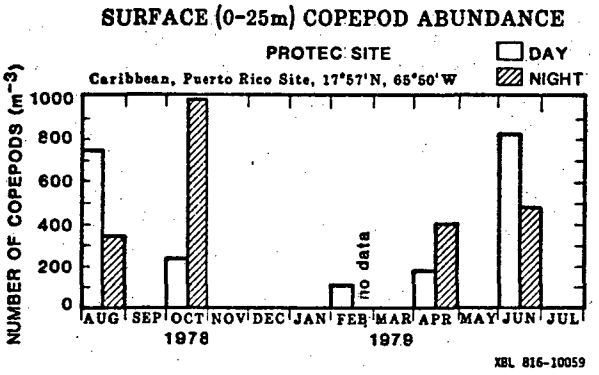

Figure 7.

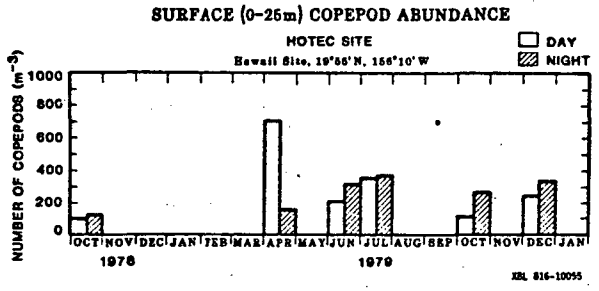

Figure 8.

3.3.3 Ichthyoplankton

The first larval fish (ichthyoplankton) samples were taken this year and the results are being tabulated. Ichthyoplankton and fish abundance are discussed in more detail in the paper by Ryan and Jones in this conference.

3.3.4 Other Larval Animals

These are collected with macrozooplankton samples, but the data has not been analyzed.

4. Summary

The OTEC biological oceanographic program has concentrated its efforts on acquiring data for engineering design and impact assessment. The latter goal was the subject of this paper. Impact assessment is evaluated through analysis of change in affected biological communities. Therefore, initial OTEC studies were directed at determining community composition, mean abundances and natural variability.

For initial environmental studies a deep-water moored OTEC system was envisioned. The impact of this OTEC configuration would be principally on the planktonic community. This community has been examined at five (5) potential OTEC sites The results show that the components of the planktonic community exhibit a high degree of variability with depth, space and time. Whereas accounting for the variability with depth and space are straight forward accounting for the variability with time is the subject of present investigations.

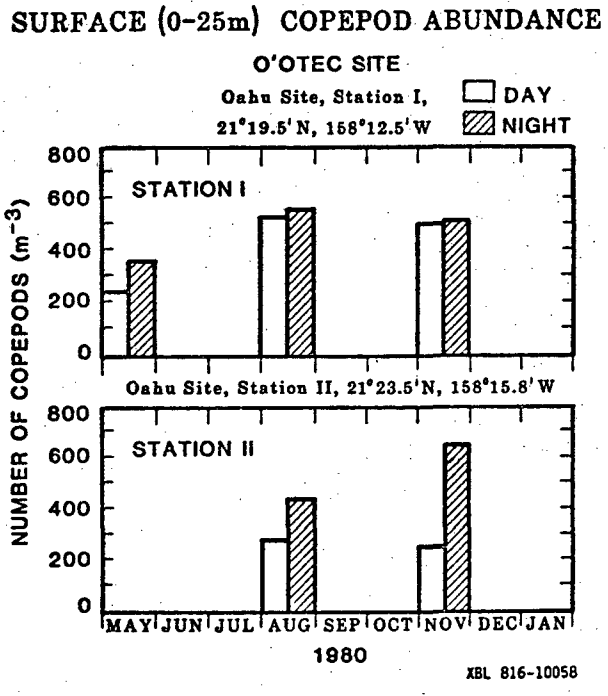

Figure 9.

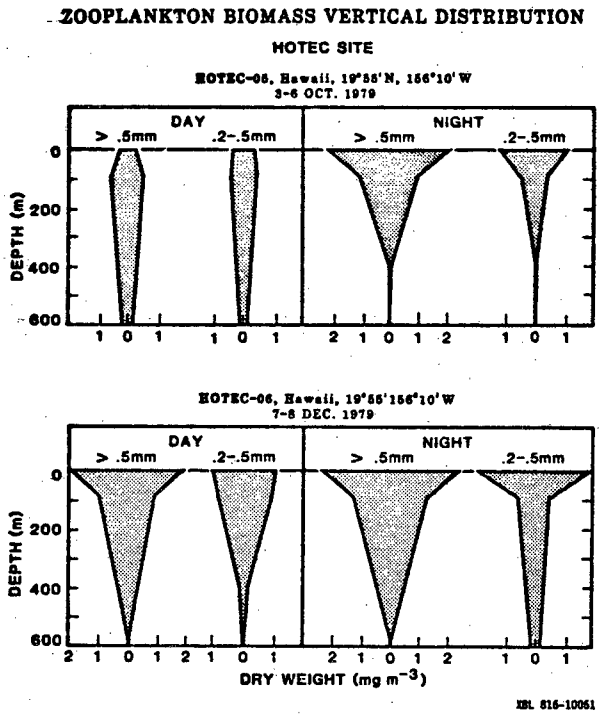

Figure 10.

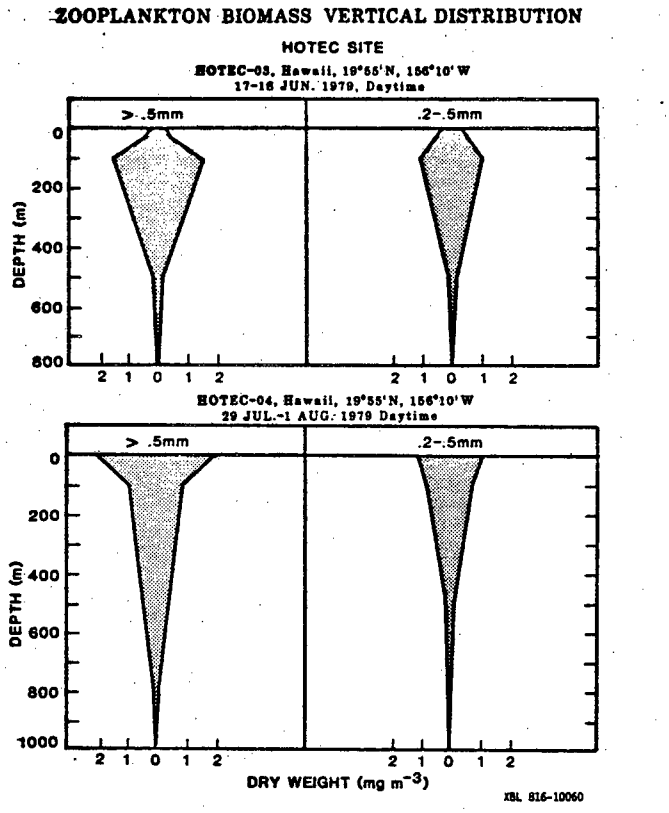

Figure 11.

TABLES

TABLE 1

MAJOR ECOLOGICAL GROUPS

I. Benthic
- A. Bacteria
- B. Plants
  - 1. Microflora
  - 2. Macroflora
- C. Animals
  - 1. Microfauna
  - 2. Macrofauna

II. Nektonic
- A. Marine Mammals
  - 1. Otters
  - 2. Seals and sea lions
  - 3 Porpoises and dolphins
  - 4 Whales
- B. Other Animals
  - 1. Micronekton
    - a. Juvenile fish
    - b. Large crustaceans
  - 2. Macronekton
    - a. Squid
    - b. Adult fish
    - c. Sharks
  - 3. Marine turtles

III. Planktonic
- A. Bacteria
- B. Plants
  - 1. Pico-/Nano-phytoplankton
  - 2. Net (Macro) phytoplankton
- C. Animals
  - 1. Microzooplankton
  - 2. Macrozooplankton
  - 3. Ichthyoplankton
  - 4. Other larval animals

TABLE :

PHYTOPLANKTON COMPOSITION. PROTEC SITE[1]

Depth	Phyletic Group									
	Diatoms		Dinoflagellates		Coccolithophorids		Monads		Blue-green filaments	
	D	N	D	N	D	N	D	N	D	N
0	10.4	20.0	3.1	1.5	13.8	39.9	72.6	37.8	-	-
10m	16.3	24.7	10.9	6.3	64.1	31.4	-	37.6	8.7	-
15m	8.6	14.7	0.4	-	9.6	85.3	81.4	-	-	-
20m	7.3	26.8	2.4	2.8	19.7	33.1	70.1	36.2	0.6	1.1
35m	30.6	22.2	5.5	2.9	63.8	47.2	-	27.2	-	0.4
45m	3.0	73.6	1.2	1.9	14.5	8.7	81.3	15.6	-	-
50m	12.6	39.2	1.8	0.5	2.9	2.9	82.6	47.5	-	-
60m	7.8	0.9	6.6	0.5	85.5	34.1	-	64.3	-	0.1
75m	47.7	3.5	9.0	4.2	43.2	7.0	-	85.3	-	-
100m	6.1	68.9	2.3	8.8	2.3	22.2	87.9	-	1.5	-
200m	46.2	6.3	22.9	-	30.9	0.8	-	91.4	-	1.5
300m	50.0	16.6	25.0	-	25.0	85.4	-	-	-	-

[1]Percent of total abundance on the day cast (D) and night cast (N) on one cruise, PROTEC-10.

TABLE 3

PERCENT OF CHLOROPHYLL a AND CARBON FIXATION IN >5 µm SIZE FRACTION. HOTEC-01

Depth (m)	Percent in >5 µm Fraction Chlorophyll a	Carbon Fixation
0	14.3	10.3
5	37.5	24.6
23	33.3	13.9
41	37.5	26 1
58	18.2	5.0
74	14.3	4 2
91	12.0	11.6
107	21.4	7.7
123	42.9	-
163	25.0	-
202	50.0	-
243	50.0	-

TABLE 4

MICROZOOPLANKTON (>35 µm and <202 µm) ABUNDANCE
O'OTEC-01
OAHU SITE, 21° 19.5"N, 158° 125"W
24 - 27 May, 1980
0-200m

Station 1, Day, Replicate A

Name	Number per Cubic Meter	
Peridinium sp.	19	
Ceratium	66	
Gastropod Veliger	14	
Pelecypod Veliger	28	
Polychaete	14	
Copepod Nauplius	2219	
Calanoid Copepod	156	
Oithona Sp.	360	
Copycaeus Sp.	9	
Oncaea Sp.	75	
Unidentified Harpacticoid	66	
Euphausiid	47	Total Taxa = 15
Larvacean	75	Total Count = 676
Eggs	19	Total Abundance = 3204
Unidentified Larva	33	% Abundance Copepod Nauplii = 69.3

Station 1, Day, Replicate B

Name	Number per Cubic Meter	
Noctiluca Sp.	4	
Peridinium Sp.	99	
Ceratium Sp.	47	
Tintinnid	14	
Gastropod Veliger	33	
Pelecypod Veliger	52	
Polychaete	19	
Copepod Nauplius	1380	
Calanoid Copepod	114	
Oithona Sp.	185	
Corycaeus Sp.	23	
Oncaea Sp.	85	
Unidentified Harpacticoid	19	Total Taxa = 16
Euphausiid	23	Total Count = 478
Larvacean	142	Total Abundance = 2267
Eggs	23	% Abundance Copepod Nauplii = 60.9

Station 2, Night, Replicate A

Name	Number per Cubic Meter	
Peridinium Sp.	4	
Ceratium Sp.	14	
Tintinnid	1	
Pteropod	1	
Gastropod Veliger	13	
Pelecypod Veliger	16	
Polychaete	2	
Ostracod	1	
Copepod Nauplius	463	
Calanoid Copepod	29	
Oithona sp.	60	
Corycaeus sp.	3	
Oncaea sp	17	
Unidentified Harpacticoid	2	Total Taxa = 17
Euphausiid	1	Total Count = 559
Larvacean	28	Total Abundance = 662
Eggs	1	% Abundance Copepod Nauplii = 69.9

Table 4 (continued)

Station 2, Night Replicate B

Name	Number per Cubic Meter	
Peridinium Sp.	142	
Ceratium sp.	128	
Dinophysis sp.	19	
Tintinnid	23	
Siphonophore	4	
Gastropod veliger	61	
Pelecypod verliger	23	
Polychaete	9	
Copepod nauplius	4352	
Calanoid copepod	303	
Oithona sp.	555	
Corycaeus sp.	14	
Oncaea sp.	94	
unidentified harpacticoid	61	
Euphausiid	23	Total Taxa = 18
Chaetognath	9	Total Count = 1280
Larvacean	228	Total Abundance/m^3 = 6068
Eggs	14	% Abundance Copepod Nauplii = 71.7

Station 2, Day, Replicate A

Name	Number per Cubic Meter	
Peridinium Sp.	9	
Ceratium Sp.	26	
Tintinnid	2	
Gastropod Veliger	14	
Pelecypod Veliger	7	
Polychaete	9	
Copepod Nauplius	1353	
Calanoid Copepod	116	
Oithona Sp.	190	
Corycaeus Sp	7	
Oncaea Sp.	35	Total Taxa = 14
Unidentified Harpacticoid	23	Total Count = 770
Euphausiid	4	Total Abundance/m^3 = 1825
Larvacean	26	% Abundance Copepod Nauplii = 74.1

Station 2, Day, Replicate B

Name	Number per Cubic Meter	
Peridinium Sp.	80	
Ceratium Sp	123	
Dinophysis Sp.	23	
Tintinnid	9	
Pteropod	4	
Gastropod Veliger	47	
Pelecypod Veliger	23	
Polychaete	9	
Copepod Nauplius	3124	
Calanoid Copepod	166	
Oithona Sp.	251	
Corycaeus Sp.	9	
Oncaea Sp.	56	
Unidentified Harpacticoid	33	Total Taxa = 17
Chaetognath	9	Total Count = 864
Larvacean	80	Total Abundance/m^3
Eggs	42	Copepod Nauplii = 4095
		% Abundance = 76 3

TABLE 5

COPEPOD RANKED ABUNDANCE*
HOTEC SITE

Date (day/night)	Dominant Genera (% of total copepods)		% Composition by Order	
25-30 Oct 1978 (day)	Oithona	31.1	Calanoida	57.5
	Acartia	7.2	Cyclopoda	41.1
	Corycaeus	6.2	Harpacticoida	1.4
	Mecynocera	4.3		
	Calocalanus	3.3		
9-13 April 1978 (day)	Corycaeus	5.8	Calanoida	89.7
	Oithona	4.1	Cyclopoda	10.3
	Acartia	1.5	Harpacticoida	0
	Hormonilla	1.0		
	Centropages	0 4		
13-14 June 1978 (day)	Corycaeus	10.5	Calanoida	73.0
	Oncaea	8.8	Cyclopoida	26.6
	Acartia	8.8	Harpacticoida	0.4
	Oithona	7.0		
	Candacia	2.4		
25-30 Oct 1978 (night)	Oithona	28.7	Calanoida	34.5
	Corycaeus	19 2	Cyclopoida	59 9
	Pleuromamma	9.7	Harpacticoida	0.6
	Oncaea	8.3		
	Acartia	4.8		
9-13 April 1978 (night)	Corycaeus	26.9	Calanoida	62.2
	Acartia	16.4	Cyclopoida	37.8
	Oithona	9.3	Harpacticoida	0
	Pleuromamma	5.3		
	Euchaeta	3.7		
13-14 June 1978 (night)	Oncaea	15.1	Calanoida	68.7
	Corycaeus	8.7	Cyclopoida	31.3
	Oithona	6.7	Harpacticoida	0
	Acartia	6 1		
	Undimula	3.6		

*All 0-25m samples for each cruise depth were used to rank copepod genera.

TABLE 6

COPEPOD RANKED ABUNDANCE*
PROTEC SITE
0-25m

Date (day/night)	Dominant Genera (% of total copepods)		% Composition by Order	
31 Jul-3 Aug 1978 (day)	Clausocalanus	19.0	Calanoida	73.3
	Calocalanus	18.1	Cyclopoida	26.7
	Undimula	16.8	Harpacticoida	0
	Oithona	14.7		
	Acartia	9.9		
10-14 Oct 1978 (day)	Clausocalanus	24.7	Calanoida	71.0
	Calocalanus	18.1	Cyclopoida	29.0
	Farranula	11 5	Harpacticoida	0
	Oncaea	8.3		
	Undimula	6.9		
10-16 Feb 1979 (day)	Clausocalanus	24.5	Calanoida	64.0
	Oithona	18 3	Cyclopoida	34.1
	Paracalanus	17.8	Harpacticoida	1.9
	Temora	9.6		
	Corycaeus	7.2		
	Mecynocera	7.2		
19-23 April 1979 (day)	Temora	32.1	Calanoid	52.4
	Corycaeus	24.4	Cyclopoid	46.6
	Clausocalanus	7.3	Harpacticoid	1.0
	Farranula	6.7		
	Oncaea	6 7		
4-9 June 1979 (day)	Clausocalanus	36.5	Calanoida	70.1
	Farranula	20.5	Cyclopoida	29.5
	Undimula	20.5	Harpacticoida	0.4
	Oithona	7.0		
	Calocalanus	4.9		

TABLE 6 (continued)

Date (day/night)	Dominant Genera (% of total copepods)		% Composition by Order	
31 Jul-3 Aug 1978 (night)	Acartia	41.5	Calanoida	87.8
	Clausocalanus	16.7	Cyclopoida	11.9
	Paracalanus	12.1	Harpacticoida	0.3
	Calocalanus	7.4		
	Oithona	5 3		
10-14 Oct 1978 (night)	Clausocalanus	16 5	Calanoida	78.0
	Calocalanus	13.9	Cyclopoida	31.6
	Temora	12.6	Harpacticoida	0.4
	Oncaea	12.1		
	Farranula	11.7		
19-23 Apr 1979 (night)	Clausocalanus	28.7	Calanoida	54 4
	Oithona	21 6	Cyclopoida	45.0
	Corycaeus	13.0	Harpacticoida	0.6
	Calocalanus	7 5		
	Farranula	6 5		
4-9 Jun 1979 (night)	Undinula	25.5	Calanoida	72 5
	Temora	11.3	Cyclopoida	25 9
	Clausocalanus	9 3	Harpacticoida	1.6
	Oithona	8 1		
	Calocalanus	6 9		

*All samples for each cruise between 0-25 m depth were used to rank copepod genera.

TABLE 7

COPEPOD RANKED ABUNDANCE*
GOTEC TAMPA SITE
0-25m

Date (day/night)	Dominant Genera (% of total copepods)		% Composition by Order	
9-21 June 1978 (day)	Clausocalanus	32.6	Calanoida	58.0
	Oncaea	16.5	Cyclopoida	40.8
	Paracalanus	11 1	Harpacticoida	1.2
	Oithona	10.2		
	Farranula	9.3		
15-27 Aug 1978 (day)	Oithona	25.0	Calanoida	48.9
	Clausocalanus	24.4	Cyclopoida	48.3
	Oncaea	11.5	Harpacticoida	2.8
	Mecynocera	9 9		
	Farranula	5.7		
21 Oct-6 Nov 1978 (day)	Clausocalanus	32.7	Calanoida	57.0
	Oncaea	19 7	Cyclopoida	40 9
	Oithona	11.6	Harpacticoida	2.1
	Farranula	7.3		
	Euchaeta	6.5		
16-20 Dec 1978 (day)	Clausocalanus	44.9	Calanoida	70 1
	Oithona	19.2	Cyclopoida	29.3
	Euchaeta	7.7	Harpacticoida	0.6
	Oncaea	3.8		
	Farranula	3.3		
10-15 Feb 1979 (day)	Clausocalanus	45.5	Calanoida	83.9
	Oithona	7.8	Cyclopoida	15.4
	Euchaeta	7 5	Harpacticoida	0.7
	Oncaea	5.8		
	Eucalanus	4.7		
25-29 April 1979 (day)	Clausocalanus	34.1	Calanoida	65.1
	Oncaea	11 8	Cyclopoida	34.6
	Oithona	11.6	Harpacticoida	0.0
	Corycaeus	7.8		
	Calocalanus	6.2		
25 Jun-1Jul 1979 (day)	Oncaea	20.3	Calanoida	56.3
	Clausocalanus	18.7	Cyclopoida	43.0
	Temora	14.9	Harpacticoida	0.5
	Farranula	10.4		
	Oithona	7 0		

Table 7 (continued)

Date (day/night)	Dominant Genera (% of total copepods)		% Composition by Order	
9-21 July 1978 (night)	Oncaea	55.4	Calanoida	17.3
	Oithona	14.7	Cyclopoida	80.9
	Corycaeus	5.9	Harpacticoida	1.8
	Farranula	3.4		
	Clausocalanus	3.2		
	Mecynocera	3.2		
15-27 Aug 1978 (night)	Oncaea	35.4	Calanoida	42 6
	Clausocalanus	12.4	Cyclopoida	54.8
	Oithona	10.4	Harpacticoida	2.6
	Mecynocera	5.3		
	Temora	4 7		
21 Oct-6 Nov 1978 (night)	Oncaea	24 4	Calanoida	59.1
	Clausocalanus	22.8	Cyclopoida	40.8
	Temora	10.0	Harpacticoida	0.1
	Farranula	9 4		
	Calocalanus	8 1		
16-20 Dec 1978 (night)	Clausocalanus	28.9	Calanoida	65.6
	Oithona	12.3	Cyclopoida	34.4
	Oncaea	10 0	Harpacticoida	0.0
	Euchaeta	3 7		
	Mannocalanus	3.1		
10-15 Feb 1979 (night)	Clausocalanus	26.7	Calanoida	71 8
	Oithona	15.4	Cyclopoida	24.2
	Paracalanus	11.5	Harpacticoida	0.5
	Oncaea	9.6		
	Mannocalanus	6 0		
25-30 April 1979 (night)	Clausocalanus	45.4	Calanoida	75 3
	Oncaea	14.5	Cyclopoida	24 2
	Temora	6 9	Harpacticoida	0.5
	Oithona	3.8		
	Farranula	3.5		
25 Jun-1 Jul 1979 (night)	Temora	26 8	Calanoida	75 8
	Farranula	11.9	Cyclopoida	23.7
	Clausocalanus	10 7	Harpacticoida	0.5
	Oncaea	8.9		
	Undimula	6.8		

*All 0-25m samples for each cruise depth were used to rank copepod genera.

TABLE 8

COPEPOD RANKED ABUNDANCE*
GOTEC MOBILE SITE
0-25m

Date (day/night)	Dominant Genera (% of total copepods)		% Composition by Order	
15-21 Nov 1977 (day)	Clausocalanus	19.2	Calanoida	69.5
	Paracalanus	16.6	Cyclopoida	29.6
	Oncaea	12.2	Harpacticoida	0 9
	Oithona	11 0		
	Calocalanus	7.0		
9-21 June 1978 (day)	Oncaea	40.8	Calanoida	23.9
	Oithona	19 9	Cyclopoida	73.1
	Temora	9.0	Harpacticoida	3.0
	Corycaeus	8.5		
	Calocalanus	7.5		
15-27 Aug 1978 (day)	Oithona	48 4	Calanoida	28.8
	Calocalanus	21.4	Cyclopoida	69.1
	Corycaeus	8.9	Harpacticoida	2.1
	Paracalanus	4.2		
	Macrostella	2.1		
	Oncaea	2.1		
21 Oct-6 Nov 1978 (day)	Clausocalanus	31.8	Calanoida	61 4
	Oncaea	17.4	Cyclopoida	38.3
	Farranula	10.2	Harpacticoida	0.3
	Calocalanus	6.0		
	Oithona	5.7		
15-21 Nov 1977 (night)	Oncaea	23.6	Calanoida	69.5
	Paracalanus	18 1	Cyclopoida	29.6
	Oithona	15.4	Harpacticoida	0.9
	Clausocalanus	12 9		
	Euchaeta	4.2		
9-21 June 1978 (night)	Oncaea	27.8	Calanoida	40 7
	Oithona	14.6	Cyclopoida	58.6
	Corycaeus	14.3	Harpacticoida	0.7
	Temora	9.9		
	Paracalanus	7.6		
15-27 Aug 1978 (night)	Oncaea	25.7	Calanoida	47.9
	Oithona	18.4	Cyclopoida	48.1
	Clausocalanus	7.2	Harpacticoida	4.0
	Corycaeus	5.0		
	Mecynocera	4.5		
21 Oct-6 Nov 1978 (night)	Clausocalanus	33.3	Calanoida	59.8
	Oncaea	20.4	Cyclopoida	39.6
	Farranula	13.9	Harpacticoida	0.6
	Temora	6.8		
	Calocalanus	5.7		

*All 0-25m samples for each cruise were used to rank copepod genera.

TABLE 9

SUMMARY OF FIVE COPEPOD GENERA RANKED ABUNDANCE[1]

	HOTEC		PROTEC		GOTEC Tampa		GOTEC Mobile		Rank Sum[3]
	Day	Night	Day	Night	Day	Night	Day	Night	
Oithona	3/3[2]	3/3	3/5	3/4	7/7	5/7	4/4	3/4	31/37
Oncaea	1/3	2/3	2/5	1/4	7/7	7/7	4/4	4/4	28/37
Clausocalanus			5/5	4/4	7/7	7/7	2/4	3/4	28/37
Farranula			3/5	2/4	5/7	4/7	1/4	1/4	16/37
Corycaeus	3/3	3/3	2/5	1/4	1/7	1/7	2/4	2/4	15/37
Calocalanus	1/3		3/5	4/4	1/7	1/7	4/4	1/4	15/37
Temora			2/5	2/4	1/7	3/7	1/4	2/4	11/37
Paracalanus			1/5	1/4	1/7	1/7	2/4	2/4	8/37
Acartia	3/3	3/3	1/5	1/4					8/37
Mecynocera	1/3		1/5		1/7	2/7		1/4	6/37
Undinula		1/3	3/5	1/4		1/7			6/37
Euchaeta		1/3			3/7	1/7		1/4	6/37
Pluromamma		2/3							2/37
Hormonilla	1/3								1/37
Candacia	1/3								1/37
Centropages	1/3								1/37
Eucalanus					1/7				1/37
Mamocalanus						1/7			1/37
Macrostella							1/4		1/37

[1] The top five (or six if last two equal) ranked abundance copepod genera at each site are ranked across all sites for the 0-25m depth.

[2] 3/3: number of times that the genera was listed in the top five ranked abundance genera over the number of cruises taking day or night samples.

[3] Rank Sum = Summation of the occurrance of a genera over the total number of cruises.

TABLE 10

GENERAL SITE DESCRIPTIONS

Parameter	HOTEC	O'OTEC	Site PROTEC	GOTEC (Mobile)	GOTEC (Tampa)
Approximate Site Location	19°55'N 156°10'W	21°20'N 158°13'W	17°57'N 65°50'W	29°00'N 88°00'W	26°00'N 85°54'W
Distance From Shore (km)	33	7.9	4.6	138	300
Depth To Bottom (m)	1,200	1 000	1,200	1 200	1,400
Average Maximum Photic Zone Depth (m)	135	120	120	125	125
Average Mixed Layer Depth (m) (Sum/Wint)	50/80	50/80	60/80	30/80	30/75
Average Surface Current Speeds (cm/sec)	10-40	10-40	10-40	25-50	30-90

TABLE 11

SUMMARY OF RANKED PERCENT COMPOSITION BY ORDER FOR COPEPODS

COPEPOD ORDER	HOTEC Day	HOTEC Night	PROTEC Day	PROTEC Night	GOTEC Tampa Day	GOTEC Tampa Night	GOTEC Mobile Day	GOTEC Mobile Night	Mean
Calanoida	73.4	56.8	66.2	73.2	62.8	58.2	38 0	49.5	59.8
Cyclopoida	26.0	43 0	33 1	26.1	36.1	40.9	60.2	48.7	39.2
Harpacticoida	0 6	0.2	0.7	0.7	1.1	1.9	1.8	1.8	1.0

TABLE 12

DEPTH INTEGRATED PHYTOPLANKTON PARAMETERS[1]
HOTEC-01-06

Parameter	HOTEC-01 Oct 78	HOTEC-02 April 79	HOTEC-03 June 79	HOTEC-04 Aug 79	HOTEC-05 Oct 79	HOTEC-06 Dec 79
[2]Chlorophyll a	17.40	14.64	22.24	23.90	24.70	44.45
[2]Phaeopigments	17.47	4.92	16.50	9.80	18 07	4.07
[3]Primary Productivity	18 70	3.12	10.01	2.86	17 32	0 72

[1] Chlorophyll and phaeopigments integrated over 250m. Primary productivity integrated over 120m

[2] Units of $mg \cdot m^{-2}$

[3] Units of $mgC \cdot m^{-2} \cdot hr^{-1}$

TABLE 13

ZOOPLANKTON SIZE DISTRIBUTION*
GOTEC MOBILE SITE

Size distribution of zooplankton from 22 samples collected between 0 amd 500 m at the Mobile OTEC site

Class	Size	Percent Composition
1	0 5mm	5.6
2	0.5mm-0.9mm	38.6
3	1.0mm-1.9mm	44.8
4	2.0mm-2.9mm	5.0
5	3.0mm-3.9mm	1.9
6	4.0mm-4.9mm	1.5
7	5 0mm-5.9mm	0.6
8	6.0mm-6.0mm	0.9
9	7.0mm-7.9mm	0.2
10	8 0mm-8.9mm	0.1
11	9.0mm-9.9mm	0.2
12	10.0mm-19.9mm	0.6
13	20.0mm-29.9mm	0.0005
14	30.0mm-39.9mm	0.001
15	40.0mm-49.9mm	-
16	50.0mm	0.003

*Size distribution from 22 samples collected between 0-500m, representing 128 copepod species and 43 other taxa.

TABLE 14

ZOOPLANKTON DIEL ABUNDANCE WITH DEPTH
GOTEC MOBILE SITE
1-2 NOVEMBER 1978

Depth	Time	Number Zooplankton m^{-3}	Number Copepods m^{-3}
0-50m	1740	3069.6	2552.1
50-100m	1740	451.2	258.5
100-300m	1930	70.5	50.3
300-500m	1930	42.9	34.6
0-50m	2230	250.1	160 5
50-100m	2230	4938.6	3562 8
100-300m	2415	32.5	27.2
300-500m	2415	97.3	63.5
0-50m	0325	262.9	170.7
50-100m	0325	2543 0	1847.7
100-300m	0515	172.4	117.3
300-500m	0515	49.8	43.6
0-50m	0915	1813.8	1274.0
0-50m	1030	2554 3	1981.7
0-50m	1145	2131.3	1504.2
50-100m	0915	359.8	211.5
50-100m	1030	197.6	147.2
50-100m	1145	458.1	304.6
100-300m	1300	720.5	486.9
100-300m	1415	101.5	75 6
300-500m	1300	117.8	99.5
300-500m	1415	46.1	38.7

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