REPORT OF SCOR WORKING GROUP 15
PHOTOSYNTHETIC RADIANT ENERGY

Sea Trials on R/V DISCOVERER, 2 May - 4 June 1970

Introduction

At the meeting of SCOR Working Group 15 in August, 1966, tentative plans were outlined for the collection of experimental data at sea. Primary objectives of the work at sea were to be the further testing and development of simple instrumentation for measuring the radiant energy available for photosynthesis and the collection of data to reveal any relationship between primary productivity and the radiant energy available for photosynthesis. A broad program including measurements of primary productivity, chlorophyll concentration, nutrient analysis, and other variables as well as optical measurements was outlined in order to have at each station a large body of interrelated data under specified lighting conditions.

It was originally suggested that this research should be conducted during the period of May to August, 1969, in the vicinity of the Canaries, and it was anticipated that a scientific party of 15 would participate.

Dr. W. Wooster initiated ship requests to various oceanographic organizations, but it was not until early in January, 1969, that a firm commitment was made. At that time, through Dr. Harris Stewart, Director of the Atlantic Oceanographic and Meteorological Laboratory, ESSA, and Rear Admiral D.A. Jones, Director of the Coast and Geodetic Survey, ESSA, the vessel, DISCOVERER, was scheduled for our use for a period of three to five weeks during the spring months of 1970.

In November, 1969, the Working Group met in Miami to discuss the program to be conducted during the expedition and to visit the ship. It was decided to equip the stern of the ship with a 25- to 30-foot boom so that the launching of the optical equipment could take place well away from the ship and the presence of the ship as a perturbation to the light field would be minimized. Also at the meeting, each Working Group member was assigned specific tasks related to the objectives of the expedition and arrangements were made to assure that all required instrumentation would be available for the work.

The Working Group was scheduled to sail from Miami on April 30, 1970, but late arrival of essential scientific instrumentation from Europe delayed the departure until Saturday morning, May 2. The effect of late sailing increased the cost of the expedition by approximately $1000. The cost to the Atlantic Oceanographic and Meteorological Laboratory was undoubtedly also increased as a result of late sailing but the dollar amount is not known. Late sailing did not affect the duration of the expedition's sea time.

The ship returned to Miami on Thursday, June 4, and all members of the SCOR group were on their way to their homes by Saturday, June 6. During the period at sea the Working Group obtained data at 23 stations.

Participants

The SCOR scientific party aboard the DISCOVERER during the expedition consisted of 17 scientists from eight nations, as follows:

- James J. Alberts; Chemist; now at State Geological Survey of Kansas, the University of Kansas, U.S.; sponsored by Dr. C. Oppenheimer.
- Roswell W. Austin; Research Engineer; Scripps Institution of Oceanography, University of California, San Diego, U.S.; accompanied Mr. J.E. Tyler.

Ian E. Baird; Biologist; Department of Agriculture and Fisheries, Marine Laboratory, Scotland; member of Working Group 15.

Jeane-Pierre Bethoux; Attaché de Recherche, C.N.R.S.; Laboratoire d'Oceanographie Physique, France; accompanied Dr. A. Morel.

David Carpenter; Experimental Officer, C.S.I.R.O.; Division of Fisheries and Oceanography, Australia; accompanied Mr. H.R. Jitts.

Niels Højerslev; Research Associate; Institute of Physical Oceanography, University of Copenhagen, Denmark; accompanied Dr. K. Nygaard.

Harry R. Jitts; Senior Research Scientist, C.S.I.R.O.; Division of Fisheries and Oceanography, Australia; member of Working Group 15.

Thomas C. Malone; Graduate Student; Hopkins Marine Station, U.S.; sponsored by Dr. M. Gilmartin.

Andre Morel; Maitre Assistant; Laboratoire d'Oceanographie Physique, University of Paris, France; delegated by Working Group member Professor A. Ivanoff.

Nobutada Nakamoto; Graduate Student; Department of Biology, Tokyo Metropolitan University, Japan; accompanied Dr. Y. Saijo.

Kjell Nygaard; Chief Engineer; Institute of Physical Oceanography, University of Copenhagen, Denmark; delegated by Working Group member Dr. N. Jerlov.

Yulen Ochakovsky; Physicist; Institute of Oceanology, USSR Academy of Sciences, USSR; member of Working Group 15.

Yatsuka Saijo; Biologist; Water Research Laboratory, Nagoya University, Japan; member of Working Group 15.

Raymond C. Smith; Physicist; Scripps Institution of Oceanography, University of California, San Diego, U.S.; accompanied Mr. J.E. Tyler.

Anatol Susliaev; Engineer; Institute of Oceanology, USSR; accompanied Dr. Y. Ochakovsky.

Jahn Throndsen; Magister Scientia; Institute of Marine Biology, University of Oslo, Norway; delegated by Professor Steemann-Nielsen.

John E. Tyler; Research Physicist; Scripps Institution of Oceanography, University of California, San Diego, U.S.; Chairman of Working Group 15.

The officers and other personnel on the ship provided valuable scientific and logistic support and in a very real sense became a part of the Working Group effort during the voyage. Comdr. R.E. Alderman, the Executive Officer, easily solved the many problems associated with the presence of two international Working Groups on the ship[1].

Comdr. R.C. Johnson, Jr., Chief Engineer, and his staff solved numerous electrical and mechanical problems associated with the use of our specialized equipment on the ship. Comdr. Johnson personally assisted in re-engineering and repairing scientific equipment that was damaged or failed to function properly.

Comdr. Archibald Patrick, Jr., Operations Officer, provided valuable assistance during several weeks of pre-expedition arrangements, and during the voyage, assisted in scheduling the experiments and acted as liaison between the Working Group and the ship's personnel.

Because of the importance of local sun time to the determination of primary productivity and to the scheduling of radiant energy measurements, the ship's Navigation Officer, Lt.(jg.) Floyd Childress, made arrangements to provide the laboratory with a "sun-time" clock which was set correctly each morning to indicate noon when the sun reached maximum altitude. He also had posted under the clock zulu time for sunrise and sunset and provided latitude and longitude determinations for the beginning and end of each daily drift station as well as the ship's position for local apparent noon.

The computer officers, Ens. Lawrence Lake and Ens. Stephen Mangis, together with the group of survey technicians under Mr. Hopkins, took full responsibility for providing the SCOR

(1) The other Working Group was engaged in intercalibration of radiometersondes. The instruments were launched with helium-filled balloons in the evenings. The group was chaired by Mr. P. Kuhn.

group each day with a record of temperature, salinity, and density as a function of depth to 500 meters. They also made two daily casts with a mechanical BT to 275 meters, generally at times 1000 and 1400, and obtained surface temperature with a bucket thermometer. On several days expendable BT's were used every four hours to locate upwelling and the associated high chlorophyll concentration.

Chemical analysis of the sea water at each station was conducted by James Alberts. Alberts used sea water from the "Jitts bottles" (explained below under simulated-in-situ procedure) and, at greater depths from the Nansen bottles. He determined phosphates, silicates, nitrates, and nitrites and reported phosphorous, silica, and nitrogen in microgramatoms per liter. On the water from the Nansen bottles he also obtained water temperature and salinity. During the first week of the expedition he obtained samples to depths of 200 meters and after that he extended his sampling to 500 meters in order to more precisely describe the water type.

Continuous recording of total energy and energy available for photosynthesis (both at the ocean surface) was the responsibility of Dr. Yulen Ochakovsky. Total energy, including the infrared, was measured by means of a thermopile and electrolytic integrating recorder. Integration was carried out from noon to sunset every day to coincide with the period of incubation of the primary productivity samples. Measurements of total energy by means of a second thermopile were also continuously recorded on a strip-chart recorder for the same period of time. Measurements of the total energy available for photosynthesis were continuously recorded by the Russian Amici-prism instrument on a second strip-chart recorder and for the same period of time. The Amici-prism instrument isolates and records the energy within the spectral regions from 350 nanometers to 700 nanometers by means of a fitted template in the image plane of an Amici-prism dispersing system.

The time recorded energy, on occasion, showed massive changes in surface energy due to the passage of clouds over the sun. This, of course, is a real event to the phytoplankton and should be recognized for purposes of correlation. These events do, however, create problems with subsequent integration of the time recordings. These problems were discussed and tentative methods were adopted for reporting the time based data.

The Amici-prism instrument was also used to collect data on total energy as a function of depth in the ocean. These measurements will provide additional means for studying the relationship between primary productivity and the energy available for photosynthesis.

Identification of plankton species and estimation of relative populations was the responsibility of Jahn Throndsen. Throndsen generally analyzed six samples at as many depths at each station. He separated the phytoplankton into five size groups and counted the dinoflagellates, coccolithophores, diatoms, and flagellates in each size group. He also reported the total number of cells per liter in each size group, the total cells for each form and the percents of total in each case.

Spectral irradiance as a function of depth was measured by Dr. R.C. Smith, who employed the Scripps spectroradiometer. This measurement was made at or near noon, sun time, to avoid possible changes in irradiance due to changes in the altitude of the sun. A scalar irradiance collector was used as a deck reference cell. In order to avoid taking data during the intervention of a cloud over the sun, Smith observed the performance of the Russian instruments that were monitoring and recording surface energy on strip-chart recorders. The Russian instruments were located where they could be easily observed for this purpose. Smith also used the spectroradiometer to obtain monochromatic values of irradiance as a function of depth. These latter measurements were for intercomparison with similar measurements being made from the ship with other instruments. Measurements with the Scripps spectroradiometer were made to a depth of 30 meters. During the time assigned for this work on the stern boom an average of about five or six spectroradiometric curves were obtained at each station.

Spectral irradiance measurements were also made by Dr. A. Morel with a French designed instrument capable of rapid spectral scanning. Spectral irradiance measurements were made to a depth of 150 meters with this instrument. The French group employed other instrumentation for measuring radiant energy. Attached to the same frame, and lowered at the same time, were an underwater thermopile and a quanta meter of French design. Results from these three instruments will be exactly comparable in space and time. To record the deck irradiance the French group employed an Eppley thermopile and an irradiance meter filtered to have sensitivity at 480 nanometers.

During the time assigned to the French group on the stern boom they were able to obtain an average of about 20 measurements of spectral irradiance per station as well as measurements with the thermopile and the quanta meter lowered on the same frame.

The measurement of the total quanta available for photosynthesis was undertaken primarily by the Danish group, who constructed quanta meters for their own use during the expedition and supplied, as well, several of these instruments to other members of the Working Group. The quanta meters were used, for example, in conjunction with other radiant energy measurements, in the incubators used for simulated-in-situ primary productivity work and in connection with the in-situ samples for primary productivity.

The measurement of total quanta as a function of depth was obtained regularly (generally every hour) by Dr. K. Nygaard, who also frequently lowered his quanta meter by attaching it to the frame of the French or American spectral irradiance meter.

The Danish group also obtained samples of water and made laboratory scattering measurements at 45° and 90° from the forward direction. They also employed instruments for measuring the scattering function and the total scattering function which were used after dark when the ambient light in the water would not interfere with the measured results.

The transmittance of the water, for a beam of light, and the scattering function between 10° and 170° were measured by Mr. Austin. The beam transmittance was measured before and after the midday period in order to locate and describe any existing stratification and record any changes in stratification during that period.

The scattering function was measured after dark, again to avoid interference by ambient daylight underwater.

The measurement of primary productivity by the in-situ method was made each day by Dr. Y. Saijo. Dr. Saijo used water from the Jitts bottles which he inoculated with C^{14} in the usual manner. The string of about seven bottles had included with it a quanta meter located at the level where 25% (sometimes 18%) of surface light was obtained. When launched, the string of bottles was attached to a Roberts buoy inside of which was a small battery-operated strip-chart recorder. Dr. Saijo was able, therefore, to obtain exactly correlating measurements of the quanta available for photosynthesis and the in-situ primary productivity. Since the attenuation coefficient for quanta will be available for each station from Dr. Nygaard's measurements, Dr. Saijo will be able to have the quanta available for photosynthesis at every bottle depth as well as the measured productivity at each depth.

Dr. Saijo also performed enrichment experiments in the laboratory and determined particulate carbon and nitrogen.

The measurement of primary productivity by the simulated-in-situ method was carried out by Mr. Jitts. Mr. Jitts used a daylight incubator with blue filters to simulate the light level and its spectral distribution at six depths. He also used an artificial light incubator. Both incubators were equipped with quanta meters and the quanta actually available for photosynthesis during incubation in each incubator was carefully monitored and recorded.

The technique used for the simulated-in-situ procedure was the determinant for the Jitts depths and for the water samples used for other analyses. This comes about as follows. At about time 1000 a measurement was made of quanta as a function of depth at the station site. The blue filters in the Jitts incubators transmitted a fixed percentage of incident quanta. The depths at which these percentage transmissions occur in the ocean were read from the curve of quanta versus depth for the station and these depths became the Jitts depths. This technique resulted in all incubations being conducted under very nearly the same selected levels of quanta.

The determination of chlorophyll concentration was the responsibility of Dr. Ian Baird. Dr. Baird also used water from the Jitts bottles and, at greater depths, from the Nansen bottles. A typical station analysis consisted of 10 to 14 samples from as many depths. Both chlorophyll-a and phaeo-pigments were determined. The determination of chlorophyll-a was done by means of a Turner fluorometer and also by a standard spectrophotometer method.

Mr. Malone, who worked with Dr. Baird, was collecting data for a doctoral thesis which involved the determination of chlorophyll-a in nannoplankton versus net plankton. His study fitted in beautifully with the interests of the Working Group and provided a more detailed study of chlorophyll concentration than had originally been anticipated.

A daily record of all measurements made is included in the Appendix.

Planned Track

The track of the expedition was primarily planned with the objective of reaching ocean waters with widely different productivities. From Miami the track was planned to round the west end of Cuba, travel through the Caribbean Sea to the Panama Canal, through the canal into the Gulf of Panama and then southerly into the plankton rich water along the coast of South America, then southwesterly into south Pacific water as far as time would permit.

On the return voyage it was planned to repeat some of the stations south of the canal and one or two in the Caribbean. The return track would then take us through Windward Passage and into the Sargasso Sea to about 25°N65°W and then westward to Miami.

Although an early request was made to the government of Ecuador to enter the coastal waters off Ecuador for research purposes, their answer was overtly delayed and the conditions imposed by them were unacceptable, nor could their conditions be reconciled with the time requirements of the expedition.

The studies in the ocean and the collection of water samples were carried out from two deck areas, the stern area and an outboard station on the starboard side. These areas were separated by about 25 feet. The stern area had been specially equipped with a 25-foot aluminum I-beam with a trolly and appropriate rigging. The heavy optical instrumentation could be conveniently launched and hauled out to the end of the boom where the optical perturbation caused by the ship would be minimized. Also available in this area and accessible from the deck above, were the ship's smaller A-frame and two heavy duty winches. These launching facilities were prepared and used alternately. At times, wire was being payed out from the A-frame on the upper deck while instrumentation was being retrieved from the stern boom. Although the wires often crossed, careful observation and planning prevented their fouling.

On the starboard side the ship's equipment provided an overhanging platform, a suitable davit with metering pulleys and heavy duty winches. The United States group had also located an electric cable winch in this area. The STD was launched at this location followed by the Nansen cast and later by instrumentation requiring the electric cable winch. It was thus necessary to employ three wires at this location and to rerig the davit with the block appropriate for each wire.

The launching of the in-situ primary productivity experiments and the Roberts buoy also took place on the starboard side.

The scheduling of events to meet the requirements of this program was complex. The optical measurements required that the stern of the ship be exposed to the sun. The work from the starboard platform required that the wind should be on the starboard side. The in-situ primary productivity samples had to be launched at noon on the windward side and recovered at sunset. The most valuable time for optical measurements was the four hours around sun noon. All instruments, of course, had to be out of the water in order to maneuver the ship. The ship's engines required time to warm up, etc., etc.

The reconciliation of these conflicting requirements required close cooperation between the ship's officers and the scientific party. Fortunately the ship could usually be hove-to with the wind on the starboard and the stern exposed to the morning sun. At noon, as soon as the Roberts buoy was adrift, the ship was often rotated 180° to expose the stern to the sun during the afternoon. On days when conditions did not favor this simple solution, the ship was turned more often.

A chronological routine for the measurements in the ocean was soon established and is illustrated in Table I.

TABLE I

	Starboard Platform				Stern		
Sun Time	Wire 1	Wire 2	Wire 3	Ship Orientation	A-Frame	Boom	Over The Side
0800				Wind on Starboard			
0900	Hopkins	Austin C-Meter		↓			Throndsen Net Sam. Malone 3-m. Sam.
1000		Saijo Water Sam		Sun on Stern Wind on Starboard		Morel Optics Kjell N.	Hopkins Mechn.BT Jitts H-Meter
1100		Albert's NansenCst Saijo		↓	Jitts Water Sam		
1200		In-Situ Samples	Austin C-Meter	Sun on Stern and on Deck Incubator		Smith Optics	Marker Buoy over
1300			↓	↓		Optics Nygaard-Smith	Amici Prism
1400						Morel Optics	Hopkins Mech.BT
1500						Nygaard Morel Optics	Malone 3-M Sam.
1600						Nygaard Morel Optics	
1700		Saijo		Steaming to Marker Buoy		Nygaard Morel Optics	Marker Buoy
1800		Samples Aboard	Austin Scattering			Nygaard Scattering	Recovery

Intercalibration and Standardization

A tungsten-iodine lamp mounted on a 2-meter optical bench was provided on the ship for purposes of standardization and intercomparison of the various radiant energy detectors. This facility was used for checking the linearity of response of photodetectors, comparing the outputs of various instruments, rechecking output over elapsed time, determining absolute calibration within the range of energy levels provided by the lamp and performing other tests on the phototubes and photocells being used in the work.

In addition to this, the last two experimental stations, both in Sargasso Sea water, were devoted to direct underwater intercomparisons. All available radiometric instruments were first fastened to the frame of the Scripps spectroradiometer and readings were taken simultaneously with all instruments at specified depths to 90 meters. Then the same procedure was carried out with the same complement of instruments attached to the frame of the French spectroradiometer. The French and Scripps spectroradiometers could not be launched simultaneously because together they exceeded the load limit of the stern boom.

Sponsorship

The DISCOVERER Expedition was a planned activity of the Scientific Committee on Oceanic Research Working Group 15 and enjoyed the financial and moral support of SCOR, UNESCO and IAPSO.

As stated earlier in this report, the ship DISCOVERER was provided by the U.S. Coast and Geodetic Survey through the courtesy of Rear Admiral D.A. Jones, Director, Coast and Geodetic Survey, Environmental Science Services Administration and Dr. Harris Stewart, Director of the Atlantic Oceanographic and Meteorological Laboratories of ESSA.

The parent laboratories of the various Working Group members, of course, provided direct support of the participant's time during the expedition, as well as the use of specialized scientific equipment. In many cases the parent laboratories supported the modification of construction of special equipment to be used during the expedition and plan to support the time necessary for data reduction.

For the DISCOVERER Expedition, scientific skills in addition to those available among Working Group members were required to carry out the integrated program of research that had been planned. The additional expenses involved in securing skilled personnel, providing for suitable equipment, transporting both to and from the ship, and solving the many local problems attendant to a large expedition received financial and/or direct-action support from the NSF, the Royal Society, the ONR and the U.S. Air National Guard. Travel for two graduate students was provided in one case by the Hopkins Marine Station and in the other case by Florida State University.