WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

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BIOLOGICAL, CHEMICAL AND RADIOCHEMICAL STUDIES
OF MARINE PLANKTON

by

Bostwick H. Ketchum

Progress Report and Research Proposal
Submitted to the U. S. Atomic Energy Commission
under Contract AT(30-1)-1918

APPROVED FOR DISTRIBUTION

Paul M. Fye, Director

February 15, 1961

UNCLASSIFIED

PROGRESS REPORT FOR 1960

Since the last progress report and research proposal was submitted to the U. S. Atomic Energy Commission we have completed seven cruises on which the primary objectives were the study of the biology, chemistry and radiochemistry of marine plankton populations. As in the past, our program of plankton research has been jointly sponsored by the Atomic Energy Commission, by grants from the National Science Foundation, by contract with the Office of Naval Research and by Institution funds. Of the seven cruises mentioned above, three included a complete hydrographic and zooplankton collecting section of 13 - 15 stations extending from Montauk Point to the vicinity of Bermuda; one occupied the first third of this section extending across the continental shelf to the Gulf Stream, and three were for the purposes of specialized studies.

The chemical and physical observations which were made during the first three years of this program have been collated and will be submitted as Appendix C to this report as soon as bound copies are received from the reproduction department. Since our program involves the cooperative efforts of several independent investigators, each of whom is studying his particular problem in relation to the overall ecological conditions in the ocean, it has become increasingly important to have the results of our chemical and physical observations available in a convenient form so that each member of the group can use these data in the way that is most convenient to his program. Since the details of our observations have never been submitted to the Atomic Energy Commission in this way this appendix is submitted with this report. As time permits the observations on the section from Montauk Point to Bermuda will also be collated in a similar way and these data will be submitted in the future.

Seventeen papers have been published during the past year by the group who are cooperating on this investigation. Four papers by Curl and by Grice discuss work which was completed prior to their employment at the Institution on our AEC Contract and they consequently do not carry an acknowledgment to AEC support. They are included with this report since they consider problems which are pertinent to our investigation. For three of the published papers reprints are not yet available, but reprints of the fourteen published papers are submitted herewith as Appendix A of this report (see part I, Publications and Reports).

Six papers written by members of the group have been accepted for publication but have not yet appeared (Publications, Part II). Substantially similar manuscript reports of three of these have been included in a previous report; the manuscripts for three of them are included in Appendix B of the present report.

Thirteen reports on work in progress are included in Appendix B to this report which will be forwarded as soon as it is printed, collated and bound. Several of these have been prepared with the purpose of submitting them for publication but they have not been submitted or accepted as yet. A list of these reports is included in Part III of the section on Publications.

These publications and reports describe in detail the progress that has been made on this program during the last year. It would be impossible to summarize them here, but it is appropriate to mention briefly some of the advances, and to mention some of the work in progress which is not yet in a state where a detailed report is appropriate.

One of the exciting advances which has been made in the last year is that Dr. Watson has been able to culture nitrifying bacteria from the water column in the open sea. He now has these in enrichment culture, growing sufficiently well so that laboratory physiological experiments on their activity are possible. For decades some of the best marine microbiologists have attempted to isolate these nitrifying bacteria from the open sea water and have not been successful. From the observed distribution of nitrogen compounds it has been obvious that the nitrifying process must go on in the water column although the failure of several investigators to isolate the organisms responsible has led them to conclude that nitrification must be limited to the bottom sediments. Because of the stability of the ocean and the limited exchange between the bottom sediments and the surface layers it has been obvious to oceanographers that this explanation could not be correct. Dr. Watson's success depended upon obtaining large samples of sea water, enriching them with ammonia and starting the cultures in the laboratory on shipboard. Active nitrifying enrichment cultures have now been obtained from slope water collected at 50 and 1300 meters, just off the edge of the continental shelf, from Sargasso Sea water from 10 meters depth and from nine out of ten water samples taken from a depth of 10 meters over the continental shelf. The physiology of the nitrifying bacteria isolated from the sea is sufficiently different from that of terrestrial nitrifying organisms to indicate that it is indeed a different population and probably consists of different species. The nitrifiers are, however, euryhaline so that they do not appear to be obligate sea-water species. A preliminary report of the results of the physiological studies on these enrichment cultures is included in Appendix B.

The most significant advance in the study of phytoplankton ecology during the past year has been the successful isolation and culture of a number of truly oceanic species of plankton algae including representatives of the Chlorophyceae, Bacillariophyceae, and Coccolithophoridae. Of particular interest are a variety of small centric diatoms, most of which are undescribed or of uncertain taxonomic position. The morphology of these organisms is being investigated with the aid of both light and electron microscopy with the aim of describing this largely unknown flora. We have also isolated a coccolithophoride tentatively identified as Coccolithus huxleyi, the dominant alga during most of the year in the Sargasso Sea and many other oceanic regions.

With these organisms in pure culture, a host of problems may be attacked through controlled physiological experimentation by means of which their occurrence and abundance in nature may be related to the physical and chemical characteristics of the environment. Examples of the work now in progress with these cultures include: (1) Possible and preferential use of various nitrogen sources, particularly organic compounds; (2) Vitamin requirements and the possible enhancement of growth by vitamins in species not showing an absolute requirement, (3) The form of iron available to and preferred by the algae; (4) The relation between growth rate and nutrient concentration (Fe, N, vitamins) in oceanic vs. neritic species; (5) The assimilation number (photosynthesis/chlorophyll) and potential growth rate of oceanic vs. neritic species; and (6) Photosynthesis-light relations in oceanic vs. neritic species, summer vs. winter, and surface vs. deep-living populations.

An intensive study of the phosphorus metabolism of unicellular algae has been initiated by Dr. Kuenzler using P^{32} as a radioactive tracer. A preliminary report of part of this work included in Appendix B compares the rate of assimilation by nutrient-deficient Phaeodactylum tricornutum with the rate of exchange by cells in equilibrium with their medium. The rate of assimilation is one or two orders of magnitude greater than the rate of exchange and it has been shown that the cells are able to reduce the concentration of phosphorus in the culture medium to levels below those which it is possible to detect by the analytical method. This suggests that a bioassay technique using radiophosphorus may be the only way presently available to obtain accurate analyses of the amount of phosphorus left in the ocean at the end of an intense plankton bloom.

One of the special problems studied on the Crawford in September of 1960 was the comparison between the uptake of radiophosphorus and radiocarbon by the natural populations. This time of year was selected as the most likely for nutrient-deficiencies in the phytoplankton populations. Before definite and final conclusions can be reached these observations will have to be repeated, but a tentative conclusion is that the assimilation of phosphorus and carbon at this time is not the same as one would expect from the normal composition of marine organisms. In most samples the phytoplankton appeared to be phosphorus-deficient since they assimilated a larger proportion of phosphorus than would be expected.

As mentioned in the previous report, we have found a variable but significant amount of organic phosphorus¹ in the water at depths greater than 2000 meters beneath and south of the Gulf Stream on our cross section. When the data from Chain cruise 15 (January 1961) are worked up we will have two complete years of analyses and this

¹Defined as the difference between the inorganic and the total concentration of phosphorus.

material will be prepared for publication. To date we have found statistically significant amounts of organic phosphorus at depths greater than 2000 meters in December 1958, February and May 1959, and in March 1960. No detectable amount was present in July 1958, in August, September or December 1959 nor in August 1960. It is clear that there is a seasonal variation in the amount of organic phosphorus, but it is not in phase with the seasonal variation in the plankton populations in the water directly overlying the place where the samples are taken. In April of this year a cruise is planned to the eastward in order to determine whether similar concentrations of organic phosphorus are found in the deep water there. This organic phosphorus may be material which is produced in northern latitudes, and which sinks with the water there during the winter. It could possibly be a good tracer for the newly-formed deep water in the southward moving undercurrent below the Gulf Stream.

The temperature and salinity variations of the waters over the continental shelf over a period of three years has been analyzed, and the results confirm the hypothesis stated in an earlier report that the deep water on the continental shelf, which remains cold throughout the summer, is a relict of winter water which persists until uniformly mixed with surface waters again in the fall. The three years are markedly different in the way in which temperature and salinity change in this deep-water pool. Qualitatively it appears as though in 1957, the year when the water was warmest, there was a preponderance of horizontal mixing with waters offshore since in this year the accumulation of heat exceeded the amount that could reasonably be derived from direct sunlight, and the salinity of the deep water increased, indicating the admixture of offshore water of high salinity. In 1958, when the waters were coolest, the salinity of the deep water decreased as the summer warming took place, suggesting that mixing with the overlying, fresher surface water was predominant in this year. In 1959, an intermediate year for water temperatures, the salinity of the deep water remained nearly constant as the water warmed during the summertime, suggesting a balance between the mixing horizontally with warmer more saline offshore water and vertical mixing between the deep water and the surface, fresher water.

The most remarkable result developed in the analysis of these observations is that there is a fairly simple linear relationship between the average salinity of the continental shelf and the average value for the river flow of the Connecticut River for the six months prior to the observation. The Connecticut River is not, of course, the only source of fresh water added to this part of the ocean but apparently it is an adequate index of the total volume of fresh water supplied. Since the distribution of fresh water (and of salinity) in an estuary or a coastal area is a complicated function of river flow, of vertical and horizontal mixing, and of the ocean currents which may bring in or carry away the diluting fresh water in variable ways, a simple relationship such as has been found was really unexpected.

As a matter of fact, our first attempt to evaluate the variations in salinity and in the mixing processes was an analysis of the wind system, but no correlation between the wind and the salinity conditions could be found. The observed relationship indicates that for every thousand cubic feet per second increase in river flow of the Connecticut River the average salinity for the continental shelf water decreases by .0895 parts per thousand. If one aberrant point is omitted, the correlation coefficient is very high (0.863) which indicates that approximately 75% of the variation in salinity has been accounted for by this simple correlation with the flow of one major river which empties into the area. The standard error of the prediction of salinity is 0.276‰.

The significance of this result is, of course, that one can predict the average salinity of the continental shelf by a knowledge of the river flow of the Connecticut River. Since the average over a period of six months correlates so nicely with salinity it suggests that this length of time is critical for the movement of water, and consequently of any included materials in the water, through this area of the continental shelf. This six month period contrasts with the period of one and a half years previously derived by Ketchum and Keen¹ for the entire continental shelf between Cape Cod and Chesapeake Bay.

The analyses of the zooplankton populations collected between Montauk Point and Bermuda for the past year have been completed. A checklist of the species composition by location and by time of year is given in the paper in Appendix B by Grice and Hart. The population is frequently dominated by copepods, and more than one-third of the 374 species which have been identified were copepods. A definitive paper concerning these populations and their relationship with the environmental conditions is in preparation. This stage of the investigation was essential before more detailed observations could be planned and undertaken. It is hoped in the coming year to do more detailed studies of the vertical distribution and of the geographical distribution than has been possible in the past.

Dr. Hulburt has completed the analysis of many of the phytoplankton populations collected on our cruises and in the Appendix to this report he discusses the way in which various species are distributed in relationship to the salinity of the water. All taxonomic works, of course, include definitions of species as belonging to the neritic or the oceanic province but it is difficult to find data which indicate just how common they are at any given salinity. Dr. Hulburt's data confirm many of the neritic-oceanic definitions of the distribution of these species and does give specific salinities at which they have been observed. His analysis also reemphasizes the predominance of dinoflagellates and coccolithophores in the oceanic population and the predominance of diatoms in the inshore populations. Some surprises came out of the investigation, however. For example, at times of dense populations in the neighborhood of Bermuda many of the species present in strictly oceanic waters are those which are commonly considered to be neritic.

¹Ketchum, B.H. and D.J. Keen. 1956. Deep-Sea Res., Suppl. to Vol. 3: 346-357.

Participation in Meetings and in Educational Programs

During 1960 the group has not been as active in participating in meetings as it was last year, but several of us have become more involved in teaching in the field of marine ecology.

Dr. Ketchum attended the meeting of the Special Committee on Oceanographic Research (SCOR) held at Copenhagen, Denmark in July and proceeded from there to the Geophysical Congress held in Helsinki, Finland, in August. As retiring President of the American Society of Limnology and Oceanography he also attended the Annual Meeting held at Stillwater, Oklahoma. Travel funds for all these meetings were provided from other sources; none were charged to our AEC contract.

In terms of our teaching effort during the last year, Dr. Ketchum gave a course at Harvard University during the spring semester on Problems in Aquatic Ecology. This spring semester he is giving a course on Biological Oceanography in cooperation with Dr. George L. Clarke. In the future this course in Biological Oceanography will be given in the spring semester of every other year. Dr. Ryther continued his teaching in the Marine Ecology course which is jointly sponsored by the Marine Biological Laboratory and the Oceanographic Institution at Woods Hole during the summer.

Several members of the group have participated in National Science Foundation Summer Institutes. Dr. Curl participated in the Summer Institute in Marine Biology for High School and College Teachers held at Santa Barbara, California. Mr. Yentsch gave a series of lectures at the Science Education Program for High School Teachers at Rensselaer Polytechnic Institute, Albany, New York. Dr. Ryther gave a series of lectures at the Summer Institute for College Ecology Teachers held at Boulder, Colorado, and also at the Summer Institute for High School Science Teachers held at the State University of New York at Albany. We are firmly of the conviction that participation in the Summer Institutes for college and high school teachers is an important part of our objectives in developing an interest and an understanding of marine ecology.

Participation in National and International Committees

Both Dr. Ketchum and Dr. Ryther have been appointed to national and international committees during the course of the past year. Dr. Ketchum is Chairman of the SCOR Committee on Chemistry which is organized to consider and plan the chemical work to be conducted during the Indian Ocean Expeditions in 1962-65. He is also a member of the U.S. Working Group on Physical and Chemical Oceanography for the Indian Ocean and of the Chemistry Committee of the International Association of Physical Oceanography. This year he has been appointed to the review panel in Environmental Biology of the National Science Foundation; the panel for the review of applications for the Fulbright and Smith-Mundt Act Fellowships; and continues his membership on the AIBS-ONR Hydrobiology Committee. Dr. Ryther is a member of the SCOR-Indian Ocean Working Group on Biology and is Chairman of the U. S. Working Group on Biology for the Indian Ocean. He has also been made a member of the National Science Foundation Biological Oceanography Panel.

Publications and Reports

I. Published Papers:

- A = Reprints submitted as Appendix A to this report.
B = Studies completed prior to employment at Woods Hole Oceanographic Institution on AEC AT(30-1)-1918. These publications, consequently, do not include AEC acknowledgment, but are included in Appendix A.
C = Reprints not yet available.

- Bowen, Vaughan T. and Thomas T. Sugihara. 1960. Strontium-90 in the 'mixed layer' of the Atlantic Ocean. *Nature* 186(4718): 71-72. A
- Curl, Herbert, Jr. 1959. The hydrography of the inshore north-eastern Gulf of Mexico. *Inst. Mar. Sci. VI*: 193-205. B
- Curl, Herbert, Jr. 1959. The phytoplankton of Apalachee Bay and the northeastern Gulf of Mexico. *Inst. Mar. Sci. VI*: 277-320. B
- Grice, George D. 1960. Calanoid and cyclopoid copepods collected from the Florida Gulf Coast and Florida Keys in 1954 and 1955. *Bull. Mar. Sci. Gulf and Carib.* 10(2): 217-226. B
- Grice, George D. 1960. Copepods of the genus *Oithona* from the Gulf of Mexico. *Bull. Mar. Sci. Gulf and Carib.* 10(4): 485-490. A
- Grice, George D. and Everet C. Jones. 1960. Two new species of *Candacia* (Copepoda: Calanoida) from the Central Pacific, with notes on two other species. *Pacific Sci.* XIV(3): 280-291. B
- Hulburt, E. M., J. H. Ryther and R. R. L. Guillard. 1960. The phytoplankton of the Sargasso Sea off Bermuda. *Jour. Cons. Internat. Explor. Mer.* XXV(2): 115-128. A
- Ketchum, B. H., N. Corwin and R. F. Vaccaro. 1958. * The annual cycle of phosphorus and nitrogen in New England coastal waters. *Jour. Mar. Res.* 17: 282-301. C
- Ketchum, B. H. 1960. Marine pollution problems in the North Atlantic area. *Biological Problems of Water Pollution. Trans. of 1959 Seminar, U. S. Dept. Health, Education and Welfare, Public Health Service.* 212-217. C
- Ketchum, Bostwick H. 1960. Oceanographic research required in support of radioactive waste disposal. *Disposal of radioactive wastes, International Atomic Energy Agency, Vienna.* 1960. 283-291. A

* Volume 17 dated 1958 but issued in January 1961.

- Richards, F. A. 1958. Dissolved silicate and related properties of some western North Atlantic and Caribbean waters. Jour. Mar. Res. 17: 449-465. C
- Ryther, John H. 1960. Organic production by plankton algae, and its environmental control. Ecology of Algae, The Pymatuning Symp. in Ecol., Special Publ. #2, Pymatuning Lab. Field Biol., Univ. Pitts. 72-83. A
- Ryther, John H. and E. M. Hulburt. 1960. On winter mixing and the vertical distribution of phytoplankton. Limnol. and Oceanogr. 5(3): 337-338.
- Ryther, John H. and David W. Menzel. 1960. The seasonal and geographical range of primary production in the Western Sargasso Sea. Deep-Sea Res. 6: 235-238. A
- Steele, J. H. and C. S. Yentsch. 1960. The vertical distribution of chlorophyll. J. Mar. Biol. Assoc. U. K. 39: 217-226. A
- Vaccaro, Ralph F. and John H. Ryther. 1960. Marine phytoplankton and the distribution of nitrite in the sea. Jour. Cons. Internat. Explor. Mer. XXV(3): 260-271. A
- Yentsch, Charles S. 1959. The influence of phytoplankton pigments on the colour of sea water. Deep-Sea Res. 7: 1-9. A
- II. Papers accepted for Publication:
- D = Manuscript included in previous reports.
E = Manuscript included in Appendix B of this report.
- Grice, George D. Candacia ketchumi, a new calanoid copepod from the Northwestern part of the Sargasso Sea. Crustaceana (in press). E
- Guillard, R. R. L. and J. H. Ryther. Studies of marine planktonic diatoms. I. Detonula solitaria spec. nov. and Detonula confervacea (Cleve) Gran. Canad. J. Microbiol. (in press). D
- Ryther, J. H. and R. R. L. Guillard. Studies of marine planktonic diatoms. II. Detonula solitaria as an assay organism for vitamin B₁₂. Canad. J. Microbiol. (in press). D
- Ryther, J. H. and R. R. L. Guillard. Studies of marine planktonic diatoms. III. The level, response to temperature and temperature acclimatization of respiration in six species of diatoms. Canad. J. Microbiol. (in press). D
- Sugihara, Thomas T. and Vaughan T. Bowen. 1960. Radioactive rare earths from fallout for study of particle movement in the sea. Paper presented at Radioisotope Conf., Copenhagen, Sept. 1960. (in press). E
- Yentsch, Charles S. Environmental Physiology of Marine Phytoplankton. In: Physiology and Biochemistry of Algae. ed. R. A. Lewin, Academic Press, Inc., New York. E

III. Reports on work in progress included in Appendix B.

Curl, Herbert, Jr. Analyses for total and carbonate carbon in marine plankton.

Curl, Herbert, Jr. and Guy C. McLeod. The physiological ecology of a marine diatom, Skeletonema costatum (Grev.) Cleve.

Grice, George D. Candacia ketchumi, a new calanoid copepod from the northwestern part of the Sargasso Sea. Crustaceana (in press).

Grice, George D. and Arch D. Hart. Preliminary report on the analyses of zooplankton collected on four cruises between New York and Bermuda.

Hulburt, E. M. A note on the horizontal distribution of phytoplankton.

Hulburt, E. M. and Janet Rodman. The distribution of phytoplankton species with respect to salinity and other variables between the coast of southern New England and Bermuda.

Ketchum, Bostwick H. and N. Corwin. The persistence of "winter" water on the continental shelf south of Long Island, New York.

Kuenzler, Edward J. and B. H. Ketchum. Rate of phosphorus uptake and exchange by Phaeodactylum tricornutum.

Sugihara, Thomas T. and Vaughan T. Bowen. Radioactive rare earths from fallout for study of particle movement in the sea. Paper presented at Radioisotope Conf., Copenhagen, Sept. 1960. (in press).

Watson, S. W. Nitrification by marine bacteria.

Yentsch, Charles S. Environmental Physiology of Marine Phytoplankton. In: Physiology and Biochemistry of Algae., ed. R. A. Lewin, Academic Press, Inc., New York

Yentsch, C. S. and Langley Wood. Measurements of primary production in the Red Sea, Gulf of Aden and Indian Ocean.

Yentsch, Charles S. and C. A. Reichert. The interrelationship between water-soluble yellow substances and chloroplastic pigments in marine algae.

PROPOSAL FOR RENEWAL OF CONTRACT AEC(30-1)-1918

It is proposed to continue our joint laboratory and field investigations of the biology, ecology, chemistry, and radiochemistry of plankton populations. As our studies progress we recognize more and more the need for experimental studies conducted at sea on the biological populations as soon as they can be brought aboard the ship and studied in the laboratory.

To retain continuity of the program we will continue to conduct studies on the distribution of the plankton populations and of the chemistry of the water between Montauk Point, Long Island and Bermuda. This has proved to be an extremely valuable section because of the wide range of ecological conditions which exist in the various water masses: the coastal water, the slope water, the Gulf Stream water, and the Sargasso Sea water. During the coming year, however, we propose more specialized investigations, and we believe it is no longer necessary to continue the systematic observations as frequently as we have taken them in the past.

On the special observations we are particularly anxious to expand the diurnal studies which were started in a small way this last year in order to evaluate the changes in the populations and in the chemistry of the water which take place over relatively short periods of time. We have obtained a submersible pump which makes it possible to deliver large samples of water to the deck of the ship from any selected depth. This technique makes it possible to do analyses of water samples for the chemical nutrients, for oxygen, for chlorophyll, and for the salinity and temperature of the water at frequent intervals during the course of the day. Another program in the laboratory has developed a photometer which makes it possible to measure the bioluminescence of the organisms as they pass through the measuring cell which can be connected to this submersible pump and the variation in bioluminescence of the natural populations can thus be studied.

While final results are not yet available from the diurnal studies which we have conducted during the last year, the technique seems admirably suited to study the patchiness and the short-term variations in plankton populations, both zooplankton and phytoplankton, which we know to occur in the sea but which are as yet inadequately evaluated.

Studies of the vertical distribution of zooplankton will be emphasized during the coming year. Now that we know the species which are involved and their seasonal variation in this area the finer details of their distribution become increasingly important. It is always a subject for argument, for example, how significant a single plankton tow is in characterizing the population when the stations occupied are 50 or 60 miles apart. We have developed a large Clarke Bumpus type of sampler which obtains six times the sample ordinarily collected by the Clarke Bumpus. This has been tested and shown to open and close reliably at any depth, and should make it possible without exorbitant use of shiptime to obtain

samples from the deeper parts of the zone over which zooplankton migrate with a certainty that the sample was obtained at a known depth and for a fixed towing time. We have constructed a winch which is specially designed for plankton towing work which will carry the four-conductor electric cable with a depth indicator on the bottom of the wire. In this way we will know exactly where our samples are taken.

In the laboratory work we plan to continue and intensify the study of the assimilation of radiophosphorus and radiocarbon by pure cultures of marine algae and to survey the species of marine phytoplankton which we now have in culture for their ability to accumulate phosphorus. It will be of interest to know whether all of them are as efficient as Phaeodactylum tricornutum in reducing the external level of phosphorus to extremely low values ($10^{-8}M$). From these experiments we will also gain a considerable knowledge concerning the phosphorus content of various species. The culture experiments on other physiological aspects of these unicellular algae will be continued. It has become apparent that the iron content of the water may be an important limiting element in the waters of the Sargasso Sea, though it is probably always plentiful enough in inshore waters. Studies of the importance of iron and other trace elements on the nutrition of the phytoplankton will be continued.

Now that active cultures of nitrifying bacteria are available the laboratory studies of these will be intensified. For this purpose we have been using the oxygen electrode which is a splendid instrument since it permits repeated observation on the same culture after changing the environmental conditions. On two cruises we have cooperated with Dr. Dugdale of the University of Pittsburgh who has been studying, using N-15, the nitrogen fixation by natural populations in the sea. This collaboration will be continued.

The joint effort on the study of phytoplankton populations off Bermuda, which was very productive last year, will be repeated in April of this year. This is the time of the spring bloom in that area and by working out of Bermuda in a joint effort with the program supported there by the Atomic Energy Commission Contract AT(30-1)-2078 considerable valuable and useful information has been obtained.

Expenditures on Contract AT(30-1)-1918

The following table shows the actual expenditures during the first four years of this program. During the first three years, Institution funds and AEC funds are included; since that time the accounting is for AEC funds separately. The actual expenditures for the current contract through the end of 1960, and the estimated expenditures for the remainder of the current contract period are given in the last two columns.

<u>Expenditures</u>	5/15/56-	5/15/60-	Est. Total
	<u>5/14/60</u>	<u>12/31/60</u>	<u>5/15/60-</u> <u>5/14/61</u>
Salaries	\$ 173,312	\$ 29,721	\$ 51,230
Equipment and supplies	18,716	9,547	12,000
Travel	4,548	811	1,300
Ships	118,219	8,673	15,000
Indirect Costs	<u>113,941</u>	<u>24,294</u>	<u>40,970</u>
Total expenditures	\$ 428,736	\$ 73,046	\$120,500
AEC Funds	278,000		120,500

The following amounts were also expended from Institution funds and from other sources during the calendar year 1960 in support of the research of the personnel cooperating on this program of plankton biology and chemistry:

<u>Expenditures</u>	<u>WHOI</u>	<u>Other</u>
Salaries	\$ 19,850	\$ 57,030 ¹
Equipment and supplies	5,000	9,874
Travel	--	2,800
Ships	--	58,239
Indirect Costs	<u>25,616²</u>	<u>37,035</u>
Total expenditures	\$ 50,466	\$164,978

¹Funds from contract AT(30-1)-2174 are included to the extent of the contribution towards the salary of Dr. V. T. Bowen. No other AEC funds are included.

²This item includes \$9,736 of institution funds which contribute to the indirect costs of NSF grants. The indirect costs under "other" are low by this amount.

Personnel

The following personnel have been engaged in this program. The percentage of their salary requested from the Atomic Energy Commission in this proposal is indicated for each. All of those listed are essentially spending full-time on the broad objectives of this program, and the remainder of their salaries is provided by Institution or other funds as indicated in the proposed budget.

Principal Investigators:

B. H. Ketchum	Senior Oceanographer	50%
V. T. Bowen	Geochemist	--

Investigators:

N. Corwin	Res. Assoc., Chemistry	50%
H. C. Curl, Jr.	Res. Assoc., Marine Biology	--
G. D. Grice	Res. Assoc., Marine Biology	50%
R. L. Guillard	Res. Assoc., Marine Biology	50%
E. M. Hulburt	Res. Assoc., Marine Biology	100%
E. J. Kuenzler	Res. Assoc., Marine Biology	50%
J. H. Ryther	Marine Biologist	33%
Mary Sears	Planktonologist	--
J. C. Thunberg	Res. Assoc., Chemistry	--
R. F. Vaccaro	Res. Assoc., Microbiology	--
S. W. Watson	Res. Assoc., Marine Bacteriology	--
C. S. Yentsch	Res. Assoc., Marine Biology	50%

Assistants and Technicians:

Barbara Baker	Bacteriology	50%
C. W. Chadwick	Plankton	--
Elizabeth Guillard	Marine Biology	50%
A. D. Hart	Zooplankton	100%
Yolande Kahler	Microbiology	--
Anne Langenheim	Secretary	33%
Eileen McCormack	Radiochemistry	100%
Emily Merrill	Secretary	50%
Juanita Mogardo	Chemistry	100%
John L. Schilling	Chemistry	--

Proposed Budget

The budget for 1961-1962 requests \$140,800 from the Atomic Energy Commission in support of the program, the total cost of which is estimated at \$380,450. The increase over the amount granted last year is largely the increase in the salary budget and in the related indirect costs. Some salary increases have been made during the last year, and we have added one assistant in bacteriology and one secretary to those charged to the program.

During the coming year the amount requested for ship time is the same as in last year's budget. This will provide for two cruises on the section from Montauk Point, Long Island to Bermuda (24 days), two cruises for special studies to the continental shelf, the Gulf Stream and the Sargasso Sea (20 days), one cruise to the shelf area in September (6 days) and ten periodic cruises to the continental shelf throughout the year (20). Of the total estimated cost of \$70,000 the AEC is asked for \$25,000.

The requested budget for travel and communications is the same as last year. Several members of the group have been invited to participate in the Pacific Science Congress in Hawaii in August and in the Zooplankton Symposium which will be held in conjunction with the ICES Meeting in Copenhagen in October. Some support for these purposes will be available through ONR by MATS and some through direct NSF travel grants. Some of the funds requested for travel in this proposal may be needed for these purposes.

Total Budget for 1961-1962 for Studies of Plankton Biology, Chemistry and Radiochemistry as jointly supported by AEC, WHOI, NSF and ONR

	<u>Total</u>	<u>AEC</u>	<u>WHOI</u>	<u>Other</u>
Salaries				
14 Investigators	\$113,700	\$ 34,800	\$ 18,300	\$ 60,600
10 Assistants and Technicians	36,900	18,200	5,100	13,600
Service Personnel	<u>6,000</u>	<u>6,000</u>	<u>--</u>	<u>--</u>
Total Salaries	156,600	59,000	23,400	74,200
Indirect Costs	126,850	47,800	28,950	50,100
Equipment and Supplies	21,000	6,000	5,000	10,000
Travel and Communications	6,000	3,000	--	3,000
Ship time (70 days)	<u>70,000</u>	<u>25,000</u>	<u>--</u>	<u>45,000</u>
Total Expenditures	\$380,450	\$140,800	\$ 57,350	\$182,300

Bostwick H. Ketchum, Senior Oceanographer

Harvey MacKillop, Controller

Paul M. Fye, Director