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technical series

11

Bruun memorial lectures

Presented at the eighth session of the IOC Assembly
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PREFACE

Presented during the eighth session of the Assembly of the Intergovernmental Oceanographic Commission, this series of lectures is dedicated to the memory of the noted Danish oceanographer and first chairman of the Commission, Dr. Anton Frederick Bruun. The "Bruun Memorial Lectures" were established in accordance with Resolution 19 of the sixth session of the IOC in which the Commission proposed that important inter-session developments be summarized by speakers in the fields of solid earth studies; physical and chemical oceanography and meteorology; and marine biology. The Commission further requested Unesco to arrange for publication of the lectures and it was subsequently decided to include them in the "IOC Technical Series".

Anton Bruun was born on 14 December 1901 as the oldest son of a farmer, but a severe attack of polio in his childhood led him to follow an academic, rather than agrarian, career.

In 1926 Bruun received a Ph. D. in zoology, having several years earlier already started working for the Danish Fishery Research Institute. This association took him on cruises in the North Atlantic where he learned from such distinguished scientists as Johannes Schmidt, C. G. Johannes Petersen and Thomas Mortensen.

Of even more importance to his later activities was his participation in the Dana Expedition's circumnavigation of the world in 1928-1930, during which time he acquired further knowledge of animal life of the sea, general oceanography and techniques in oceanic research.

In the following years Bruun devoted most of his time to studies of animals from the rich Dana collections and to the publication of his treatise on the flying fishes of the Atlantic. In 1938 he was named curator at the Zoological Museum of the University of Copenhagen and later also acted as lecturer in oceanology.

From 1945-1946 he was the leader of the Atlantide Expedition to the shelf areas of West Africa. This was followed by his eminent leadership of the Galathea Expedition in 1950-1952, which concentrated on the benthic fauna below 3, 000 m. and undertook the first exploration of the deep-sea trenches, revealing a special fauna to which he gave the name "hadal".

The last decade of Bruun's life was devoted to international oceanography. He was actively involved in the establishment of bodies like SCOR, IACOMS, IABO, and the IOC and was elected its first President in 1961.

His untimely death a few months later, on 13 December 1961, put an end to many hopes and aspirations, but Anton Bruun will be remembered for his inspiring influence on fellow oceanographers and his scientific contribution to the knowledge of the sea which he loved so much.

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INTRODUCTION

Dr. T.S. Austin

INTERNATIONAL CO-ORDINATOR FOR THE INTERNATIONAL CO-OPERATIVE INVESTIGATIONS OF THE TROPICAL ATLANTIC (ICITA)

CHAIRMAN, BRUUN MEMORIAL LECTURES 1973

I welcome each of you, Ladies and Gentlemen, to the 1973 Anton Bruun Memorial Lectures. Anton Bruun, as many of you remember, was the first elected President of the Commission. He played a very significant rôle in the successful development of the Commission, and his personal magnetism and his ability are keenly missed.

Anton Bruun was active in the planning of the IIOE, the International Indian Ocean Expedition. I am sure that he would have had an equal interest and played an equally important part in the development of the International Co-operative Investigations of the Tropical Atlantic - ICITA.

The Executive Council of the Intergovernmental Oceanographic Commission decided at its first session in July 1972, that the International Co-operative Investigations of the Tropical Atlantic (ICITA) should be the subject for the Anton Bruun Memorial Lectures during this Assembly session. A decision of the second session in May 1973, called for the lectures to be based on the theme "Developments in the tropical Atlantic which have taken place since the International Co-operative Investigations of the Tropical Atlantic (ICITA), leading up to contemporary planning for GATE (GARP (1) Atlantic Tropical Experiment)".

The operational phases of ICITA were completed nearly one decade ago (1963-1964). Planning for ICITA began during the first session of the Intergovernmental Oceanographic Commission, which met in Paris in 1961. A joint proposal for the study of the eastern tropical Atlantic, centred in the Gulf of Guinea, was presented by the Commission for Technical Co-operation in Africa/South of the Sahara (CCTA/CFA) and the United States. This proposal, later to be called the Guinean Year, envisioned a two-pronged effort. The first would be a study of the demersal fisheries and benthic fauna from Cape Blanc to Angola, the seaward limit to be the edge of the Continental Shelf. The second effort was to be a study of the oceanography and the pelagic fisheries in the Gulf of Guinea. The first proposal was the primary interest of CCTA; the second of the then United States Bureau of Commercial Fisheries(2).

These two proposals, summarized rather neatly by our first speaker, Dr. Frank Williams, may be paraphrased as: The Guinean Year was planned to make a full inventory of the living marine resources and environmental conditions in the Gulf of Guinea. This was the conceptual precursor of the following four major co-operative programmes:

1. The International Co-operative Investigations of the Tropical Atlantic (ICITA), covering oceanographic conditions.
2. The Guinean Trawling Survey (GTS), covering demersal fishery resources.
3. The Exploratory Tuna Surveys.
4. The Sardinella Resources Surveys, as well as several national resources programmes.

Dr. Williams goes on to remind us that the preliminary results of these surveys, particularly the ICITA and the GTS, were discussed at an IOC/FAO-sponsored symposium in Abidjan in 1966.

ICITA was but one of a number of international co-operative investigations. Figure 1 provides five examples of such surveys in the major ocean areas of the world. As the first two letters of the acronym suggest, ICITA truly exemplifies an international, co-operative investigation. The ICITA survey area is shown on Figure 2 along with designation of each of the nearly one dozen nations that were involved (shown shaded).

The survey or operational phases of the investigations were divided into two seasonal periods, one in January and one in August, and named

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(1) Global Atmospheric Research Programme.

(2) Now the National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Department of Commerce

Equalant I and Equalant II. The cruise tracks, the transects, and the positions of each station for Equalants I and II are shown on Figures 3 and 4. There were also informal, follow-up surveys in the Gulf of Guinea, somewhat more specialized in that they concentrated on studies of the eastern terminus of the equatorial undercurrent and fishery development problems.

Thus we see that the various investigations included within ICITA do lead us to the theme of today's series of lectures as proposed by the IOC Executive Council - those developments which have taken place since ICITA and which lead to contemporary planning activities. The definitive studies of the equatorial undercurrent form the basis of planning for a number of the experiments in GATE. The GTS fishery surveys and the related oceanographic observations led to the development of significant sardine and shrimp resources in the Gulf of Guinea, and to a major tuna fishery using both live bait and purse seine techniques. The International Decade of Ocean Exploration (IDOE) and the Co-operative Investigations of the Northern Part of the Eastern Central Atlantic (CINECA) are continuing to study in detail the upwelling off the north-west coast of Africa and the various transport features that bring waters in and out of the Gulf of Guinea.

Finally, a number of atlases and reports have been published which present the results of the Guinean Trawling Survey and of the oceanographic studies completed during ICITA. A large number of related technical papers have been published in scientific journals. All provide grist for the planning mills, whether it be for GATE, for continued development of the fishery resources in the tropical Atlantic, or simply for more modest experiments and investigations to enhance our knowledge of that most important oceanic area.

FIGURE 1. COMPLETED INTERNATIONAL OCEANOGRAPHIC EXPEDITIONS AND SURVEY YEARS

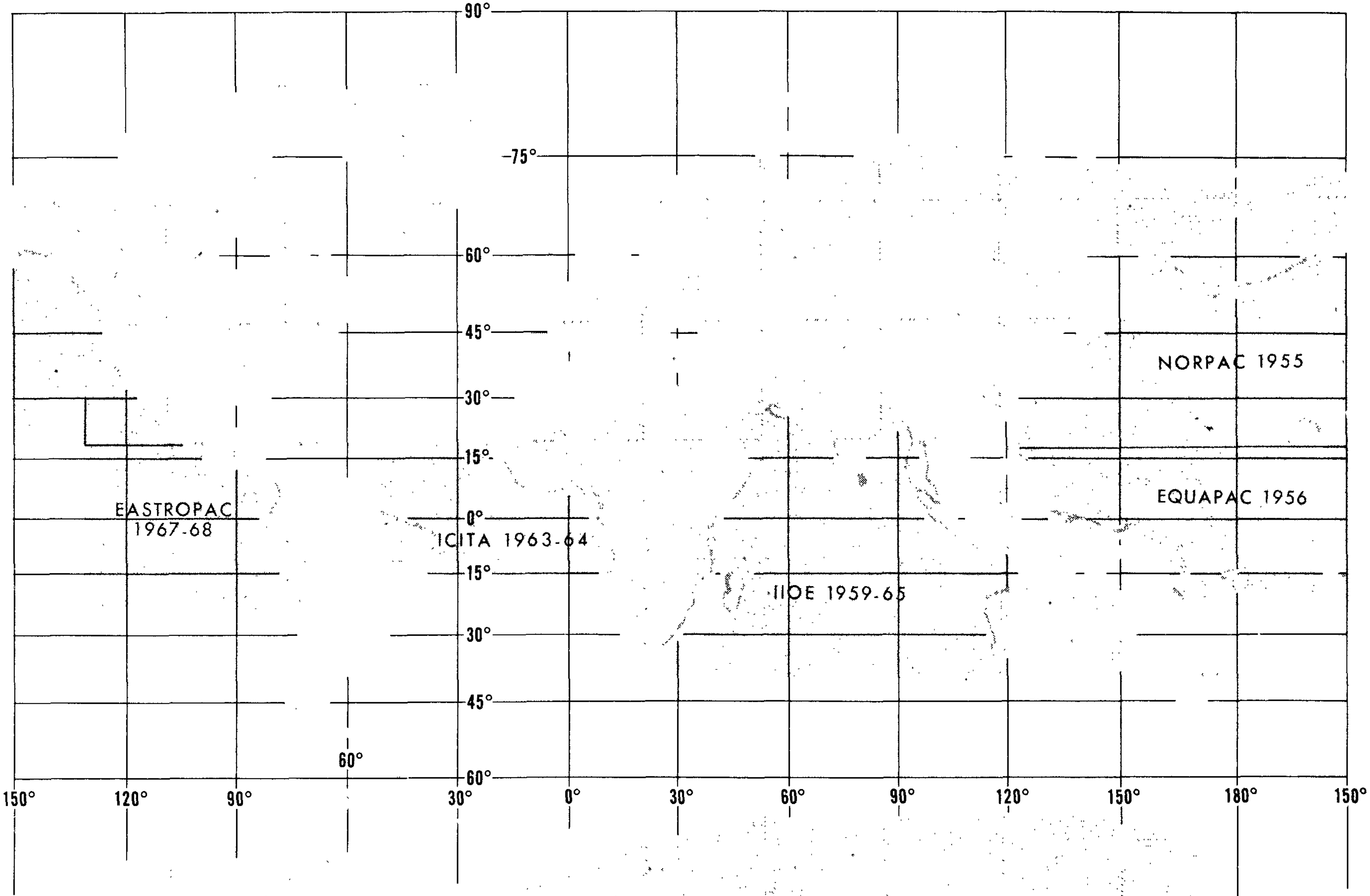


FIGURE 2. NATIONS CONTRIBUTING TO ICITA

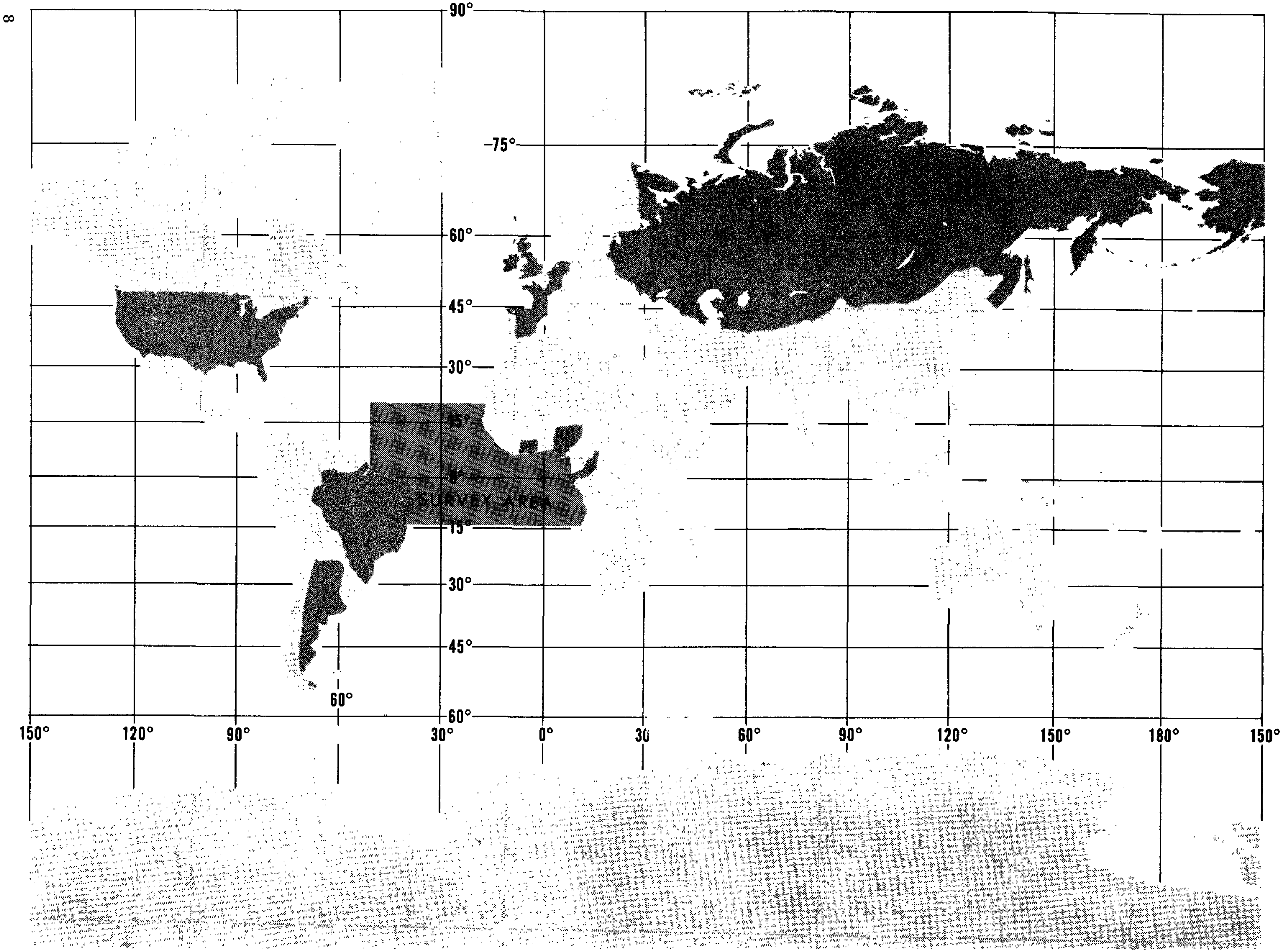


FIGURE 3. ICITA-EQUALANT I: STATION POSITIONS AND PROFILE NUMBERS

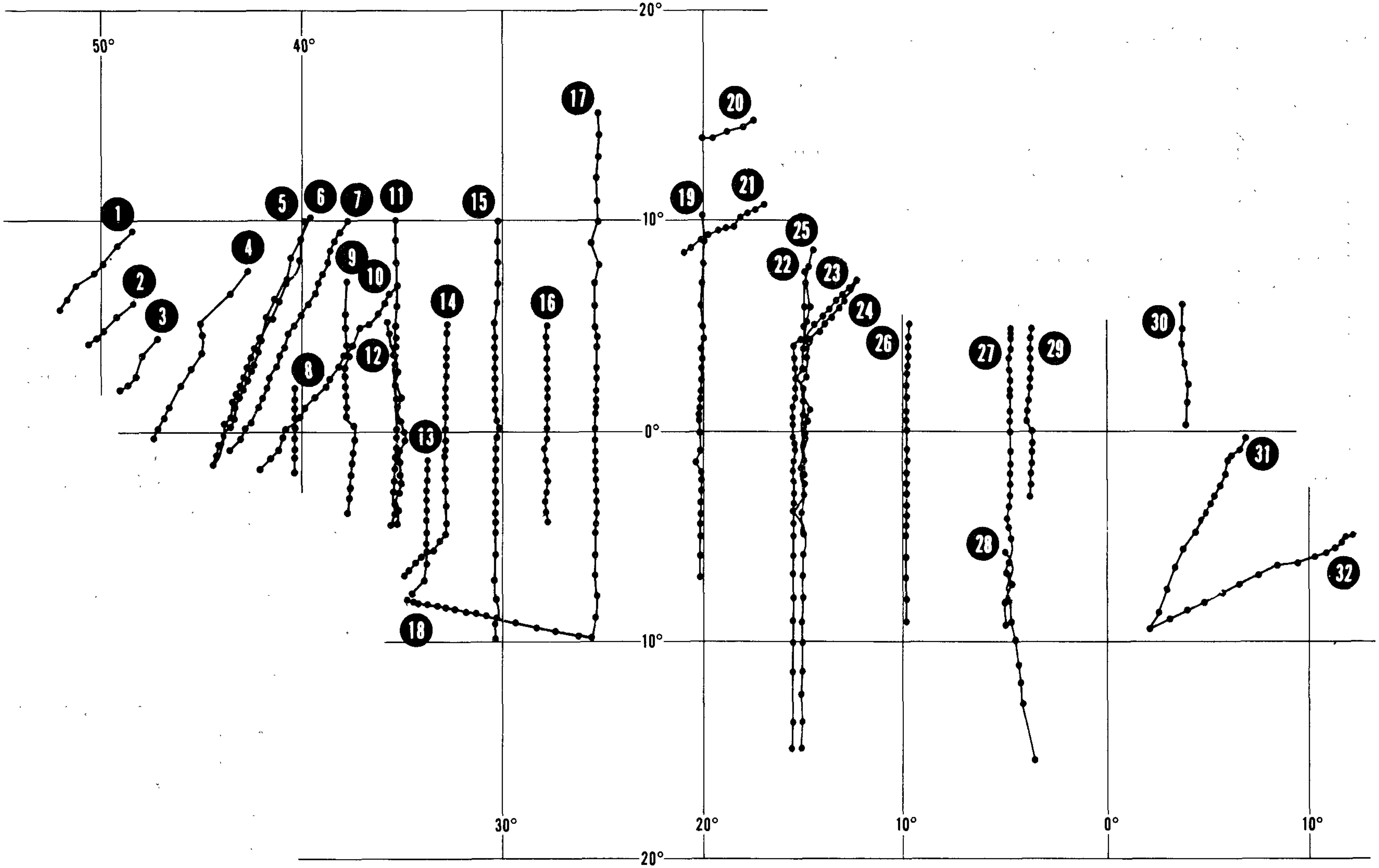
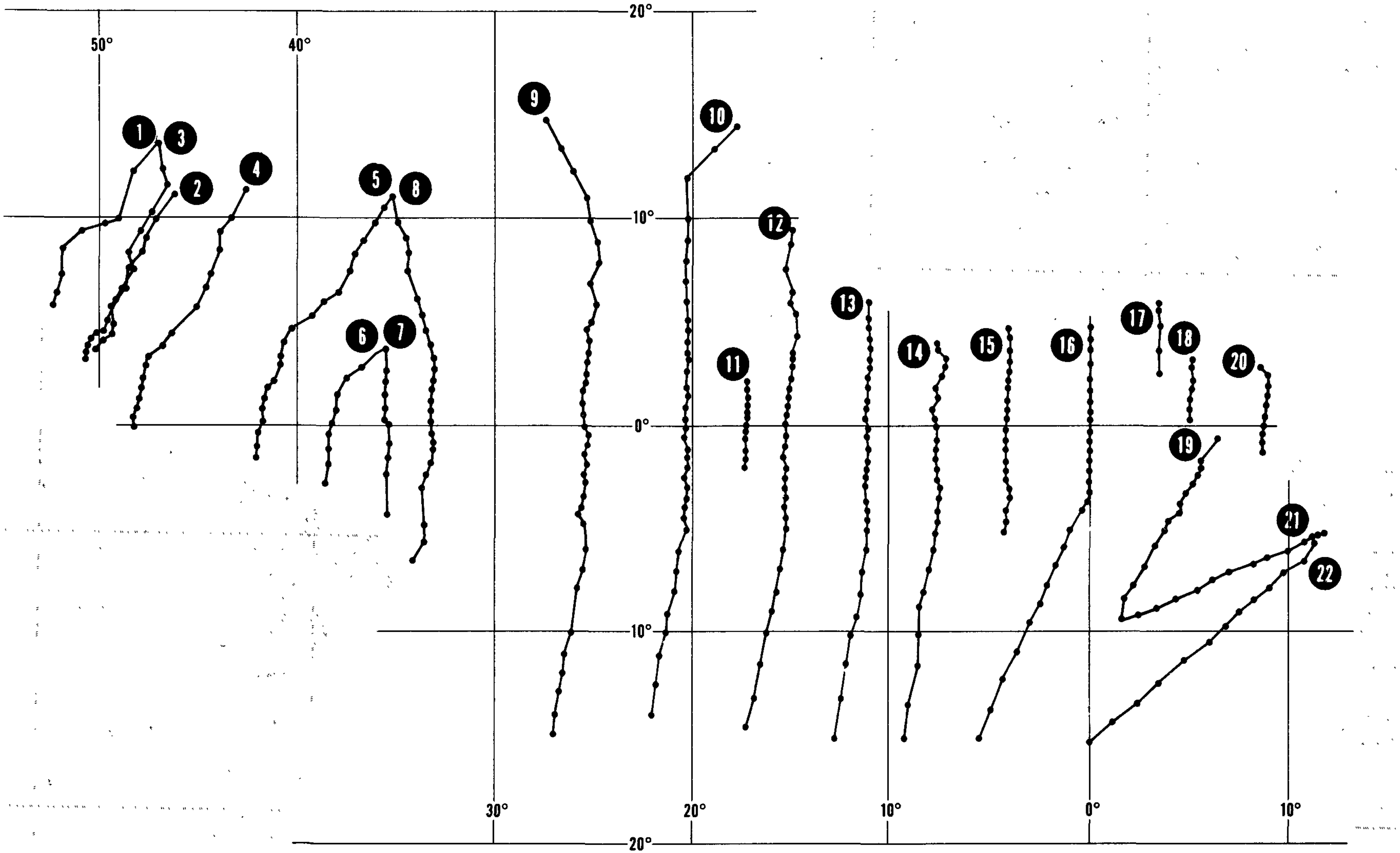


FIGURE 4. ICITA-EQUALANT II: STATION POSITIONS AND PROFILE NUMBERS



Since 1965 Dr. Klaus Voigt has been the Director of the Institute of Marine Sciences (Meereskunde) at the Academy of Sciences of the German Democratic Republic. He is one of the world's leading experts in the physical oceanography of the tropical oceans, particularly their circulation. Also, he has personally performed and guided research in the mixing processes in the Baltic Sea. From 1968 to 1972, he was Secretary of SCOR and has since then been its Vice-President.

The investigations during ICITA provided some of the most comprehensive data available to that time (1963) for describing the geographical extent, and certain of the temporal variations, of the equatorial undercurrent in the tropical Atlantic. This thin, sub-surface ribbon of current was first discovered from the German steamer Stephan in 1911. The undercurrent has subsequently been described by a number of expeditions, particularly during the 1950's and 1960's. One of the first direct current measurements was made from the USSR R/V Mikhail Lomonosov. Since then the eastward flow comprising the equatorial undercurrent has been referred to as the Lomonosov Current.

Various studies planned for GATE involve the undercurrent and much of the data used during the planning phases for GATE resulted from ICITA activities.
(Biographical note by the Chairman, Dr. T. S. Austin)

THE ATLANTIC EQUATORIAL UNDERCURRENT

by Klaus Voigt

Institut für Meereskunde,
German Democratic Republic

Our picture of the tropical oceanic circulation changed a good decade ago and this gave an impetus to the IOC for a large co-operative multi-ship survey of the tropical Atlantic.

It is of general interest to look deeper into the facts which led to the discovery, or more correctly rediscovery, of the equatorial undercurrent. The water mass transport of this third largest current reaches, with about 20 M. cu. m. per sec., the value of other large ocean currents. What were the reasons for our retaining an erroneous picture of the oceanic equatorial circulation until just before the founding of the IOC?

Outside the tropical zone, properties at the oceanic surface reflect in vast areas the three-dimensional fluxes of energy and matter which are, to a certain extent even by application, very simple theoretical models of oceanic circulation. Within the tropics, however, and along the equator in particular, the surface picture veils or hides the dynamic processes. The existence of one or more strong pycnoclines, and several important boundary effects in addition to wind stress, are the reason why the usual constant density models, without nonlinear terms, give no significant picture of the real physical structure and processes. It might be of interest to note that there is some kind of analogue between physical studies of processes in marine estuaries and the tropical zone, from the theoretical as well as the experimental point of view.

Figures 3 and 4 give a general view of the oceanic circulation at the equator in the Atlantic in terms of descriptive oceanography.

Before turning to a review of observations or experiments, theories and objectives of future studies with regard to the undercurrent in the tropical Atlantic, I would like to summarize the history of this study of equatorial circulation, quoting mainly from a paper by W. Matthäus of my institute:

Evidence of an eastward equatorial undercurrent in the Atlantic dates back at least 150 years but most of the early observations on such a phenomena were apparently lost sight of. In James Rennel's review (1742-1830) "An Investigation of the Currents in the Atlantic Ocean" (1832), I quote (page 67):

> "...anomalies also take place in the great equatorial current, and in that of the South-East Tradewind. The former has been known at one time, to run to the eastward, or directly opposite to its general, and, as is commonly understood, perpetual course; and at about the same rate...
> At another time, a like anomaly took place between the parallels of 2° N. and 7° S. This latter was observed to take place at six or seven degrees to the eastward of Cape Roque, but the other about midway between the two continents. In a third case, nearly in the middle, the current ceased altogether, or rather there was neither an easterly nor a westerlv current. This happened in February, the other two in July and August...".

A hundred years ago, Carl Koldewey (1837-1908), in his analysis of logbooks of sailing vessels, mentioned several instances when easterly surface drift occurred at the equator. There are a few other indications in well-studied sources, for example in the narrative of the "Challenger" round-the-world expedition 100 years ago and also, in the "Gazelle" Expedition which took place immediately afterwards. These distinctly show how very superficial the equatorial current is at the equator.

The discoverer of an intensive, predominantly eastward, sub-surface jet current at the equator was, however, J. Y. Buchanan (1844-1925) who was the chemist on the Challenger cruise and accompanied, from January to March 1886, the British steamer "Buccaneer" under Captain

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ERRATA

In the English version, please note the following correction: Page 12, line 1 of paragraph 4 should read – *Figures 1 and 2, not 3 and 4.*

A.S. Thomson between Ascension Island and Freetown. At three stations along the equator (about 16°, 14.5° and 13° W.), he observed at the surface a westward current of about 0.5 knots and in 50 fathoms (91.5 m), an easterly undercurrent of more than 1 knot.

In his paper presented before the Royal Geographical Society on 8 November 1886, he reports (I quote):

"...of a very remarkable undercurrent which is setting in a south-easterly direction with a velocity of over a mile per hour at three stations almost on the equator, and to the northward of Ascension Island ... the surface water was found to have a very slight westerly set. At a depth of 15 fathoms there was a difference, and at 30 fathoms the water was running so strongly to the south-east that it was impossible to make observations of temperature, as the lines, heavily loaded, drifted straight out, and could not be sunk by any weight the strain of which they could bear..."

Between 1886 and 1892 in papers for the Proceedings of the Royal Geographical Society and the Scottish Geographical Magazine, he again pointed to these data and reported:

"these currents were observed and measured by suspending current drags in the water at the depth wished".

After the exploratory cruise of the "Buccaneer" in July 1886, the cable laying steamer "Silvertown" under the same Captain Thomson, was used for observations at the equator between St. Vincent and Pernambuco (at about 30° W.), and in his presentation to the 6th International Geographical Congress in London 1895, Thomson reported:

"...whilst crossing the equatorial currents, the lead of the cable, or angle it made with the direction of the ship's keel, was much in excess of what was accounted for by the actual course of the ship over the ground. This, at the time, was considered to point to the existence of a sub-surface current of considerable extent setting in some easterly direction..."

This additional information on the data from "Silvertown" led Buchanan, at the same Congress, to the following conclusions in his lecture, "A retrospect of oceanography during the last 20 years":

"...In the observation of ocean currents... co-operation by several parties in different vessels, in different but neighbouring localities, is very useful... Could a fleet be dispatched to the equatorial regions of the Atlantic, and carry out combined operations in the equatorial currents, each series extending over at least seven days and repeated at different times of the year, we should very soon know a great deal more about oceanic circulation, and we should find a number of things which would at first astonish us, as we should find that our present theories have no place for them..."

His appeal for co-operative expeditions in equatorial waters was supported by Captain Thomson in the following statement:

"...One of the principal objectives of this paper is to call attention to the necessity for observations of sub-surface currents. They offer a rich and almost virgin field of scientific discovery..."

From these few quotations it seems to me quite obvious, that Buchanan and Thomson discovered the equatorial undercurrent in the Atlantic; their results look very good in the light of our present knowledge.

However, by their contemporaries these data and conclusions have not been acknowledged. O. Krümmel, in the second volume of his "Handbook of Oceanography" (1911), questioned the reliability of Buchanan's technique and measurements, believing that the large cable-laying ship might not have been properly anchored at the dredging rope.

It is interesting, that in 1904, A.E. Wendt, in his paper "Ocean Currents in the Gulf of Guinea" (Annals Hydrogr. and Maritime Meteorology), still quoted Buchanan's observations, but the later German monographs on Atlantic tropical waters (Jancke, 1920 in the Archives of the German Seewarte, Meyer in 1923 in the Publications of the Berlin Institute for Meereskunde and Wendler, 1935 in Gerlands Contributions to Geophysics, as well as A. Defant in the "METEOR" - results) made no reference to the results of Buchanan and Thomson.

Nevertheless a thorough study of reports and papers of research by various expeditions reveals a great deal of further evidence for the undercurrent, for example:

The observations printed from the "Plankton" - expedition of the German steamer "National" in 1889, with O. Krümmel onboard;

The German Deep Sea expedition onboard the "Valdivia" in 1895, with G. Schott;

W. Spiess, in his narrative of the "METEOR" mentioned, when laying off St. Pauls rocks in vicinity of the equator: "The Meteor shipped meanwhile around the rocks, however the circle formed an ellipse because of a heavy easterly current of 1.7 knots" (it was on 10 May 1925 and it was calm weather for landing on the rocks - an excellent example for surfacing the undercurrent during periods of calm weather!);

In the narrative of the German Antarctic expedition in 1911, with W. Brennecke onboard, there is also evidence.

Among various other expeditions, I shall finally mention that of the "Galathea" and her station at 6° W. on 11 November 1950.

There is, however, also in the METEOR work, an excellent tropospheric profile made by A. Merz in 1911 while on the German cable-laying ship "Stephan" between Monrovia and Pernambuco at about 25° W.

But nobody analysed these indicative published observations in conjunction with the conclusions made by Buchanan. C. Puls in 1895 mentioned a number of instances when easterly surface drifts were noted aboard sailing vessels becalmed at the equator and he suggested that below the surface, a constant flow to the east existed which was effective at the surface during periods of calm weather, but he wrote "there is no observational proof of this". Until the rediscovery of the undercurrent in the nineteen-fifties onboard the "Hugh M. Smith" in the Pacific and the "Mikhail Lomonosov" in the Atlantic, a great number of striking undercurrent features had been observed by numerous scientists and expeditions, but they were not acknowledged, or believed to be doubtful data or "anomalies" of tropical circulation.

I now turn to a short review of present observations, theories and proposed objectives for future studies, using as a basis the discussion in SCOR WG 43 "Oceanography related to the GARP Atlantic Tropical Experiment (GATE)" and publications, especially by S. G. H. Philander, now a member of the International Scientific and Management Group (ISMG) for GATE at Bracknell, Berkshire, England.

Recalling the present knowledge:

> The Lomonos Undercurrent is a thin, swift and relatively narrow current, flowing from east to west under the westerly Equatorial Current. Its thickness is about 300 m, its lateral extent reaches 400 km, there is strong evidence for a persistent westward undercurrent beneath, the proposed name for this is the Intermediate Equatorial Current.

There are indications that the undercurrent may sometimes have two cells, so that there are effectively two currents. It definitely surfaces when the wind dies out at the equator, in which case it is no longer an undercurrent.

Present analysis of data from the Pacific Undercurrent support the assumed meandering in the Atlantic also, having a length of some hundred kilometres and periods of 4 days, possible even longer. Water transport has been estimated in the vicinity of 15 sv (sverdrup-unit or million cubic metres per second); the largest quoted value is, however, 37.4 sv.

It has been suggested that the difference between the transport in the western Atlantic, where it is higher, and the eastern Atlantic, can amount to a factor of two.

The high salinity core associated with the current is an outstanding feature of the tropical Atlantic; in the Pacific there is a thermostad, a layer of low vertical stability below the core of the undercurrent. However, from our STD-observations on the R/V "Albrecht Penck" taken in 1964 in the Gulf of Guinea, the two maxima (salinity and current) do not necessarily coincide. According to our observations on R/V "Ernst Haeckel" during equatorial crossings in 1966 at about 30° W. (Brosin/Nehring), and since 1970 on the R/V "Alexander von Humboldt", transport and location of the current is effected by the south-east Trade Winds.

According to Cochrane, in the West the undercurrent starts as a confluence of two currents, one from each hemisphere. The larger of these currents comes from the Northern Hemisphere but the branch from the Southern Hemisphere has a considerably higher salinity maximum. The eastern part of the undercurrent has still not been sufficiently observed. However one can expect from unattended moorings, current-drogues and shear-measurements, a slowing-down of the undercurrent. This also results from the reversal of the slope of the sea surface, which slopes downward between South America and about 7° W., although further east it slopes upward.

Little is known about interactions with other currents which contribute to the equatorial circulation, and how the south-west monsoon the Gulf of Guinea changes the present picture.

In summarizing the description of physical processes connected with this "sandwiched current", several factors are of great interest: problem-oriented research concerning atmospheric or morphological forcing of ocean circulation; the so-called response of the ocean; as well as a general survey of the current, e. g. during equatorial crossings at selected, internationally recommended sections. Whilst for the purpose of regional and longer term surveys, it seems possible to arrange the form of co-operative work needed, the perplexing number of theories which have been proposed to explain the equatorial undercurrent in all oceans demands a large number of problem-oriented experiments.

In theoretical models with constant-density distribution, the long-term effect of the westerly winds over the equator, which cause an eastward pressure force, can simulate in a crude manner an eastward undercurrent. If one considers that physical processes, which are unimportant away from the Equator, cease to be neglible equatorially, a model which includes only one of these processes will at least have the correct width of the undercurrent. The freedom, however, to assign a convenient value to the coefficient of eddy viscosity, usually assumed constant, facilitates the feat of predicting other scales of the undercurrent correctly.

In order to have an easterly undercurrent when the wind dies out, stratified models are necessary to accommodate both the short- and long-term effects of wind. Philander discussed such a model and he found that when the wind dies out, the flow in the thermocline is equator-ward in both hemispheres and that this convergence can indeed sustain an eastward equatorial surface current which has a width, depth and downstream velocity comparable to that of the observed undercurrent. This model thus accounts for the surfacing of the equatorial undercurrent during periods of calm weather and predicts that the zonal velocity component reverses at depth. Indeed, a deep westward current below the undercurrent has been observed. A striking feature of the meridional circulation in the model is the occurrence of downwelling at the equator. This may be an explanation for the troughing isotherms and isopleths of oxygen concentration and other biochemical parameters which are characteristic of the equatorial thermocline.

However, this model shows the undercurrent in geostrophic balance, and other theoretical considerations must be worked up for the instable position of the core with respect to time and place. The similarity transformation also makes it impossible to answer questions concerning the origin and fate of the waters of the undercurrent.

To remove these limitations, three-dimensional models must be constructed. But even if such a model were to give results that are consistent with observations, it would still not follow that the physical processes which determine the undercurrent are adequately represented in the model, since the highly possible importance of interaction with equatorial waves has been neglected. Waves at the equator may be caused either by surface wind - the sudden onset of the westerlies over the Gulf of Guinea - or by instabilities of some of the equatorial currents. The latter subject has received practically no theoretical attention and may shed light on the cause of the peculiar mixed layers at the equator.

Other recent investigations have considered the possibility of internal gravity waves, generated extra-tropically, propagating equator-ward and having their momentum absorbed by the undercurrent which they thus sustain. Another mechanism that deserves attention is the generation of gravity waves near the ocean surface at the equator, perhaps due to up- or down-welling by variable winds. It is conceivable that the gravity waves thus generated propagate downwards until they encounter a critical layer, where their phase velocity is equal to that of the current. Absorption of momentum in this layer may be the explanation for the various eastward maxima of the undercurrent observed on several occasions.

To determine whether these models are adequate or not is important for the general development of our science. It is, however, necessary to have data as input observed under natural, rather than idealized conditions. Using various kinds of moorings for oceanic and, especially wind observations, accurate STD-instruments with depth-controlled water samples at possible satellite or at least marker-buoy fixed positions from standing or roving research vessels, will hopefully be possible during GATE 1974, as a first experiment.

As is often the case, new observations will perhaps complicate the general picture of the undercurrent even more, as we find things for which there is no place in our present theories. Let me end with a statement by Captain Thomson of the "Buccaneer" and the "Silvertown", eighty years ago:

> "... Of sub-surface currents in the open sea we know next to nothing, though we have the few isolated observations which have been made seem to point to the probability that sub-surface currents play a much more important part in the general circulation than has been hitherto supposed".

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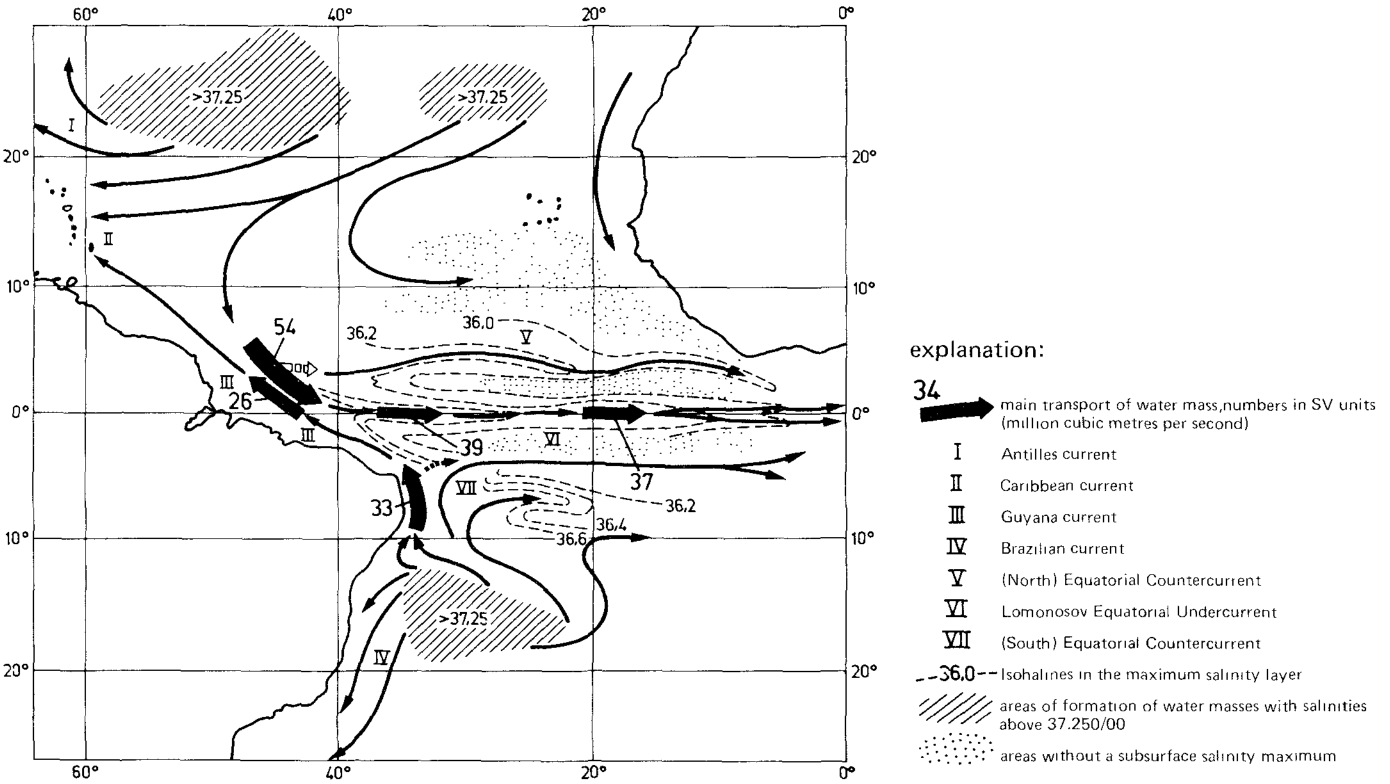

figure 1 : Easterly component of current at 29°30'W from 30 November to 3 December 1966 observed on GDR fishery-research vessel "Ernst Haeckel" according to Brosin and Nebring

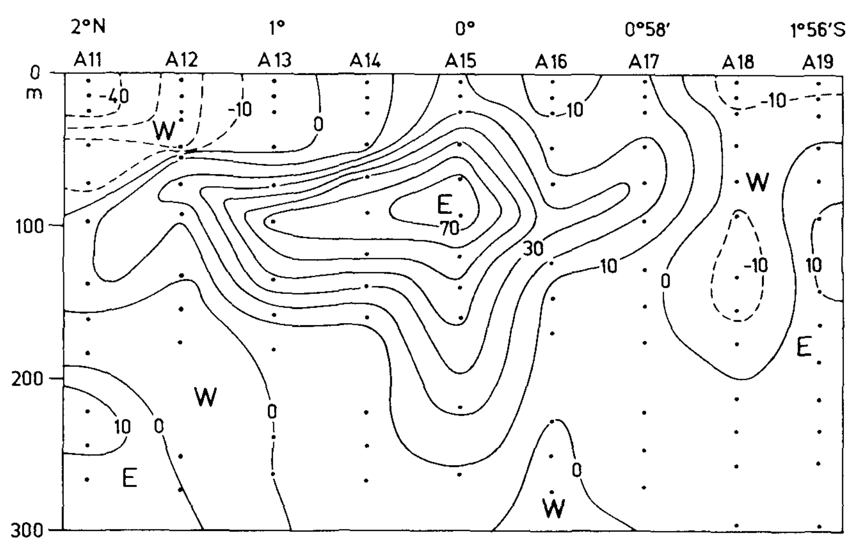

figure 2 : Scheme of the undercurrent circulation in the tropical zonr of the Atlantic Ocean according to Kolesnikov et al.

DISCUSSIONS [(1)]

A. KOLESNIKOV

I do not wish to ask a question, but to add something to what was said by Dr. Voigt. Since the discovery of the Lomonosov Current in 1959 from a vessel belonging to the Marine Hydrophysical Institute of the Academy of Sciences of Ukraine we have been conducting systematic investigations in this region in the course of ten cruises. This has allowed us to establish a physical and geographical picture of this extremely interesting phenomenon and to develop its mathematical model in two approximations - linear and non-linear. In the non-linear case, the numerical experiments, conducted with the aid of electronic computers, has enabled us to evaluate the influence of particular factors on the character of this interesting undercurrent.

Our Institute has contributed to the ICITA Atlas, of which the first volume has now been published. This contains the data on physical oceanography, and includes 286 charts our Institute prepared on temperature, salinity, density, dynamic depths, a chart of the bottom relief and other characteristics. The atlas will be distributed in the near future and then we will see what an excellent job has been done, finalizing the extremely interesting investigations in the tropical zone of the Atlantic Ocean, which, as Dr. Austin said, have been conducted collectively by a number of countries. He has mentioned that 14 vessels of different countries participated in EQUALANT I and 12 vessels in EQUALANT II; this provides an example of co-operative participation by a number of countries in solving a distinctive and clear problem. I think that this is only a beginning and we will see its continuation in GATE.

H. U. ROLL

What is known about the variability of the undercurrent? You mentioned that when the wind dies out the current comes to the surface. We had an accident when measuring the undercurrent at the equator, due apparently to strong shear, when we lost two current meter moorings, and the same happened, as I know, to the Americans in the Pacific. What is known about this variability in time and its relationship to air/sea interaction?

K. VOIGT

I can only answer by citing Philander who reports that only two equatorial crossings have so far been published which include wind observations. These are the two crossings of the "Ernst Haeckel" in 1966. From only two observational standpoints, we might conclude that there is no interaction but it seems possible, according to observations in the Pacific and to theoretical considerations, that during strong south-east winds at the equator, there is a very intense undercurrent with a large shear. During weak or starting winds the undercurrent also is weak, but this is very general. The only proof I have is that as, of course, current measurements by moorings are made exactly in the undercurrent, the high loss of meters indicates the presence of an extreme shear. Clark's current shear observations gave much more inaccurate results, but they are still valid for finding the main position of these jet-like currents.

T. AUSTIN

The undercurrents in the Atlantic and the Pacific are so strikingly different because of the two thousand plus mile zonal aspect of the Pacific compared to the trans-equatorial effects shown by Fedorov in the Atlantic. Unpublished results by Neumann and Rinkel show that the undercurrent in the Atlantic undergoes north-south excursions of approximately one degree of latitude and appears to be associated by a geostrophic relationship with the wind. In the Pacific at least once we observed the undercurrent with a full-scale easterly flow at the surface but as the speaker certainly indicated, we know very little about it.

A. KOLESNIKOV

We have observed meanders with an excursion approximately equal to the width of the current.

H. U. ROLL

Dr. Austin, you only mentioned the differences between the undercurrent in the Pacific and in the Atlantic. The "Meteor" did not find any undercurrent in the Indian Ocean; other observations have shown there is one.

Could we have some information on that, in general?

K. VOIGT

It might be that, because of the completely different wind system in the Indian Ocean, the phenomenon of the undercurrent is not so permanent as in the other oceans but we are still not sure what the main physical reasons are for these phenomena.

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(1) Names and titles of speakers are found at the end of the publication.

T. WOLFF

If I may just return to the historical issue, I should like to know whether Buchanan's observations and investigations during the "Buccaneer" expedition were a result of his primary observations on the "Challenger". If this is the case, one may deplore that these observations were made so many years after the "Challenger". If his results had appeared in the Challenger report, they would definitely have attracted much more attention than in the subsequent report of the "Bucaneer" expedition.

K. VOIGT

There is no written evidence, but of course he was a chemist in the "Challenger" whereas on the cruises of the "Silvertown" and the "Buccaneer", he was engaged more in physical oceanography. Information on the observations made on the "Challenger" cruises in the equatorial Atlantic is mainly to be found in the narrative. At some stations where the wire angle was so extreme, or where it was impossible to measure the depth because the sounding line was carried away by the current, Buchanan might have obtained evidence while on the "Challenger" but it is not very clear.

Dr. J. Krey was primarily responsible for the lion's share of the biological programmes that were conducted from the participating vessels in ICITA. Through his efforts and those of a number of the graduate students from the University of Kiel, where he is the Senior Professor, as well as the efforts of biologists from other nations with whom he interacted, the level of knowledge of the rates of primary productivity and standing crops of several of the biota in the equatorial Atlantic was appreciably increased. Dr. Krey was responsible for the drafting of a number of the observational manuals that were provided to ensure standardization in the sampling and analytical techniques used by the participating nations and to optimize standardization of analytical results. He and his staff were responsible for analyses of many of the samples at the University of Kiel.

Dr. Krey was very effective in representing the Federal Republic of Germany as a member of the International Co-ordination Group for ICITA and has been active in research and publication in his particular area of interest during the years since ICITA.
(Biographical note by the Chairman, Dr. T. S. Austin)

PLANKTON OF THE TROPICAL ATLANTIC

by J. Krey

University of Kiel, Federal Republic of Germany

The topic of this lecture covers a wide span of possible subjects, but because of restricted time, we can discuss only one section of the biology of the tropical Atlantic. We have chosen to concentrate upon plankton and must for this reason renounce the benthic flora and fauna, especially of the deep sea. The remainder of the lecture will deal chiefly with the quality and also the quantity of living organisms in the area of interest.

All organisms depend both on their own morphological and physiological properties, as well as on environmental factors. In this paper the environment of the tropical Atlantic is limited by the 25° C. temperature line in the north as well as in the south. We cannot expect the area covered to be homogeneous. This can be clearly seen in charts of sea-surface temperature in February and August (figures 1 and 2), where we observe a number of isolated patches with a temperature exceeding 25° C.

The second environmental factor is the existence of a broad system of currents. The north and south equatorial currents are as well known as the equatorial counter-current. These currents in the open ocean are also responsible for the permanent supply of the surface water with the different nutrients, which are the basis of phytoplankton development. This is also true of the equatorial undercurrent. But currents not only serve as fertilizers, they are also responsible for the transportation of organisms both from east to west and with the equatorial counter-current from west to east. This is especially important for the transportation of long-living larvae of bottom organisms. This oceanic upwelling leads to areas with a high nutrient concentration in surface waters, but it is necessary that these surface waters, stabilized by warming-up, do not exceed a depth of 200 m. if there is to be an effective production of phytoplankton. If we observe the concentration of nutrients, we will find a rather high concentration along the left side in northern hemisphere currents and along the right side in southern hemisphere currents. Concentration of nutrients is at a maximum at the surface and also in zones of mineralization at about 300-1,000 m. depth, but on the opposite sides of the currents.

We must expect, and it is shown by many investigations, that in areas with a relatively high current speed these currents change their dimensions and speed according to an annual rhythm. The fertilizing effect of the currents is followed by rather high concentrations of phytoplankton organisms (figure 3). These organisms belong to different classes of plankton algae, mainly diatoms in cold waters and peridineans in warm water regions (figure 4). This phytoplankton also causes rather high concentrations of dissolved oxygen at the surface layer, the minimum values being found at about 200 metres depth.

This is the general situation in surface waters and differs in areas with coastal upwelling. These coastal areas are bounded by a narrow shallow water belt. So the ecological areas are distinctly delineated and we may divide them into inshore waters, with and without coastal upwelling, both on the coasts of Africa and South America, and the oceanic ecological regions governed by the above-mentioned three systems of equatorial currents (figure 5). The population of these areas, with such very different environmental factors, is subdivided into phytoplankton, zooplankton and bacteria. It is only very recently that we have succeeded in photographing the very small bacteria in a living state by high enlargement. This enormous standing stock of micro-organisms covers only 20-30% of all particulate living material, in this case especially of detritus.

Considering the heterogeneity and variability of hydrographic environmental factors, we cannot expect the population and its products to be distributed uniformly. We must always be aware also that the somewhat immobile plankton is concentrated in the manner of clouds which day by day change their form and their density. We need only remember the clouds in the sky. Thus for example, a lower concentration at one place is suddenly followed by a high concentration within a few days. Also responsible for the heterogenity and variability is the so-called grazing effect, which through the feeding of organisms on high concentrations of phytoplankton, can diminish it in a few days. It must also be mentioned that there are many species which cannot be fed upon by the so-called vegetarians among the zooplankton, because of their size. These organisms sink to the bottom at a speed of about 5-20 m. per day, and this means that they reach the bottom at 4,000 m. in about 1-2 years. During this time they suffer starvation and their skeletons, especially silica and calcium carbonate, reach the bottom and form an extensive planktogeneous layer.

These introductory remarks will give everyone the conviction that our methods of studying these populations cannot be more than random spot checking. But there are some averaging methods that give us an idea of the general concentrations of life and of its by-products. A very simple way is to follow general lines by optical methods. Joseph and Wattenberg have drawn charts of the extinction of light for the surface of the entire Atlantic (figure 6). These show very clearly that both in the North and South Atlantic, there are regions almost completely devoid of particulate material, and this means that this water has a transparency comparable to that of the purest distilled water. It is remarkable that in these previously mentioned zones governed by the different equatorial currents, the extinction increases to rather high values, especially near the coast and within the south equatorial current. But there is also another method followed by Schott (figure 7), which is based on observing the colour of the sea water using the percentage of yellow light in the respective water bodies. Working by this method, Schott made use of many hundreds or even thousands of observations available from the ships' logs of commercial vessels over a period of at least 50 years. Here we can find a considerable percentage of yellow colour and this means a high concentration of phytoplankton, animals, detritus and the so-called Gelbstoff. It is only intended to give in these figures a very general idea of the population in the area of interest.

Also from the large number of observations from the research vessel "Discovery II", we get an idea of the relative density of life, confirming what has already been mentioned. Tropical waters are on an average less populated than waters in cold regions, and it follows from this fact that the density of organisms in the tropical Atlantic is subject to strong variations. This is not contradicted by measurements of the extinction coefficient nor by the variations in the water colour. Figure 4 also gives us the regions where peridineans and coccolithophorids dominate in the tropical Atlantic. In a special investigation, Hentschel found that the number of plankton individuals per litre range from 5 to 100. Again a tongue of rather high concentration is observed in the south equatorial current, with a range of 20-50 individuals per litre, and in the north equatorial current the presence of strongly enriched upwelling waters is indicated at least in its deeper parts.

It was Laevastu (see Hela, Laevastu, 1962) who for the first time drew a world-wide chart (figure 8) in which he estimated the primary production of the ocean. This first chart also gives an idea of the upwelling areas along the coast of Africa. It is constructed on the basis of the production of g. carbon/m^2 year. The maximum values range from 200 to 400 and the minimum is 50. Again the centres of the northern part of the tropical Atlantic and of the southern part are very poor.

In a similar way the biomass of zooplankton (figure 9) has been estimated in the surface layer from 0-300 m. Maximum values are again given for the equatorial region with figures ranging from 200 to 400 mg/m^3. Also in this altogether independently prepared draft, both the northern as well as the southern part are poor in the concentration of netted zooplankton, with figures less than 50 mg/m^3.

In 1970, a world-wide chart of the primary production of phytoplankton was prepared by our Soviet colleagues on the basis of the gross production in mg/carbon/m^2 day (figure 10). Again a high production can be observed in the equatorial region with pronounced patches north of the equator. Here too the vast desert-like areas of the central South and central North Atlantic are worth noting.

In quite another way Friedrich constructed a chart showing the relative density of plankton organisms of all kinds, deriving his material from the different expeditions. He assumed the highest number of individuals of one species as being 100% and on this basis drew his other lines. Even with this difficult method, the pattern of the plankton population remains very much the same as in the preceding diagrams.

Following the ideas of Hedgpeth (1957), the ocean - especially in the tropical area - is divided into a coastal section both along the coast of Africa as well as Central America, where organisms live which favour temperatures above 25° C.

According to results obtained during the ICITA, the primary production in the tropical area is calculated in terms of mg/carbon/m^2 day (figure 11). The values range between 100 and 1,000 mg. It is remarkable that this area is not in the least homogeneous. This might be explained firstly by the age of the surface layer water, which had not yet developed the total phytoplankton population, and also by intensive zooplankton grazing.

For the zooplankton population a chart is given for the cold season in units of ml/1,000 m^3 (figure 12). Values range from 0-300 ml. The trend followed by the zooplankton population is exactly the same as that followed by phytoplankton, the only difference being that the high values are concentrated towards the equatorial zone in a belt which is covered by the equatorial countercurrent.

During the expeditions of EQUALANT I, II and III, a completely different method was used to determine the standing stock of total plankton calculated from protein equivalents (mg/m^3) (figure 13).

The values range from less than 50 to more than 200 mg. But these patterns of distribution give only a rough idea of very complicated systems. This is due to the method used, which covers phytoplankton, zooplankton and bacteria and therefore does not take into account the very dynamic behaviour of the different kinds of organisms.

In order to gain an idea of the total particulate material that is essential for all filter-feeding organisms, we have determined the so-called seston (figure 14). This gives us values in mg. of dry weight per m^3. It must be considered that this seston includes not only all living material but also the detritus. Although we know only little about the nutritive value of detritus, we can consider it as adsorption material for dissolved organic substances which originate from the metabolism and mineralization of all kinds of organisms, from phytoplankton up to the fishes.

It was through the Guinean Trawling Survey (GTS) expeditions that we learned more details about the protein equivalents over the West African shelf area. Here we can distinguish between poor areas with a concentration of less than 100 mg/m^3 and rich areas with more than 100 mg/m^3. This agrees with other observations for the northern shelf areas; where again the shelf region stands out as a particularly high productive zone. In any case the patchiness of the distribution is here again remarkable. This patchiness is also supported by values of transparency. We should recall similar phenomena which have been demonstrated by the extinction chart for the entire ocean.

Zeitschel has also determined the concentration of the so-called microbiomass, which was calculated from the protein equivalent data and ranges from less than 400 to more than 2400 mg/m^3.

We may conclude that plankton must be regarded as the basis of the food supply of fishes, directly or indirectly. If we look out for areas with a high standing stock of fish, we are confronted with a patchy distribution of plankton. The final figure seems to be rather confusing and one should consult the large-scale charts. If we are to obtain a more or less precise idea of the population, it is necessary for us to ask for permanent registration of the different biological parameters. This can be done by a network of Hardy recorder lines. Further information can be gathered from automatic chlorophyll measurements from anchored buoys. These could also be equipped with turbidity meters so as to provide both large-scale as well as micro-scale information. Because of changing population densities, these three methods must be applied regularly for at least five years. An altogether different method - aerial photography from commercial aircraft - may give us a still better idea if we are in a position to take test samples simultaneously from a ship. This is only a question of organization and will give us well-founded knowledge of the natural population as well as of the possible standing stock of fish.

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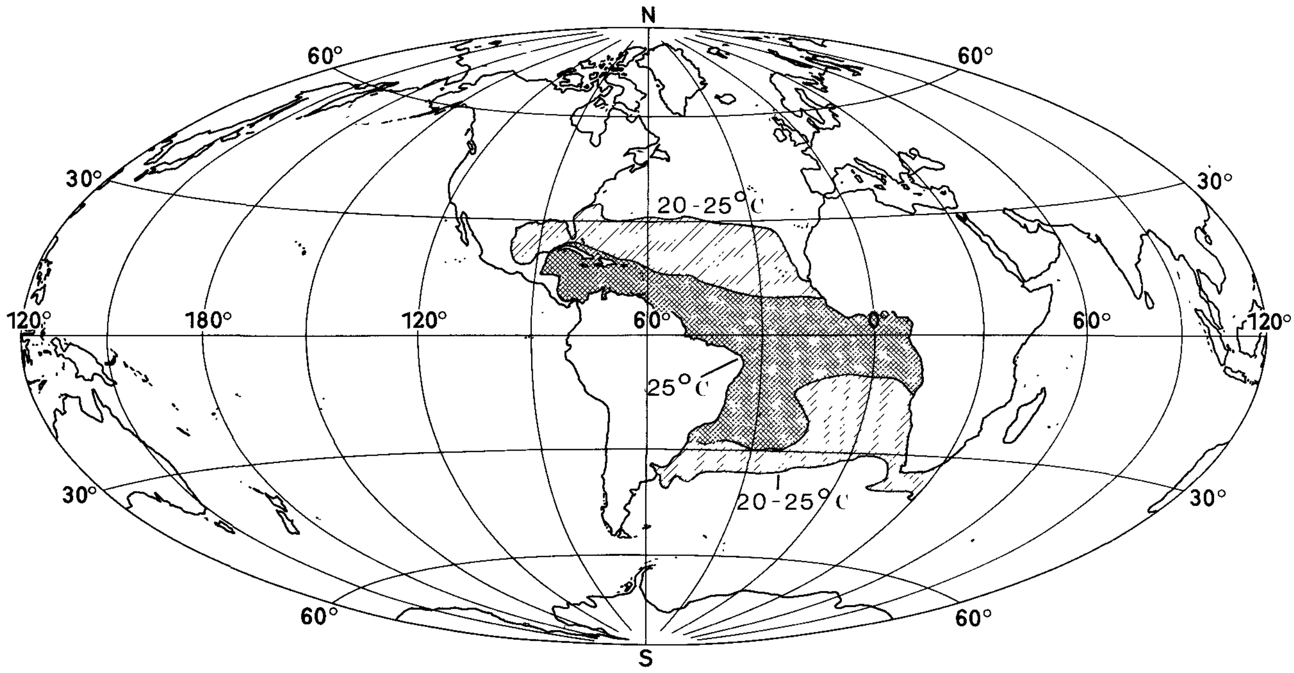

Fig. 1 - Mean Temperature in the Tropical Region, February, (after Schott)

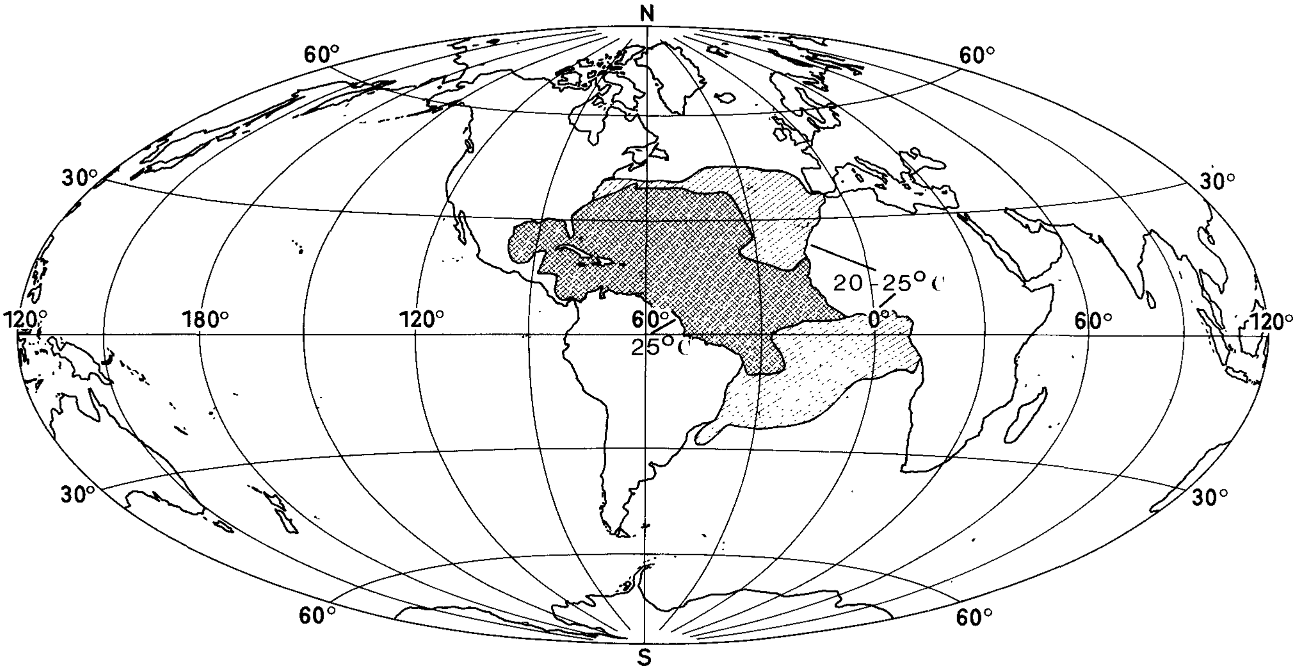

Fig. 2 - Mean Temperature in the Tropical Region, August, (after Schott)

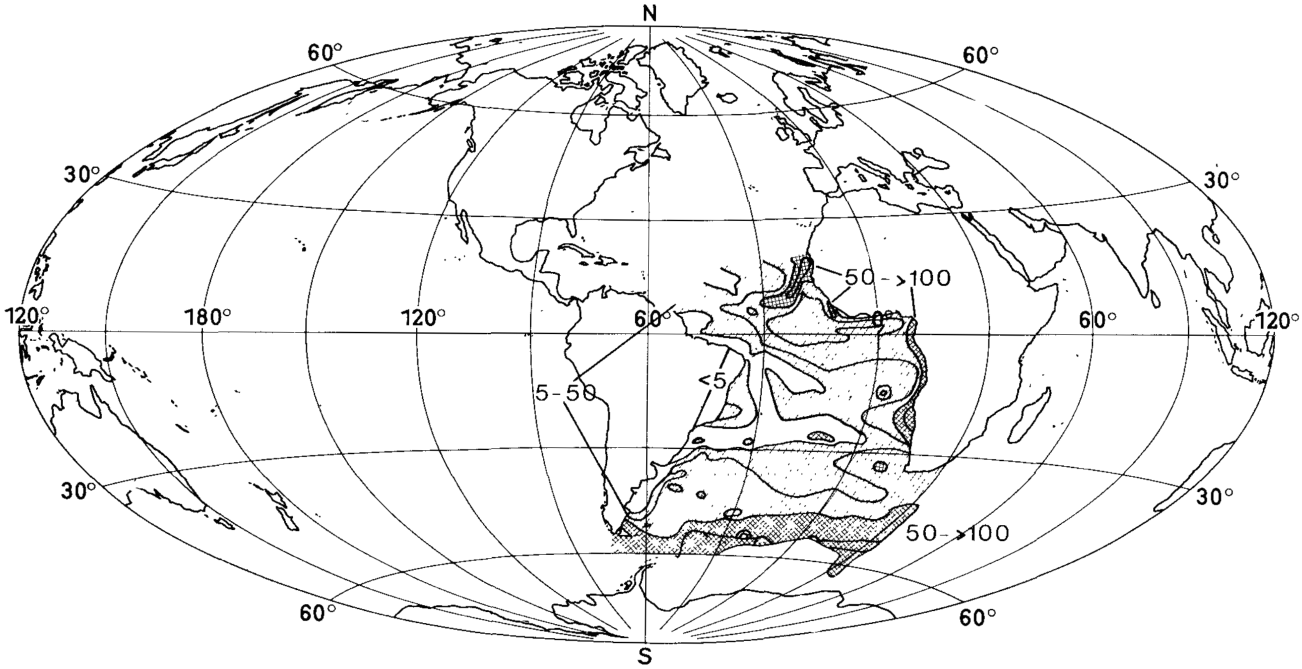

Fig. 3 - Planktonorganisms individuals / 1,0-50m (after Hentschel)

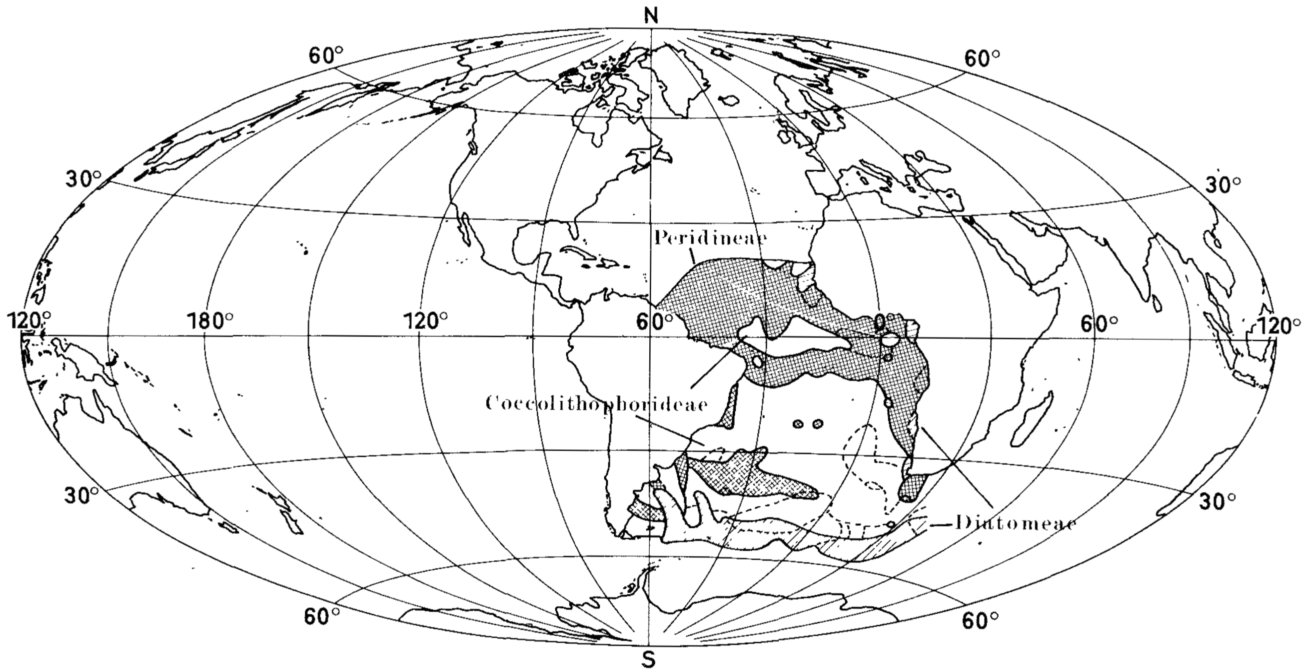

Fig. 4 - Regions of Dominating Phytoplankton (after Hentschel)

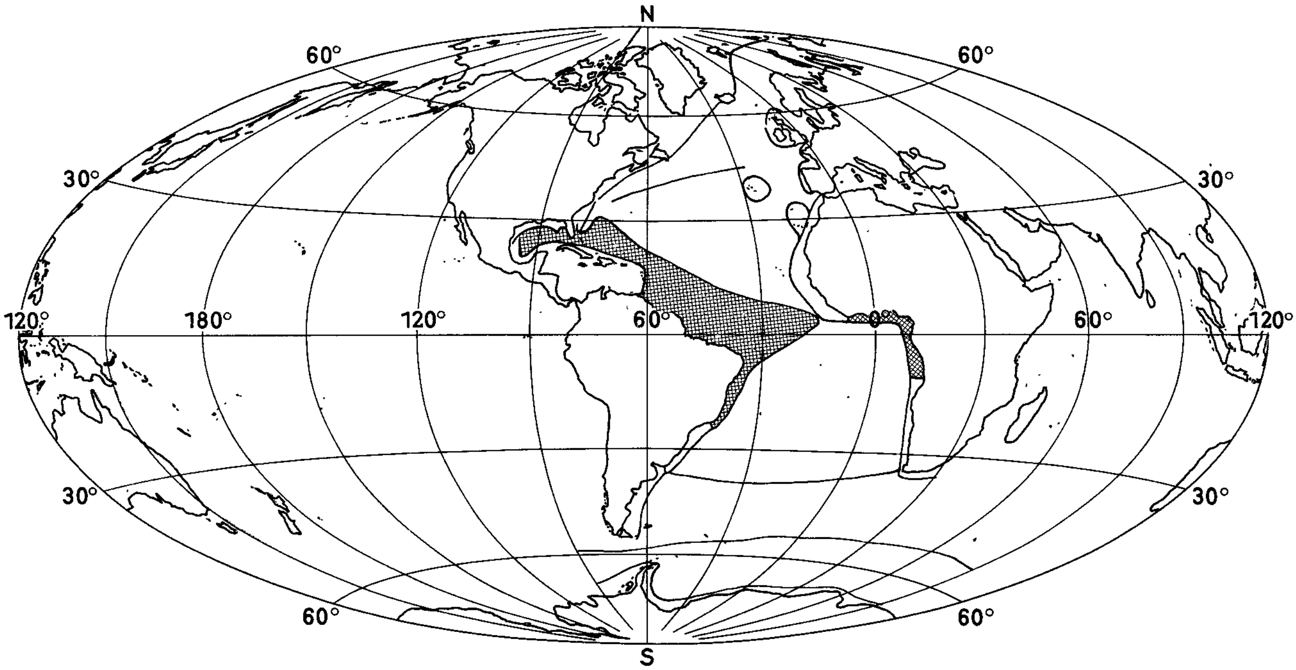

Fig. 5 - Planktographical Provinces (after Hedgpeth 1957)

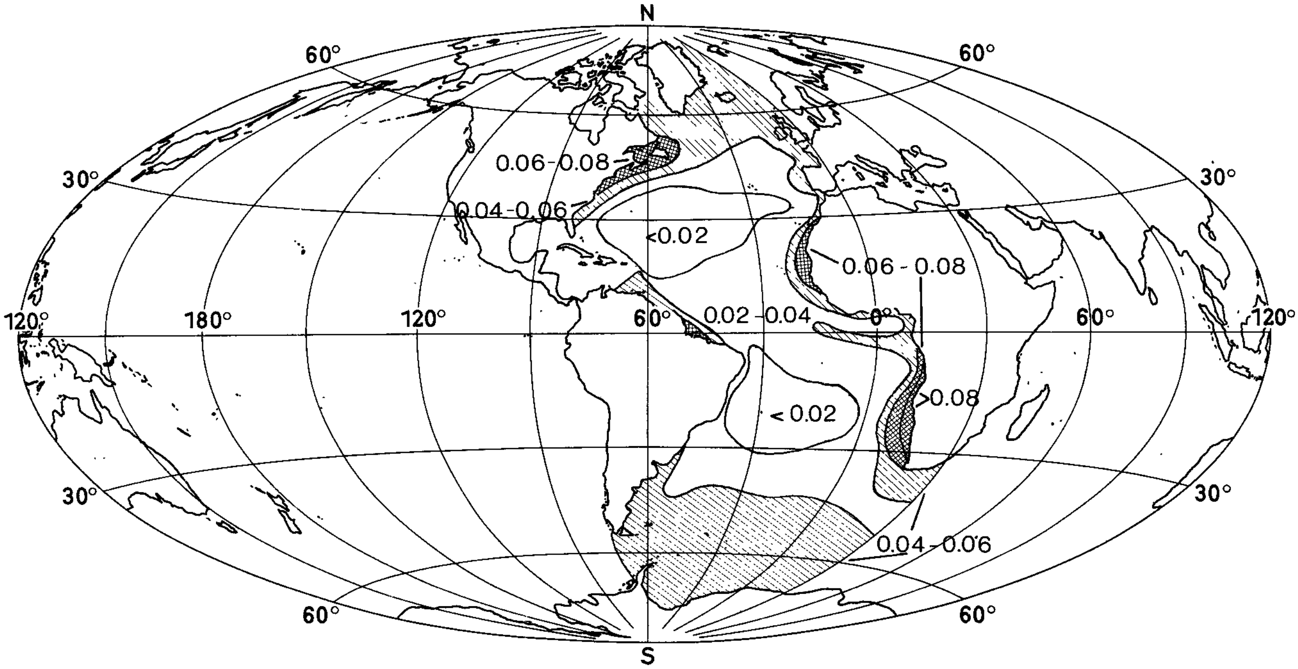

Fig. 6 - Extinction Coefficient of Blue-Green Light (after Joseph & Wattenberg)

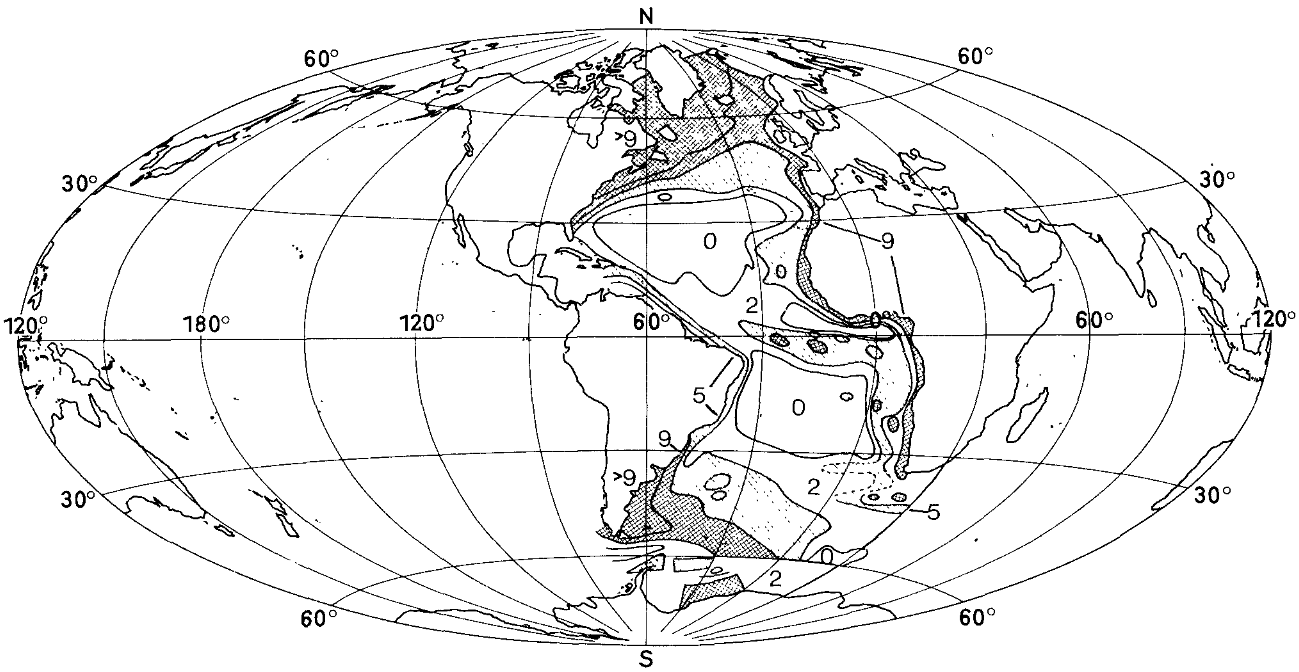

Fig. 7 - Colour of Seawater in %o yellow, Forel - Scale (after Schott)

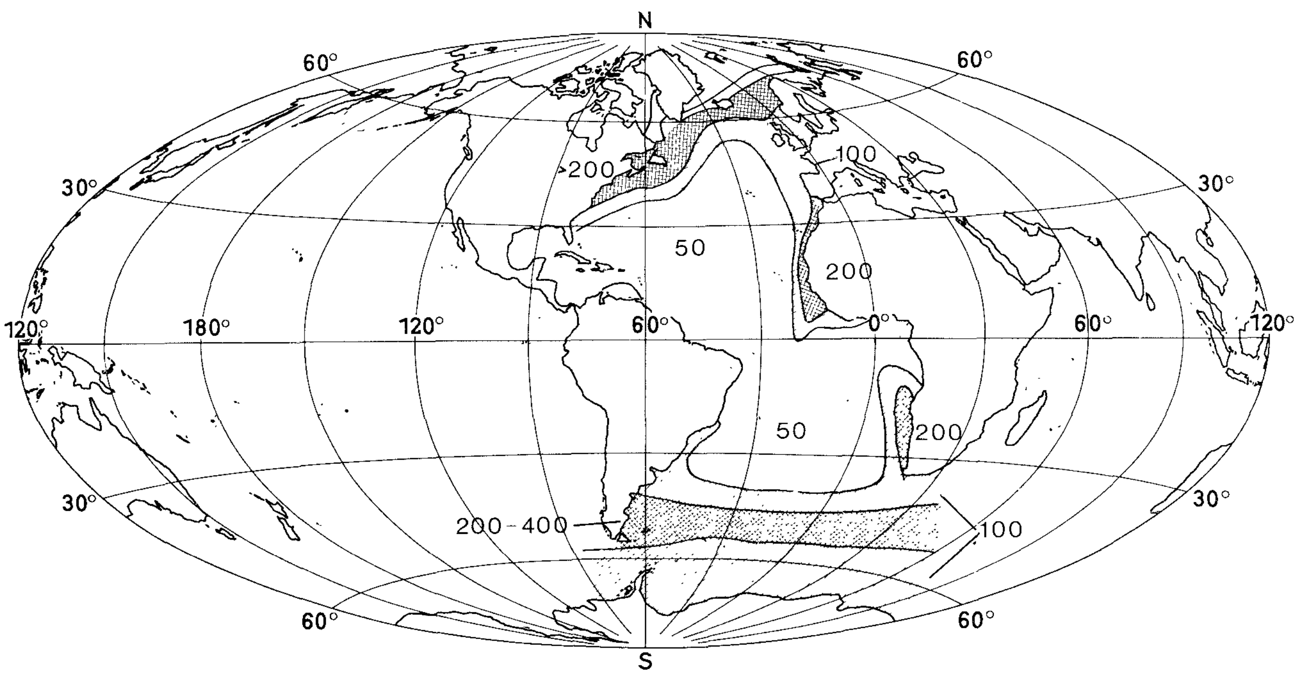

Fig. 8 - First Estimation of the Primary Production, g C/m^2y^{-1} (after FAO)

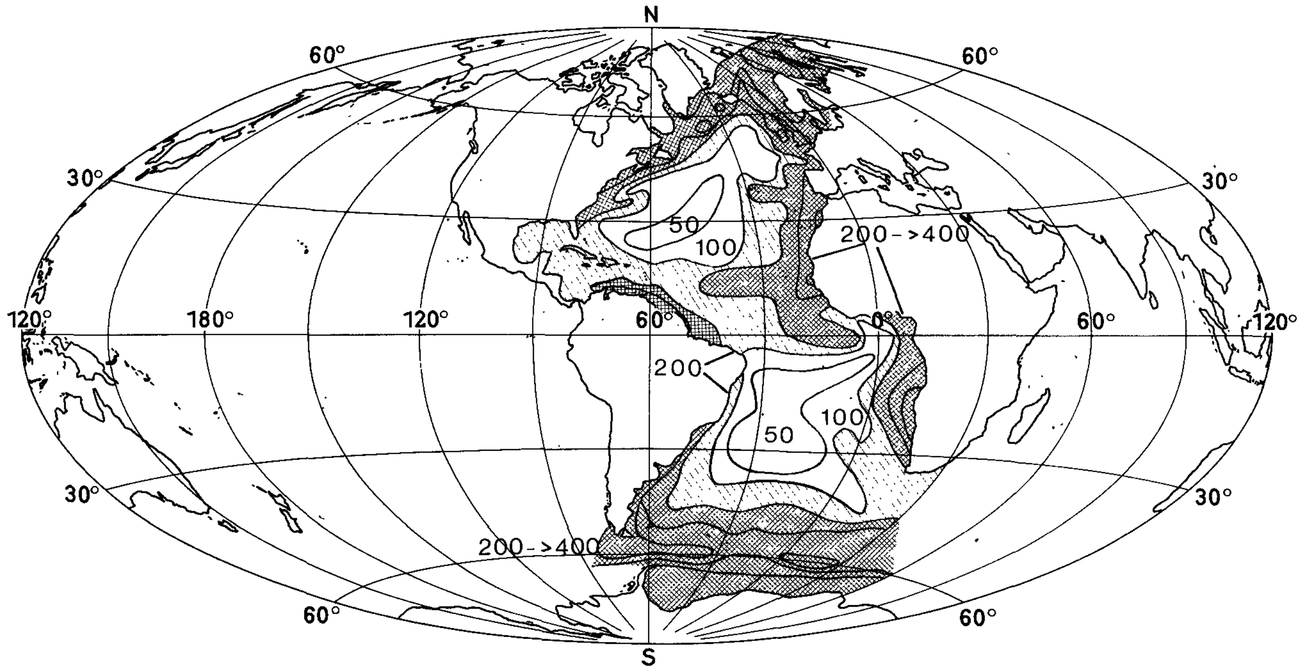

Fig. 9 - Biomass of Zooplankton mg/m^3, 0-300m (after Hela & Laevastu)

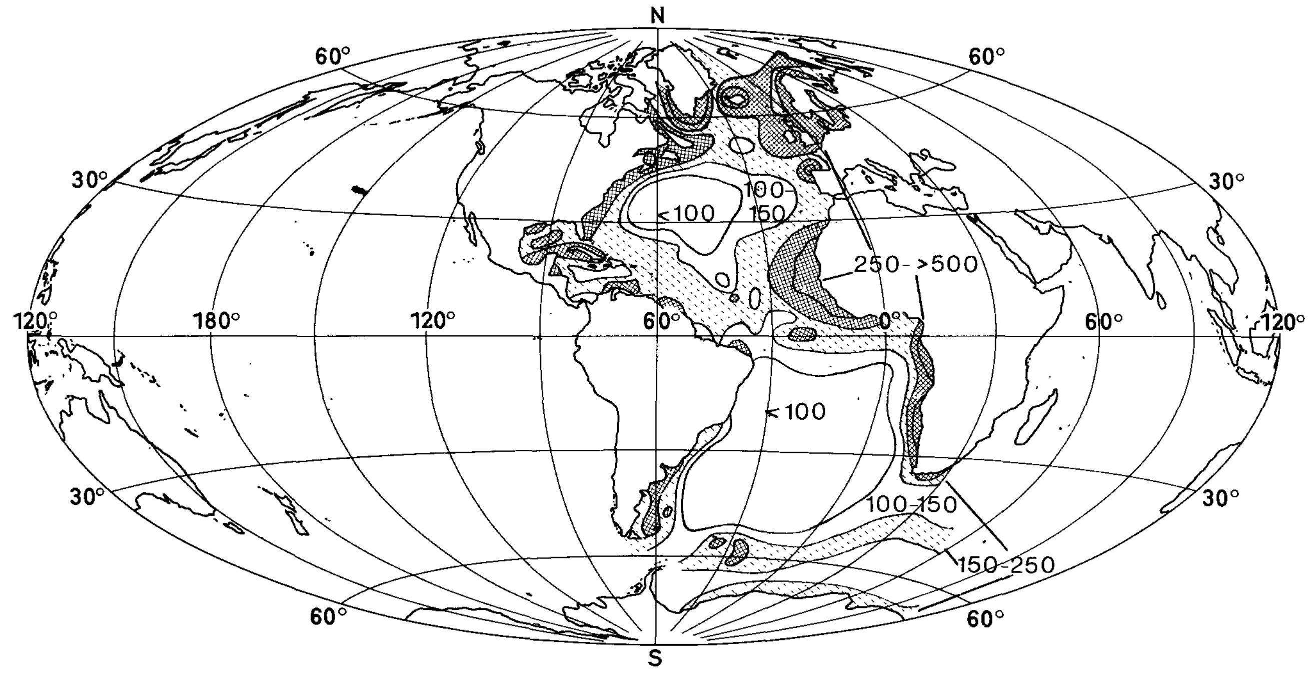

Fig. 10 - Primary Production of Phytoplankton, 1970, mg C/m^2/d (after Koblentz-Mishke et al.)

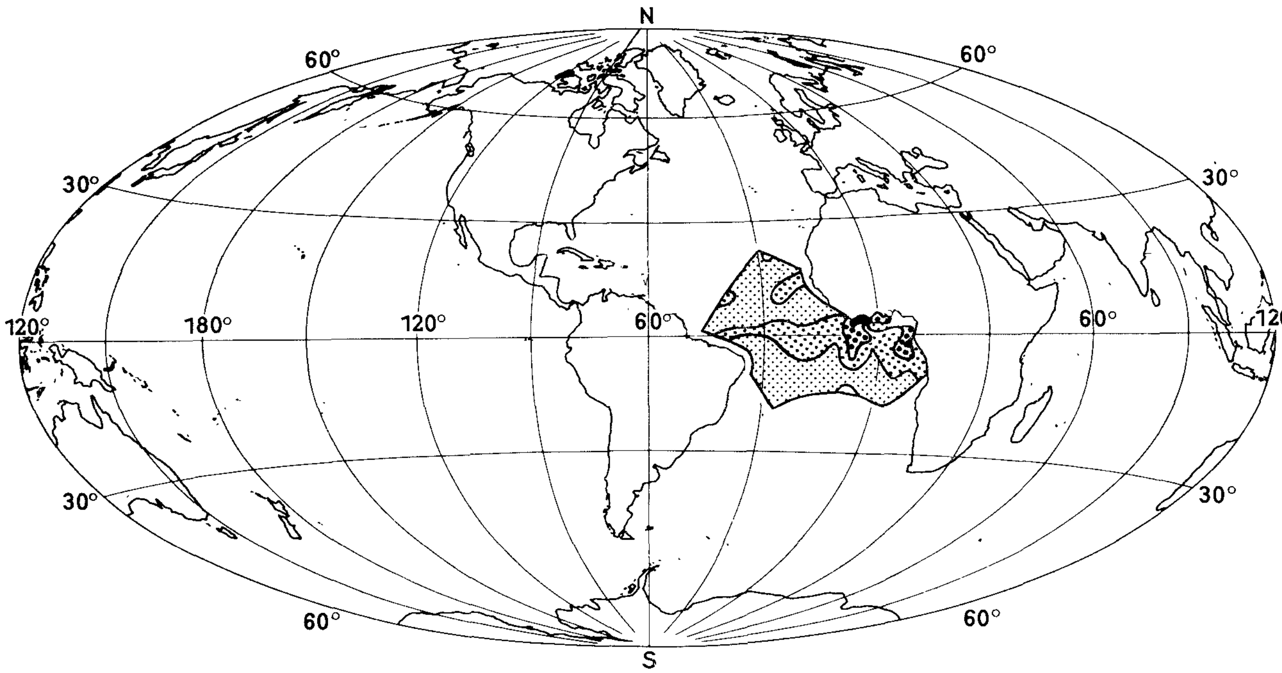

Fig. 11 - Primary Production mg $C/m^2/d$, Cold Season

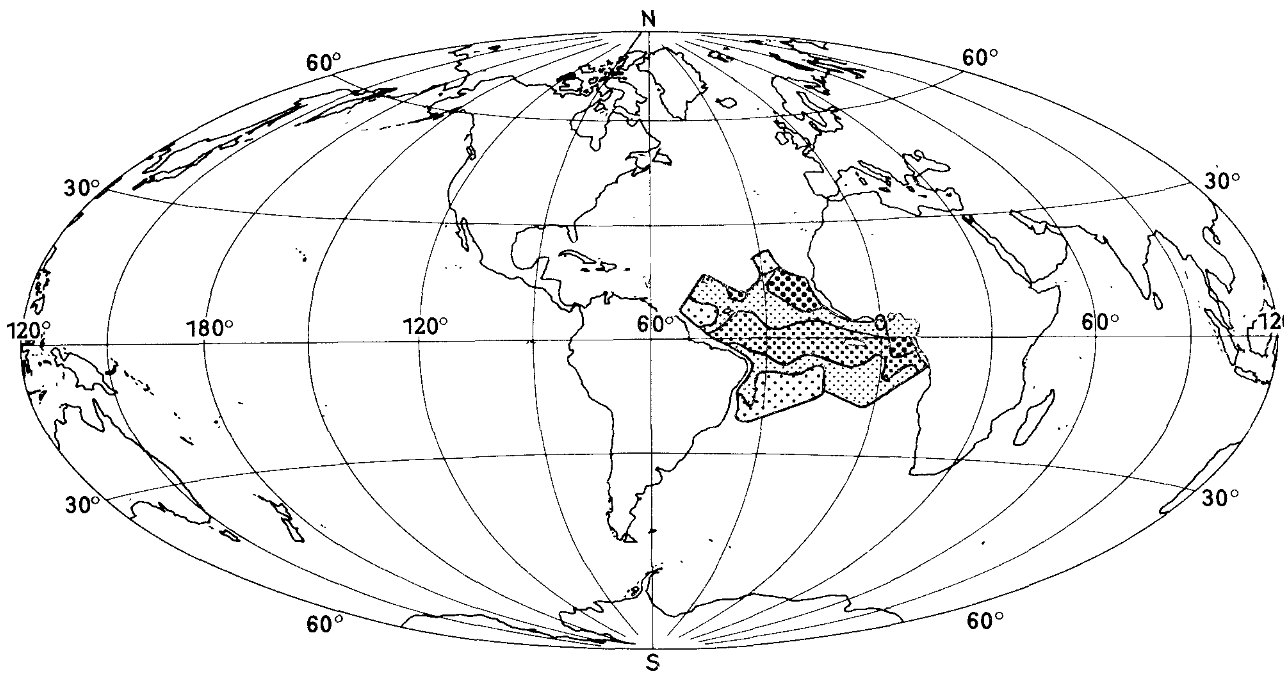

Fig. 12 - Zooplankton Displacement $ml/1000m^3$, Cold Season

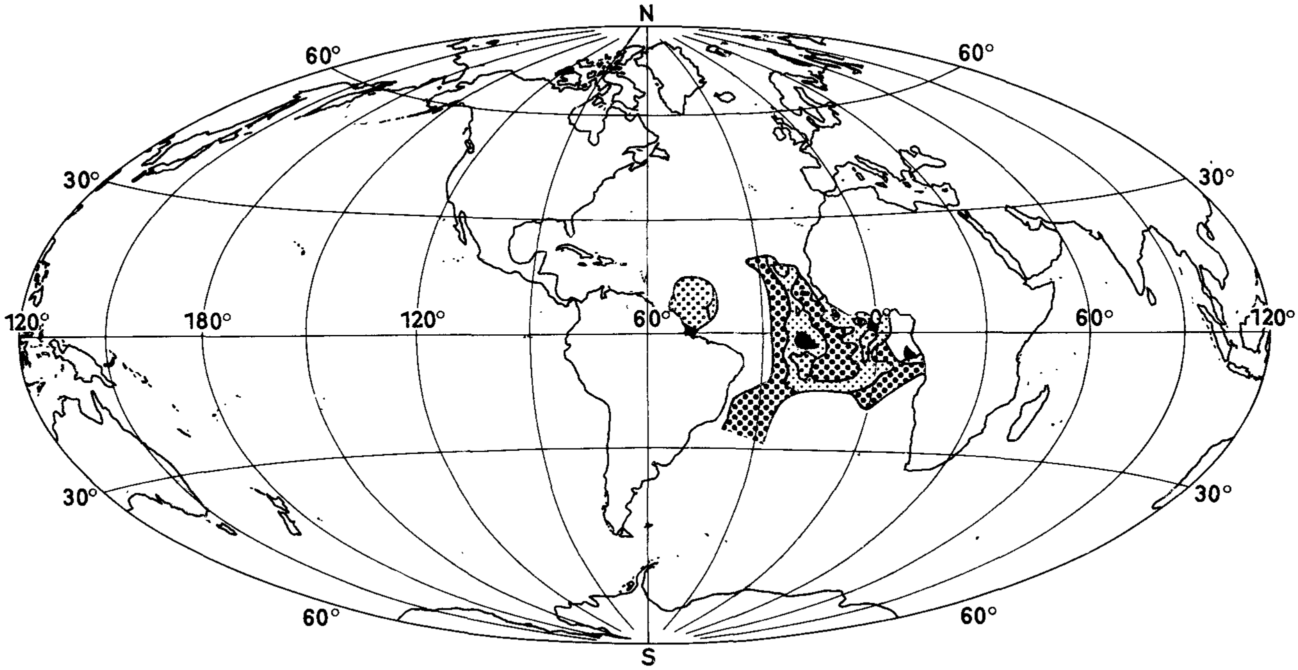

Fig. 13 - Microbiomass of Plankton given as Protein Equivalent, mg/m^3, Equalant I-III

■ > 200 -   100 - 50
200 - 100   < 50 -

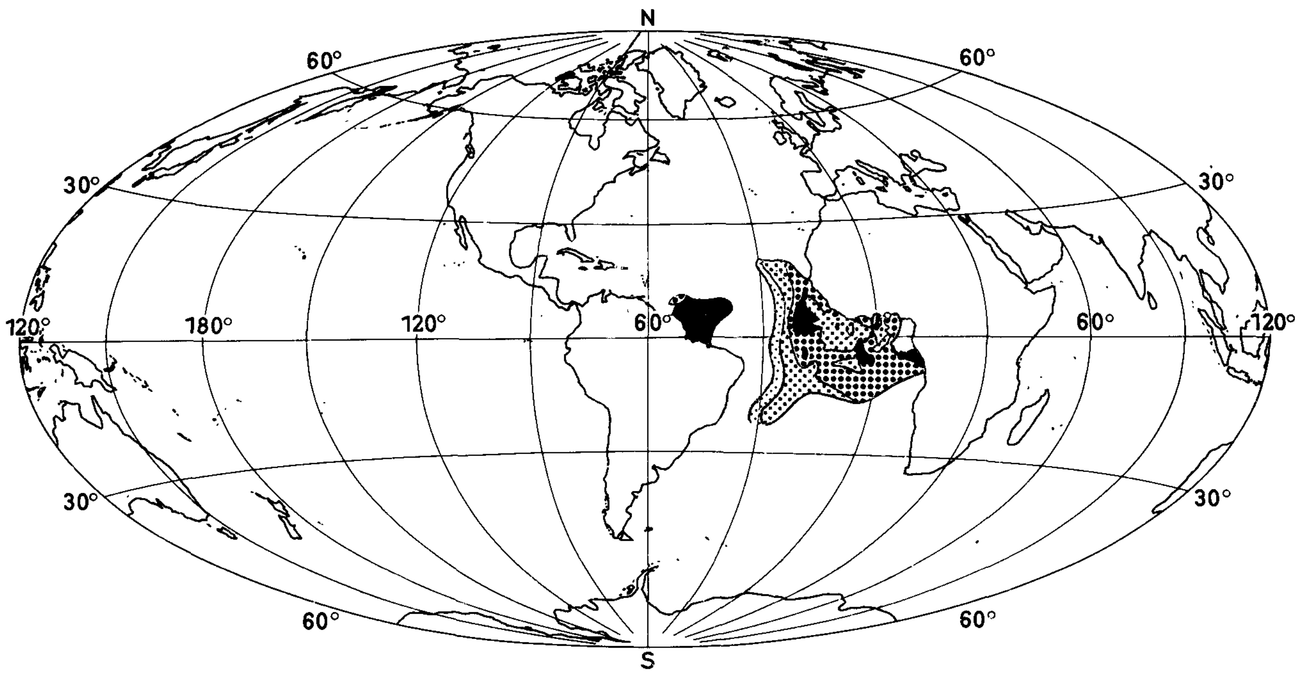

Fig. 14 - Seston, mg/m^3, Equalant I-III

■ > 700   300-100
700-300   < 100

DISCUSSION [1]

T. AUSTIN

One interesting aspect, Sir, I would like to ask you about - the work done by Botofskoi and Jones in the equatorial undercurrent. Some of the foraminifera were specific indicator organisms to the waters of the undercurrent and the contours of the counts of these different species resembled exactly the distribution of the salinity core as shown by Dr. Voigt in his paper. I believe indicator organisms have been used rather extensively to support the physicists in the tropical Atlantic. Is that correct, Sir?

J. KREY

That is absolutely correct. Unfortunately, I had no time to tell you more about these biogeographical patterns of distribution. I feel it is one of the most important things we have to do, not only to measure primary and secondary production, but also to point out the ecological background, i. e. the interaction between the organisms and their environment. In this special case of the undercurrent, I can very well imagine that these foraminifera not only depend on the temperature, but to a very high degree also on the food they take. And this must, from a theoretical point of view, be rather a special food, not only in regard to concentration but also to its quality, i. e. the size of the food particles, especially the detritus particles.

J. DERA

The primary production of the sea is extremely important not only because of food production, but I would say, even more so because of production of oxygen. As we know, something like 60% of atmospheric oxygen comes from the sea, that is, from the primary production. My question is: are there any observations in the Atlantic Ocean that indicate any tendency for the euphotic zone to decrease in thickness as a result of pollution? I have not heard of it and it may be too small to observe in the open ocean, but we can detect some phenomena like that in the Baltic Sea where pollution has a greater effect. If in the future pollution increases at the present rate, it could even be a danger to the supply of oxygen in the atmosphere. My second question is: has any change in species of phytoplankton been observed, not only due to the decrease in the amount of radiation penetrating into the ocean but also because of a change of their spectrum as a result of pollution?

J. KREY

I consider that in the Atlantic Ocean there is up to now no reason to be pessimistic. The open Atlantic provides quite a different ecological situation to the Baltic and I personally am certain that pollution does not always decrease primary production and that there are times when it rises. On occasion special organisms fill the ecological niches and in this way the total biomass, especially of primary producers, is not lowered but only replaced by others. Secondly, I am sure that the quality of radiation may give another scope to this problem, especially in the Baltic. We know from numerous measurements, that nature has a rather wide span of dynamic replacement of one species by another. I am not so extremely pessimistic on this type of pollution, that we must only follow the different ecological patterns and know precisely what type of pollution enters the sea, especially the Baltic or the open Atlantic Ocean. I think there is not yet any danger that oxygen production is lowered.

(1) Names and titles of speakers are found at the end of the publication.

Dr. Frank Williams, Chairman of the Division of Fisheries and Applied Estuarine Ecology, Rosenstiel School of Marine and Atmospheric Science of the University of Miami, was the man who had responsibility for the planning, operations, analyses of the samples and data, and the publication of the results of the Guinean Trawling Survey (GTS). He brought many years of experience in fishery research in equatorial waters, particularly the western Indian Ocean, to the task, which he undertook as Director of GTS. As I mentioned in my opening remarks, GTS was primarily directed by the Organization of African Unity (OAU); Frank Williams was stationed in Lagos (1962-1966). Subsequently, he spent two years with FAO in Rome and five years with the tuna oceanography programme of the Scripps Institution of Oceanography in La Jolla, California.

I had the pleasure of co-chairing a symposium with him in Abidjan, Republic of the Ivory Coast, in 1966 during which GTS and ICITA results were discussed in considerable depth. Since then, Dr. Williams has been involved with and certainly has carefully monitored the development of the fishery potentials in the waters off the west coast of Africa. Partially as a result of his efforts, the Gulf of Guinea is now one of the better known and perhaps understood regions of the world oceans from the viewpoint of marine protein resources.
(Biographical note by the Chairman, Dr. T. S. Austin)

FISHERY RESOURCES OF THE TROPICAL EASTERN-CENTRAL ATLANTIC OCEAN: EXPLORATION, UTILIZATION AND MANAGEMENT SINCE 1960. (1)

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Miami, Florida 33149

HISTORICAL

It seems most appropriate that the resources of the eastern-central Atlantic Ocean be the subject of a Bruun Memorial Lecture, as Anton Bruun was leader of the Atlantic Expedition to the West African continental shelf in 1945-1946. During a visit to Copenhagen in the mid-1950's, I had the opportunity to meet Anton Bruun and learn from him some of the significant faunistic features of the West African coastal area. Little did I know that in 1962 I would be asked to organize and direct an international demersal resources survey in that same area.

Professor Theodore Monod, at the 1966 Abidjan Symposium (FAO, 1967) on the Oceanography and Fisheries Resources of the Tropical Atlantic, (organized by Unesco, FAO and OAU), presented an excellent historical review, from very earliest times, of the marine sciences in the eastern tropical Atlantic. He included information on events leading to the recent projects, which formed the theme of the symposium. It is important to reiterate some of the salient features at this time, so that you may place subsequent events in perspective.

The Commission for Technical Co-operation in Africa (CCTA) was set up in 1945, and later with the Scientific Council for Africa (CSA) and other bodies, to promote co-operation and planning in scientific matters in Africa, south of the Sahara. A CCTA/CSA Symposium in 1957 (CCTA/CSA, 1957) stressed the need for a full investigation of the marine resources and the environmental conditions in the Gulf of Guinea. A draft programme was prepared by my colleague Dr. Postel, accepted by a group of experts in December, 1960, (Postel, 1960) approved by CCTA in 1961 (CCTA/CSA, 1961) and given the title of the Guinean Year. The priorities were determined as:

1. a trawling survey of the demersal resources from Mauritania to Angola;
2. a campaign to study the meteorology and physical, chemical and biological oceanography of the Gulf of Guinea;
3. an experimental fishing campaign for sardine-like fishes; and
4. an experimental fishing campaign for tunas.

Subsequent discussions between CCTA and United States authorities resulted in the U. S. Agency for International Development (USAID) agreeing to finance the demersal fisheries resources survey and the United States itself undertaking the tuna resources survey and the oceanographic investigation in the Gulf of Guinea. By June 1962 the latter project had developed into what we now know as the International Co-operative Investigation of the Tropical Atlantic (ICITA). The tuna survey was undertaken in a modified form by the then U.S. Bureau of Commercial Fisheries and the trawling survey, renamed the Guinean Trawling Survey (GTS), was undertaken by the Scientific, Technical and Research Commission (STRC) of the Organization of African Unity (OAU) which had by then assumed the functions of CCTA. A UN/Expanded Technical Assistance Programme, under FAO, was started in Ghana in 1963 to study the fishery and biology of sardines. Partly as a result of this work, the UNDP/Special Fund in 1965 sent a scientific mission to West Africa to consider requirements of certain other countries (Congo, Ivory Coast, Sierra Leone, Senegal) for national resources projects on sardines and for a co-ordinated regional project, complementary to the national ones.

THE INTERNATIONAL CO-OPERATIVE INVESTIGATION OF THE TROPICAL ATLANTIC (ICITA)

Earlier in this session you have heard from Dr. Voigt of the advances in our knowledge of the equatorial undercurrent during the ICITA. This is extremely important in our overall understanding of oceanic circulation, dynamic balance and the origin of sub-surface high salinity water in the Gulf of

(1) Contribution from the Rosenstiel School of Marine and Atmospheric Science, University of Miami.

Guinea. Equally important was confirmation of the basic oceanographic features of the coastal (near shore) region for which Berrit and his colleagues were largely responsible in the 1950's (Berrit 1952, 1958, 1959, 1961, 1962a-c) and which were synthesized from a biologist's standpoint by Longhurst (1962).

Biologically one of the most important oceanographic features is the thermocline (25° - 19° C.), between the Tropical Surface Water (TSW) and the underlying South Atlantic Central Water (SACW), which is directed downwards away from the coast. The depth of the thermocline averages 20-35m. over the edge of the shelf but can be much shallower.

Based on previous work, the inshore area of the Gulf of Guinea was subdivided into five oceanographic zones (figure 1) (Williams 1968).

(a) a Northern Transitional Zone (NTZ) Cape Blanc, Mauritania to Cape Verga (Guinea).
(b) a Western Tropical Zone (WTZ) Cape Verga to Cape Palmas, Liberia.
(c) a Coastal Upwelling Zone (CUZ) Cape Palmas to Cotonou, Dahomey.
(d) an Eastern Tropical Zone (ETZ) Cotonou to Cape Lopez, Gabon.
(e) a Southern Transitional Zone (STZ) Cape Lopez to Cape Frio, Angola.

North and south of the transitional zones (NTZ and STZ) are respectively the permanent upwelling areas of the Canary and Benguela Currents. In the NTZ, CUZ and STZ there is seasonal replacement of Tropical Surface Water by colder, more saline water (figure 2). In the transitional zones this results from movement of the oceanographic fronts between the eastern boundary currents and the tropical surface water masses (approximately six months apart in the two hemispheres) and in the CUZ by coastal upwelling. In the two tropical zones (WTZ, ETZ) fluctuations in temperature are much less, but there are very considerable fluctuations in salinity due to precipitation and run-off from the land.

Surface current flow is mainly zonal with the Guinea Current, flowing from west to east, formed principally from the North Equatorial Counter Current and an offshoot from the Canary Current. South of Cameroon there is a coastal offshoot of the Benguela Current, which turns west (well to the south of the Guinea Current) and joins the South Equatorial Current.

The physical oceanographic results of the ICITA relevant to the eastern Atlantic /discussed at the 1966 Abidjan symposium (FAO 1967; Unesco 1969), published in the ICITA Atlas (Unesco 1973) and elsewhere/ have better defined the causes, timing and extent of upwelling and the seasonal movement of the major oceanographic fronts, and the boundaries of the principal current systems and water masses.

Physical oceanographic work since the ICITA has been primarily (i) in support of localized resources surveys and (ii) directed to a better definition of oceanographic events on a continuing and annual basis. This in no way implies that our physical oceanographic studies are completed in the region but rather the scale and size of operations needed to solve the overall problems in circulation, etc.

My colleague Professor Krey has just discussed the biological productivity (lower trophic levels) of the region based on ICITA and other work. It suffices to say that primary production is highest in the coastal upwelling and transitional zones and in an oceanic area near the Equator, and that distribution of zooplankton standing stock follows fairly closely that of primary production. Benthos measurements, even of biomass, are relatively few and from selected areas of the continental shelf. None were made during the ICITA/GTS, but past work indicates correlation with type of bottom sediment and with depth.

TUNA RESOURCES

I will restrict myself to the tropical tunas (yellowfin, skipjack and bigeye) and principally to the yellowfin tuna. Two distinct fisheries are involved, the longline fishery at sub-surface levels across the entire Atlantic and the surface fisheries, using the pole-and-line live-bait method and purse seining, in the tropical eastern Atlantic (figures 3 and 4)

The Atlantic longline fishery by the Japanese began in late 1956-1957 (Kamenaga, 1967) with 3 million hooks fished in the tropical zone. In the next five years it spread rapidly to cover most of the Atlantic Ocean with 55 million hooks fished in 1963. In the last decade overall Japanese fishing effort has declined but fleets from Taiwan and South Korea have entered the fishery. In the tropical region the fishery initially exploited the large yellowfin (but also bigeye) concentrations in the offshore Gulf of Guinea. However, by the early 1960's catches indicated a switch away from yellowfin, because of declining catch rates, and towards the albacore in the more temperate parts of the northern and southern Atlantic.

The surface fishery for small yellowfin and skipjack in West Africa began in 1954/1955 when French live-bait boats arrived in Senegal to fish out of there in the winter months. These small vessels normally operated in the inshore north-east Atlantic albacore fishery in the summer, and were short range coastal vessels depending on local ports for ice, trans-shipment of catch, supplies, etc. However, with an increasing tuna fishery (surface and longline) such port facilities sprang up along the West African coast and by 1963 the fishery area extended as far as Angola and with more than 150 vessels of varying nationalities. In recent years another surface fishery area has been located close to the Equator on either side of the Greenwich Meridian.

In the late 1950's and early 1960's a few American and Canadian vessels made exploratory fishery trips for tunas in the eastern tropical Atlantic with mixed results. Three U.S. purse seiners entered the fishery in 1967 but by 1969-1971 an average of 25 seiners were present, together with large modern seiners from Canada, France, Spain Japan, Panama, Portugal, Norway (≥1,000 tons capacity), as well as smaller ones from the West African countries. The arrival of the U.S. seiners (and others) in the Gulf of Guinea was a result of the IATTC(1) regulation, through catch quotas, of yellowfin catches in the eastern tropical Pacific fishery. Such diversion of effort from the eastern Pacific introduced the seiners into the Gulf of Guinea fisheries in summer and fall, which coincides with the peak tuna season.

Tuna fisheries are oceanwide and multinational and because of this, research and management of the stocks are best handled on an international basis. A series of meetings in the early 1960's emphasized this view. Demand for tuna was doubling each decade and the exploitation of world tuna stocks was already well advanced at that time. One population, the eastern Pacific yellowfin, was already believed near the limit of productivity, thus fishing pressure on stocks would form the basis for future research.

The first of the meetings referred to above was organized by CCTA/CSA at Dakar in December 1960 (CCTA/CSA, 1960). Resolution 16 proposed an international convention for the conservation of tunas in the Atlantic specifically aimed at the West African area. Subsequently a Pacific tuna conference was held in Honolulu, August 1961 (Marr, 1962) and an Indian Ocean one at Mandapam Camp, January 1962, (Mar. Biol. Ass. India, 1964, 1967, 1969) followed by the "World Scientific Meeting on the Biology of Tunas and Related Species" organized by FAO at La Jolla, California, in July 1962 (Rosa, 1963). The proceedings of these meetings form the baseline texts for all subsequent work on tunas.

It was not until May 1966 at Rio de Janeiro that representatives of 17 nations drafted an Atlantic Tuna Convention. A review of the convention is given in Carroz and Roche, 1967. The International Commission for the Conservation of Atlantic Tuna (ICCAT) held its first meeting in Rome in 1969 and there are presently 12 member states. The ICCAT is unique in that it includes all of the Atlantic Ocean and adjacent seas and covers all tuna and tuna-like fishes (including billfishes but excluding mackerels and snake mackerels). In the short period from 1969 the Commission has been concerned principally with establishing the guidelines for its main aims - conservation and management. Thus emphasis has been primarily on the collection and compilation of accurate statistics of the tuna fishery and on stock assessment of the species. In particular, they have concentrated on those species causing immediate concern such as the yellowfin.

It is patently impossible to review for you here the wealth of scientific work that has been completed on tunas in the region since 1960. Indeed it is difficult to consider some of the work on just a regional basis except in the field of stock assesment. I will simply indicate the main types of work undertaken.

Initial scientific effort in West Africa was directed to the collection, compilation and analyses of statistical data on the developing tuna fisheries. ORSTOM(2) scientists at Dakar, Abidjan and Pointe Noire deserve great credit for the tireless way in which they monitored catches from the surface fishery, and also from longline catches from Japanese vessels, landed or transhipped at those ports. Using this data (from 1955 at Dakar and 1963 at Pointe Noire) they were able to develop information on yellowfin such as definitions of fishing effort in the area, biometrics, age and growth, etc. Exchange of information and ideas with tuna workers in the U.S. was excellent following the U.S. participation in the ICITA and the tuna oceanography surveys of that time and later.

Catch data on the Japanese longline fisheries are published annually by the Fishery Agency of Japan. Using this data, and also the data from West African sampling programmes, French and U.S. scientists have produced many papers and atlases on the distribution, relative abundance and possible migrations of tunas and billfishes in the tropical Atlantic, in particular on the stock of yellowfin exploited by the longline fleet. Other papers have used relatively sophisticated population dynamics approaches for prediction of yield-per-recruit estimates of Atlantic yellowfin stocks. Our Japanese colleagues at the Far Seas Fisheries Laboratory, Shimizu, have also produced a large number of papers on the biology and dynamics of the stocks of yellowfin and other species from the longline fishery, as well as relationships of the fishery with oceanographic conditons.

The Expert Panel for the Facilitation of Tuna Research established by FAO met in 1964, 1966, 1969 and 1971 (FAO, 1964, 1966, 1969a, 1971a). A working group of the panel meeting at Miami in 1968 (FAO, 1968) noted that the yellowfin stocks (mature fish) fished by the longline fleets in the Atlantic had been drastically reduced. A further increase in effort was expected only marginally to increase the catch and could probably decrease

(1) Inter-American Tropical Tuna Commission.

(2) Office de la Recherche Scientifique et Technique Outre-mer.

it. The West African surface fishery was based on small immature fish and this had apparently decreased recruitment to the longline fishery. The surface fishery could increase the total catch of yellowfin but if the fish size decreased in this fishery then there was certain to be a decrease in total catch from the two fisheries.

The 1970 ICCAT subcommittee on stocks noted more studies were still needed on age and growth, especially above 4 year old, and on migrations. There was a need for models analysing growth and mortality rates to assess effects on the yield-per-recruit for any combination of fishing rates in the different fisheries. The same group meeting in November 1971, concluded that the yellowfin fishery in the Atlantic was reaching, or had reached, the point where control of fishing effort and/or size of fish caught was desirable. As a result of a subsequent meeting at Abidjan in June 1972 (ICCAT, in press) and other work, the 1972 ICCAT Council meeting (ICCAT, 1973) recommended a 3.2 kg. minimum size of landing, with 15% tolerance by numbers, and decided to continue discussion of yellowfin catch quotas at the December 1973 meeting in Paris. A minimum size for skipjack was proposed, but no preparatory scientific work having been done, active discussions were postponed until 1973.

Other extremely important aspects of work on yellowfin, other tunas and billfishes have included the following topics:

(a) the distribution of eggs and larvae of tunas, which formed a major part of the U.S. tuna projects during and subsequent to the ICITA (Richards, 1969a; Richards and Simmons, 1971). These data coupled with fishery catch data resulted in the formulation of a hypothesis on yellowfin migration in the eastern Atlantic (Richards, 1969b);

(b) the food of tuna in the region has been thoroughly examined (Dragovich, 1969, 1970; Dragovich and Potthof 1972);

(c) the distribution and relative abundance of species has been outlined and correlated with oceanographic features. In particular, the surface yellowfin (and skipjack) fishery on the eastern Atlantic has been related to specific aspects of major oceanographic features such as the transitional zone fronts in the Dakar and Pointe Noire areas and to the Angola and Guinea Domes (Beardsley, 1969).

COASTAL PELAGIC RESOURCES

The principal species involved are the sardinellas (Sardinella spp), with also bonga (Ethmalosa fimbriata), chub mackerel (Scomber colias), horse mackerels (Trachurus spp) and scads (Caranx rhonchus, Decapterus spp, Selar crumenophthalmus) (figure 3). The flat sardinella (S. eba) is the more inshore of the two species and is usually found in low salinity waters with the main stocks from southern Senegal to Sierra Leone, Gabon to Angola and off the Ivory Coast. The round sardinella (S. aurita) is distributed in more saline waters than the previous species, and with the main stocks in the upwelling areas. Young of both species are mainly distributed inshore. The bonga is restricted to very shallow brackish waters with the important stocks in the truly tropical (non-upwelling) areas. Mackerel, horse mackerels and scads are most important in the area from Sierra Leone northwards, mainly over the outer part of the shelf.

Traditional canoe fisheries exist for sardinellas and bonga along the entire West African coast, but vary considerably from country to country. They are extremely important in Senegal (>25,000 m. tons/yr.) and Ghana (30-40,000 m. tons/yr: 74,000 in 1972).

There has been a rapid increase in small to medium sized purse-seiners based on the Ivory Coast and Congo (late 1950's), Ghana and Senegal (early 1960's) and Mauritania (late 1960's). Initially in the range 15-20 metres, but with new ones of 20-25 metres, the vessels are becoming more efficient with larger purse-seines, power blocks, acoustic equipment and better holding facilities. These purse-seiners normally fish over the local inshore continental shelf (<50 m.), but many are becoming increasingly mobile and following schools along the coast. In 1970 and 1971 the approximate landings of these vessels in Senegal, Ivory Coast, and Ghana were about 70-75,000 metric tons.

The industrial fisheries of the long distance fleets are concentrated mainly from Senegal northwards. These fisheries began on a large scale in the early 1960's with medium to large trawlers, using pelagic and bottom gear, but since 1969 with medium-sized purse-seiners fishing for large factory ships. The trawling fleets were principally from the USSR, Poland, German Democratic Republic, Bulgaria, Romania, Ghana, with the USSR predominating. Catches were initially for human consumption. The USSR introduced purse-seiners (converted trawlers) into the fishery in 1969 and by 1971 about half of their total pelagic catch of near 800,000 tons was caught by this method. About the same time Norway and South Africa commenced purse-seine operations in the area, using the catches (about 314,000 metric tons in 1971) for reduction to fish meal. The main species caught in this fishery are the horse mackerels, scads, mackerel and sardinellas. Species catch composition and fishery areas vary considerably during and between years; recently vessels have extended fishing out beyond the continental shelf.

The introduction of small purse-seiners into the sardinella fisheries in the 1950's, the exploratory pelagic fishing surveys of the USSR in 1957 and 1964 and the GTS catches of pelagic species prompted a demand in the region for increased scientific effort on coastal pelagic resources. A large part of the work of the fishery research unit in Ghana (UNDP/SF-FAO) was devoted to the sardinella fisheries. At the Abidjan symposium a major contribution was the review (Zei, 1969) of the life history of the sardinella species in the Gulf of Guinea, especially data collected since the FAO World Meeting on Sardines in 1959.

Implementation began in 1966-1968 of the FAO coastal pelagic resources projects for Senegal, Sierra Leone, Ivory Coast and the Congo, and also the Regional Fisheries Survey (RFS). A prime aim, especially of the regional project, was acoustic surveying, with accompanying experimental fishing, to determine the distribution and abundance of the resources, especially the sardinellas. Other aims were initiating (or continuing) egg and larval surveys, life history studies including age, growth and maturity, migrations, stock identification and assessment, local fisheries development and utilization, with some matching environmental observations. These surveys have been, or are, almost completed and the countries, the FAO and all the scientists involved are to be congratulated on the work accomplished, many of the results of which have already been published. Standardization of gear and methods, and excellent co-operation and co-ordination of activities is a prime cause of this achievement.

The facilities for surveys, such as the RFS, aimed at assessing relative and absolute abundance of stocks, were determined and sophisticated acoustic equipment (calibrated echo-sounders of various frequencies with time varied gain, storage oscilloscopes, echo-integrator) was purchased to meet these requirements and installed in the vessel(s). As expected, the Regional Fisheries Survey encountered many problems, mainly related to the sophisticated acoustic techniques being used for the first time in a tropical area on a sustained basis. Though the RFS did not achieve all its aims the experience gained is absolutely invaluable for all future surveys of this type in tropical areas. Information was obtained on the overall distribution of coastal pelagic species and on their vertical and horizontal movements, diel behaviour and the relative abundance of certain local stocks. Under perfect conditions, some estimates of absolute abundance were obtained for homogeneous single species layers of fish in small areas. Major points to be concerned about in similar future surveys are related to the identification and strength of targets, surveys in shallow water, the use of fixed or flexible grids and the time needed for calibration of equipment.

Some general comments can now be made on the migrations of sardinellas (figure 4) (FAO, 1971b). For example, in the round sardinella of the northern and southern transitional zones, the considerable seasonal migrations of the adult fish appear to parallel the coast and approximate the seasonal movement of the oceanographic fronts. This does not necessarily mean that the fish are always available to the fishery. For instance, in the period when the northern front is moving rapidly north (April to May), behaviour of the schools is erratic, their rate of migration can be as high as 30 nm/day and fish are rarely caught. The stock of round sardinella off Ghana is considered to make only limited lateral movements. There are considerable vertical movements in the round sardinella, with schools being found near the surface or just above the bottom in daylight and dispersing with other species and plankton into scattering layers in mid-depths at night.

The flat sardinella has a much more restricted movement. In the Congo larvae and juveniles found inshore appear to be the result of drift from spawning areas off northern Angola. Development takes place in Congolese waters with some slight movement offshore during the two years they are present there. Local exploitation takes place in this period, after which they disappear from the Congolese coast to reappear in the Angola fisheries some time later. A similar migration pattern may exist in the Senegal - Sierra Leone area. When cold upwelled water is present off the Ivory Coast the round sardinella appears to migrate into eastern Liberian waters.

Other scientific studies on sardinella include determination of maturity stages and fecundity, distribution and abundance of eggs and larvae, age and growth, and movements related to physiological states of the fish, moon phase, phosphorescence, etc. Statistical data from the locally based fleets is reasonable and permits determination of catch-per-unit effort estimates of varying kinds. For the canoe fisheries the statistical problem is more difficult and depends on periodical sampling surveys. For the long distance fleets the data are variable, but very good for the Polish vessels. Stock structure of sardinella resources is being investigated using morphormetric, biochemical, biological and catch data. The UNDP/SF-FAO projects have been responsible for most of the recent scientific work on sardinella and the USSR and Poland in particular on the other species, such as mackerel, horse mackerel and scads (not discussed here).

DEMERSAL RESOURCES

The demersal resources of the region are mainly restricted to the continental shelf, with very little of importance on the continental slope.

Many resource surveys of varying sizes,

intensity, and geographic area, using both research and exploratory vessels, were carried out before and concurrent with the Guinean Trawling Survey. However, few were carried out in the systematic manner of the GTS; such exceptions were those carried out by my colleagues in ORSTOM off Cameroon (Crosnier, 1964), Dahomey and Togo (Crosnier and Berrit, 1966), and by Longhurst off Nigeria (1965). It is inappropriate for me to enter into a long discussion of the GTS - the full 3 volume report having been published by OAU/STRC in 1968 (Williams, 1968). We were able to establish for 13 statistical areas between Cape Roxo and the Congo River, the catch rates (kg/hr), density (kg/ha.), and standing stock (metric tons) for each of eight depth intervals from 15-400 m. (figure 5). The overall standing stock (with many inshore areas already overfished) was about 956,000 metric tons with 60% (577,000 m. tons) between 15-50 metres and 40% (379,000 m. tons) between 50-200 metres. Some 58% of the total regional standing stock (551,000 metric tons) was found in the two northern-most areas - the Bissagos-Guinea Shelf - where the continental shelf is wide and comprises 38% (89,000 km^2) of the 233,500 km^2 total for the region. Gulland (1972), assuming half of the shallow water and all of the deep water stocks were lightly fished and the balance of shallow water stocks heavily fished, indicated the demersal fish potential of the region is approximately 300,000 metric tons.

The main characteristic of the demersal resources in this tropical area is the very large number and variety of species of fish (most of which appear short-lived) involved in the fisheries. The abundance of demersal stocks varies greatly from area to area along the coast, and appears to be maintained by the lack of any marked inter-area migration patterns. There are some inshore-offshore migration patterns depending on age, maturity and environmental conditions. The demersal resources are richest from 0-40 m. then decrease steadily until 70-120 metres where abundance increases again (though usually not as high as in the inshore zone), before a rapid decrease at the shelf edge (figure 6). The species composition of the inshore resources varies greatly according to the bottom substrate. On soft bottom the sciaenid (croaker) community is dominant with a specialized sub-community in low salinity estuarine waters. On hard bottom there is a sparid (seabream) sub-community. Offshore, on hard and soft bottom below the thermocline, there is another richer sparid sub-community; a few species are common to both sub-communities. Fager and Longhurst (1968) discussed in detail assemblages of West African demersal fishes determined by recurrent group analysis.

The principal commercial species of shrimp is the pink shrimp (Penaeus duorarum), large resources of which are found in inshore waters (to 60 metres) off the major river mouths and lagoon entrances which are the nursery areas for the species. Deep sea (royal red) shrimps (Parapenaeus longirostris, Aristeus varidens, Plesionika spp.) are found and exploited on the continental slope from 200-600 metres mainly off Senegal, Guinea and the Congo (figure 6). Reference must be made here to the work of Crosnier and de Bondy (1967) on the shrimp resources of the Gulf of Guinea.

The canoe fisheries exploit parts of the inshore demersal stocks using handlines, traps, set nets and beach seines. The trawling fleets mainly originated after World War II with old, small low-powered European style vessels (largely under 20 metres and 250 hp. and fishing trawls with headropes >25 metres). The small size of the vessels meant that the grounds exploited were those in shallow water close to the home port. With the richest stocks in the inshore zone, the incentive to go elsewhere was low, hence the drastic overfishing of these resources. The offshore stocks are only lightly fished in a few places. However, since the mid-1960's in countries with rapidly developing fisheries (such as Ivory Coast, Ghana Cameroon), larger (30-45 metres) and more sophisticated fishing units were being added to the fleets. The increase in size and horsepower of the local fleets and data from exploratory surveys, is permitting, or will permit, the exploitation of inshore stocks in areas between the main ports (some of which remain lightly fished), fishing in deeper water (70-120 metres) and the use of heavier gear in areas previously considered too rough.

The shrimp fishery is largely for export to the United States, Japan and Europe with mainly double-rigged shrimp boats (or converted fish trawlers). Starting in Nigeria about 1965, it had spread to all West African countries by 1971. About 100 vessels were working the region in 1972. Juvenile shrimp are taken in the lagoons and estuaries by local fishermen principally using traps, set nets, and seines.

The overfishing of the inshore stocks adjacent to the major ports had become obvious (reduced catches and catch per-unit effort and smaller size of individuals) well before the GTS and the Abidjan symposium. The few fisheries scientists based in the area were attempting to gather the basic statistical and biological data necessary for quantitative analyses of these localized stocks. The increasing interest in the fisheries of the region in the early 1960's, followed by resources surveys, such as the GTS, and the increased number of fisheries scientists trained in modern techniques, especially those of ORSTOM, brought new emphasis to the problems of management of the demersal stocks. This, despite the fact that the large-scale developments were in the field of pelagic species - tunas and sardinellas.

The Abidjan Symposium discussions showed that the Gulf of Guinea was probably the most completely explored region in the tropics as regards demersal resources. The next steps were obviously related to the collection of more accurate statistics on the fisheries (catch, effort, size composition) and the determination of parameters related to the life history and yield equation (age, growth, spawning, recruitment, mortality, etc.) of the major species involved. However, we are still lacking population dynamics models for the complex multispecies fisheries found in the tropical seas.

MANAGEMENT IN THE REGION

The Fishery Committee for the Eastern Central Atlantic (CECAF), was established in September 1967 by FAO and the first session held in Ghana, March 1969 (FAO, 1969b), the second at Casablanca in May 1971 (FAO, 1971c), and the third at Santa Cruz de Tenerife in December 1972 (FAO, 1973). The CECAF region extends from the Straits of Gibraltar to the mouth of the Congo River with a major division at lat. 20° N. (approximately Cap Blanc). There are currently 27 members of CECAF, including both local nations and expatriate ones fishing the area. In view of the existence of ICCAT, the CECAF has mainly restricted its activities to fisheries other than those for tunas and related species. Much of the early work of CECAF (as with ICCAT) has been involved in the collection of more accurate statistics for the region to allow better assessment of the state of the resources. The CECAF sub-committee on implementation of management measures reported in June 1972 (FAO, 1972a) on the need for a minimum mesh size of 70 mm. for hake and seabream throughout the CECAF area, plus other information of techniques for measuring meshes, chafing gear and possible effort limitations. There have been CECAF Working Parties on Regulatory Measures for Demersal Stocks, reporting in 1970 and 1971 (FAO, 1970, 1971d), and on Resources Evaluation in 1972 (FAO, 1972b). These Working Parties considered the status of the demersal and pelagic stocks in the light of present and expected exploitation levels, and discussed possible management measures, collection of statistics, future research.

It has been stated (Gulland et al, in press) that management measures can and should be applied on a national basis in the CECAF tropical areas for those fisheries remaining principally within national boundaries. Tropical inshore demersal fisheries for fish and shrimp, and coastal ones for pelagic species, such as bonga, can be placed in this category. As migrations of such species are restricted mainly to onshore-offshore movements, local management of such exploited stocks can probably be effective. In fact, such locally based scientific management is already in operation in several tropical West African countries. However, the pelagic resources surveys have indicated the need not only for national management, but regional co-operation in management of stocks such as the sardinellas.

Considering the newness of the CECAF, and also of the ICCAT, the progress made to date towards the effective management of living resources in the Gulf of Guinea must be considered reasonable, if compared with other areas of the world ocean. However, exploitation of the resources of the CECAF region has increased exponentially, and agreed and enforceable management measures are already required for some stocks in certain areas. A request was made by the FAO in 1972 to the UNDP for support of an international project for the development of the fisheries in the central-eastern Atlantic (similar to the Indian Ocean Fisheries Project). Although, it could not be financed at that time, a start may be made in the near future.

MISCELLANY

Several other events or items of importance relating to the marine resources of the eastern-central Atlantic must be at least listed:

(a) the work of the University of Miami Deep-Sea Biology Expeditions to the Gulf of Guinea, 1964-1965 (Inst. Mar. Sci. 1966);

(b) the 1964 CSA Zanzibar symposium on African crustacea (OAU/STRC, 1967);

(c) the Proceedings of the joint ICES/FAO Symposium held at Santa Cruz de Tenerife, March 1968, on the Living Resources of the African Atlantic Continental Shelf between the Straits of Gibraltar and Cape Verde (Letaconnoux and Went, 1970);

(d) the Blache, Stauch and Cadenat (1970) identification keys to the fishes of the eastern Atlantic between lat. 20° N. and 15° S. Originally started prior to GTS, they were expanded and draft copies prepared for that expedition. Later the work was again expanded, revised and published by ORSTOM in 1970. This contribution has proved invaluable for all fishery workers in the region;

(e) the Fish Resources of the Ocean compiled and edited by J. Gulland (1972) in which a complete section is devoted to the resources of the eastern Central Atlantic. The tunas, molluscs and crustaceans are considered separately on a world-wide basis;

(f) the section of the Cephalopod Resources of the World (Voss, 1973) on the eastern-central Atlantic indicates that in the tropical area the fishery is just beginning (25,000 metric tons of cuttle fish and 5,000 m.t. of squid in 1971).

For this resource the area is inadequately explored but the resource is thought to be considerable;

(g) the training provided by large regional activities such as the GTS, the FAO/UNDP(SF) regional and national sardinella projects, and bilateral fisheries programmes has been invaluable. Several scientists, both local and expatriate, have received higher degrees based on work in the region.

SUMMARY

You will realize from this discussion the great developments which have taken place in the fisheries of the tropical central-eastern Atlantic since 1960. This is also true of our scientific knowledge of the distribution, abundance and biology of the living resources themselves, and of the relationships of these resources with the environmental conditions of the region. That national, regional and international co-operation in marine science has advanced at a very rapid rate in the region, is evidenced, I believe, by the success of the many activities mentioned earlier. I would like to suggest that to date, perhaps more than most persons realize, this is due to the harmonious personal relationships established at all levels, but particularly among the younger scientists and administrators during the co-operative programmes of the 1960's. Even though we must be realistic and realize that management decisions are necessarily involved with policies other than the strictly scientific, there is no lack of communication between the individuals concerned.

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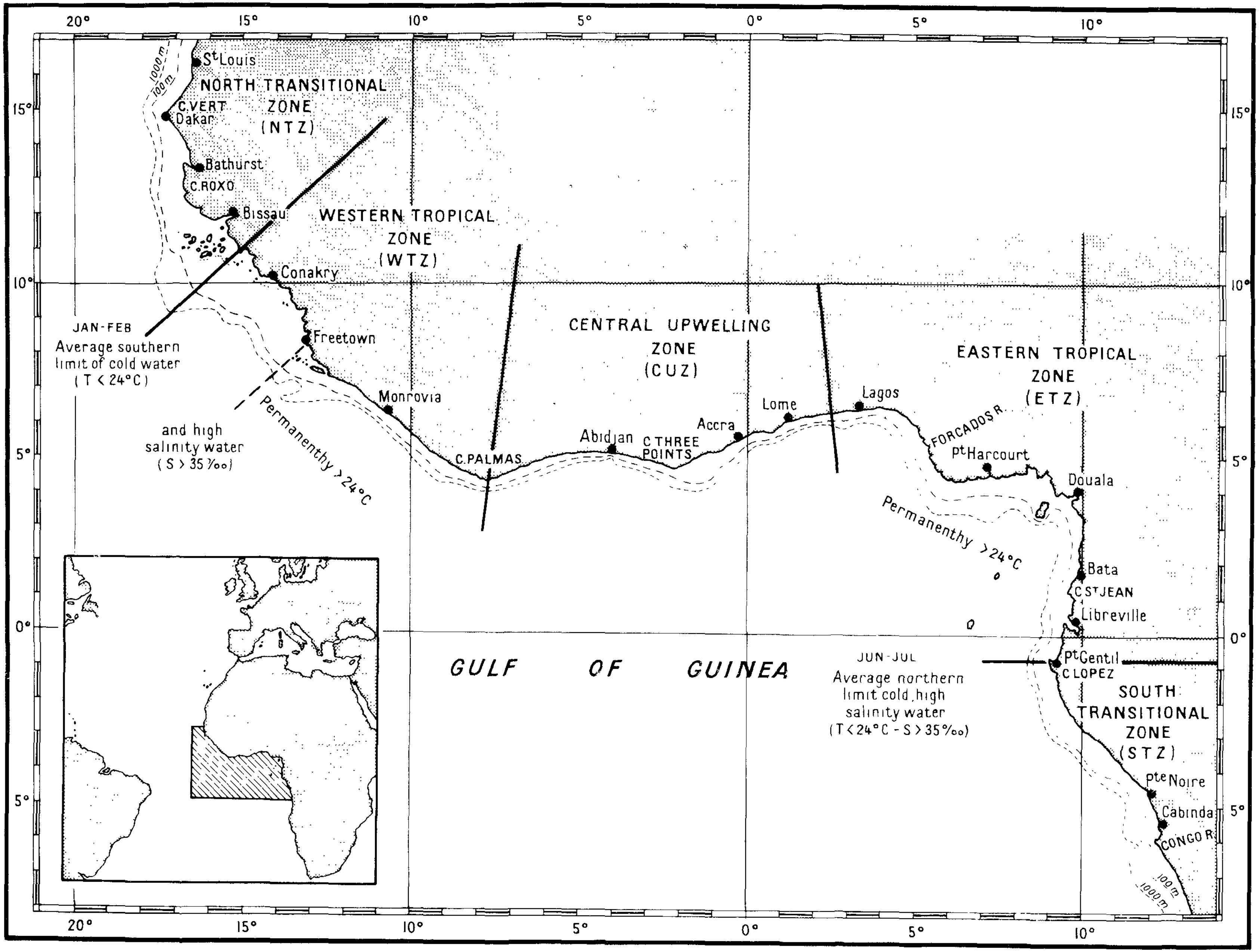

Figure 1. The oceanographic zones of the tropical West African coastal area (after Williams, 1968).

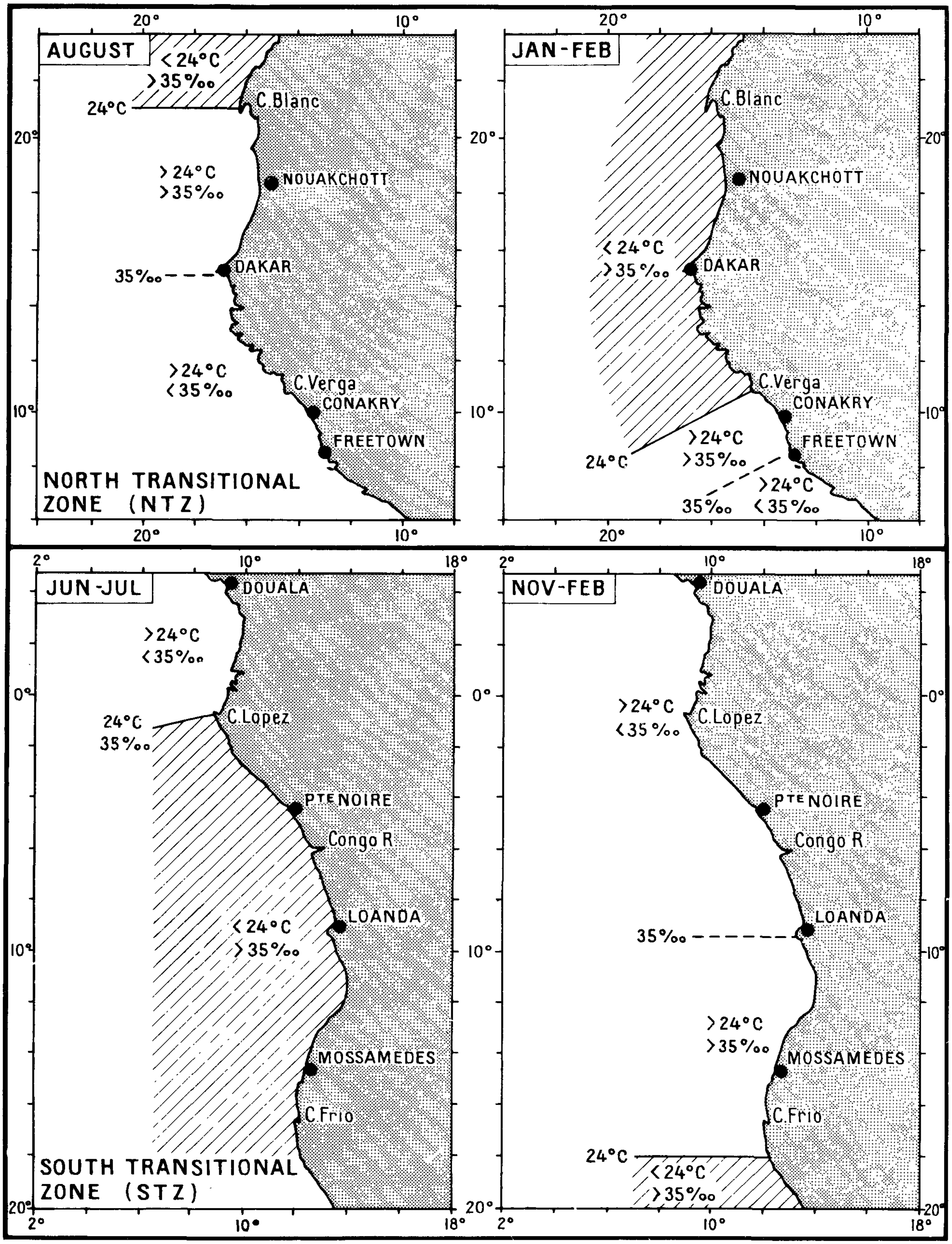

Figure 2. Seasonal movements of the oceanographic fronts in the North Transitional Zone and the South Transitional Zone of the tropical West African coastal area (after Williams, 1968).

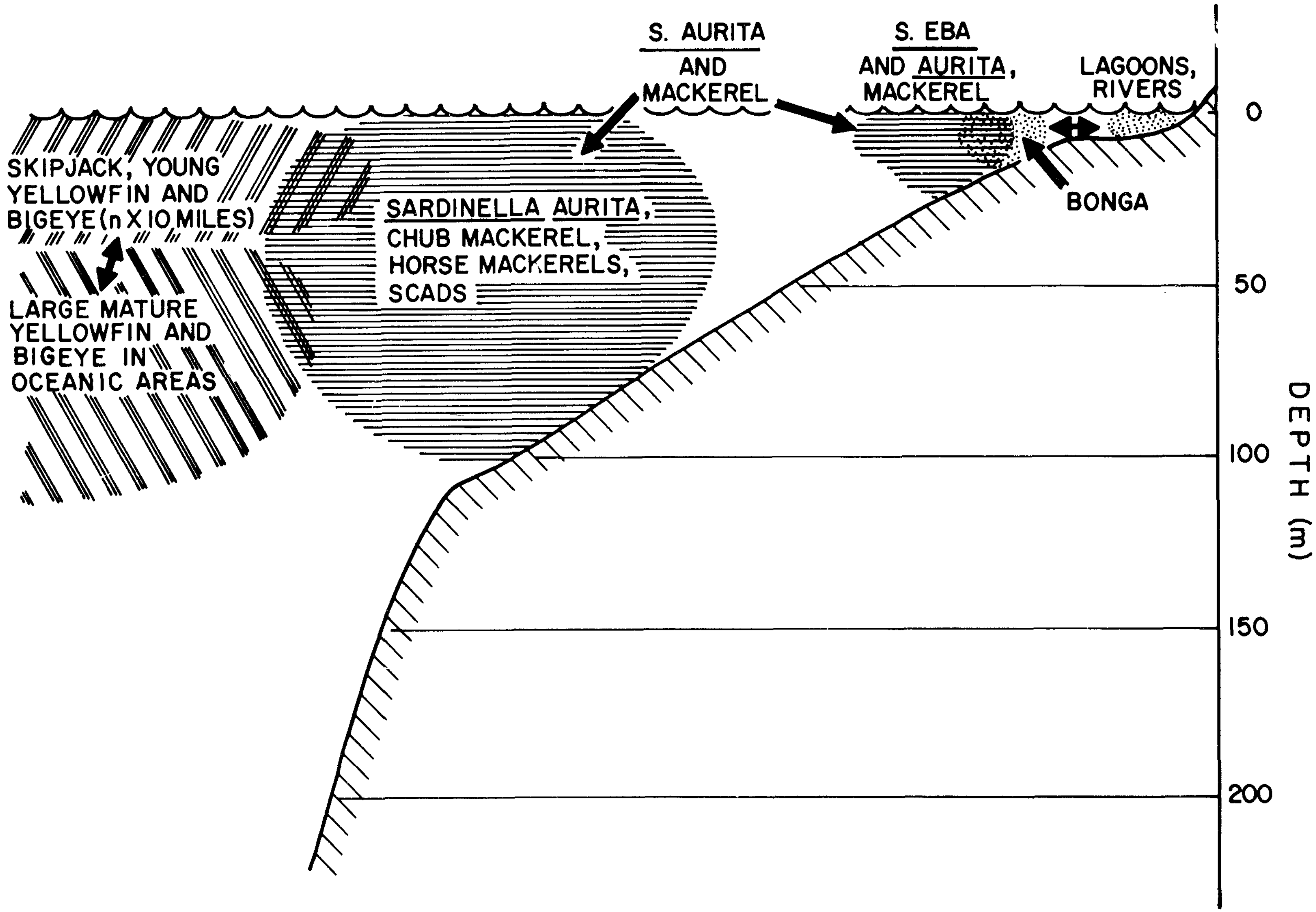

Figure 3. Distribution of important pelagic resources off the tropical west coast of Africa (after FAO, 1971b).

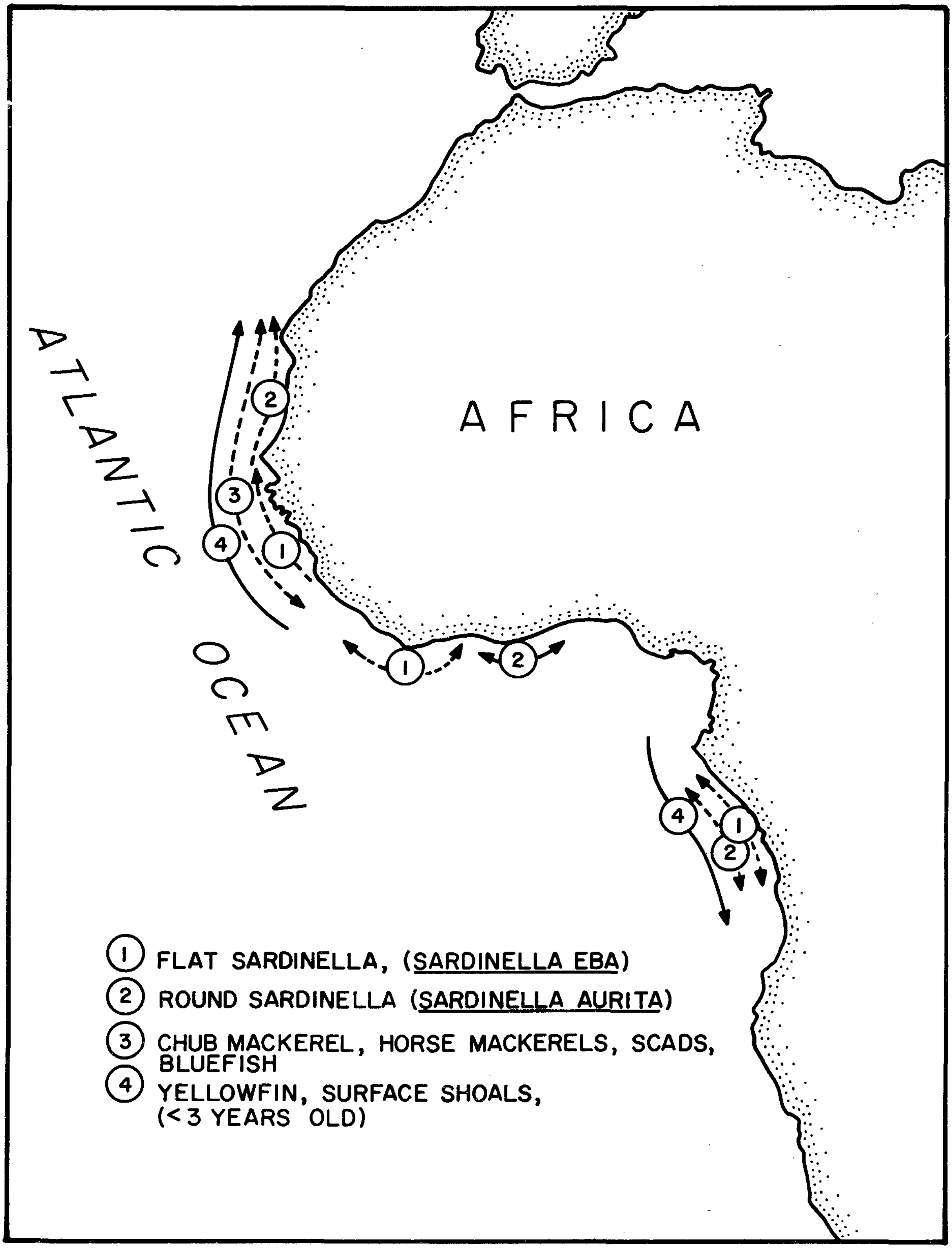

Figure 4. Migration patterns of important pelagic resources off the tropical west coast of Africa; known (——) migrations and assumed (--------) migrations (after FAO, 1971b).

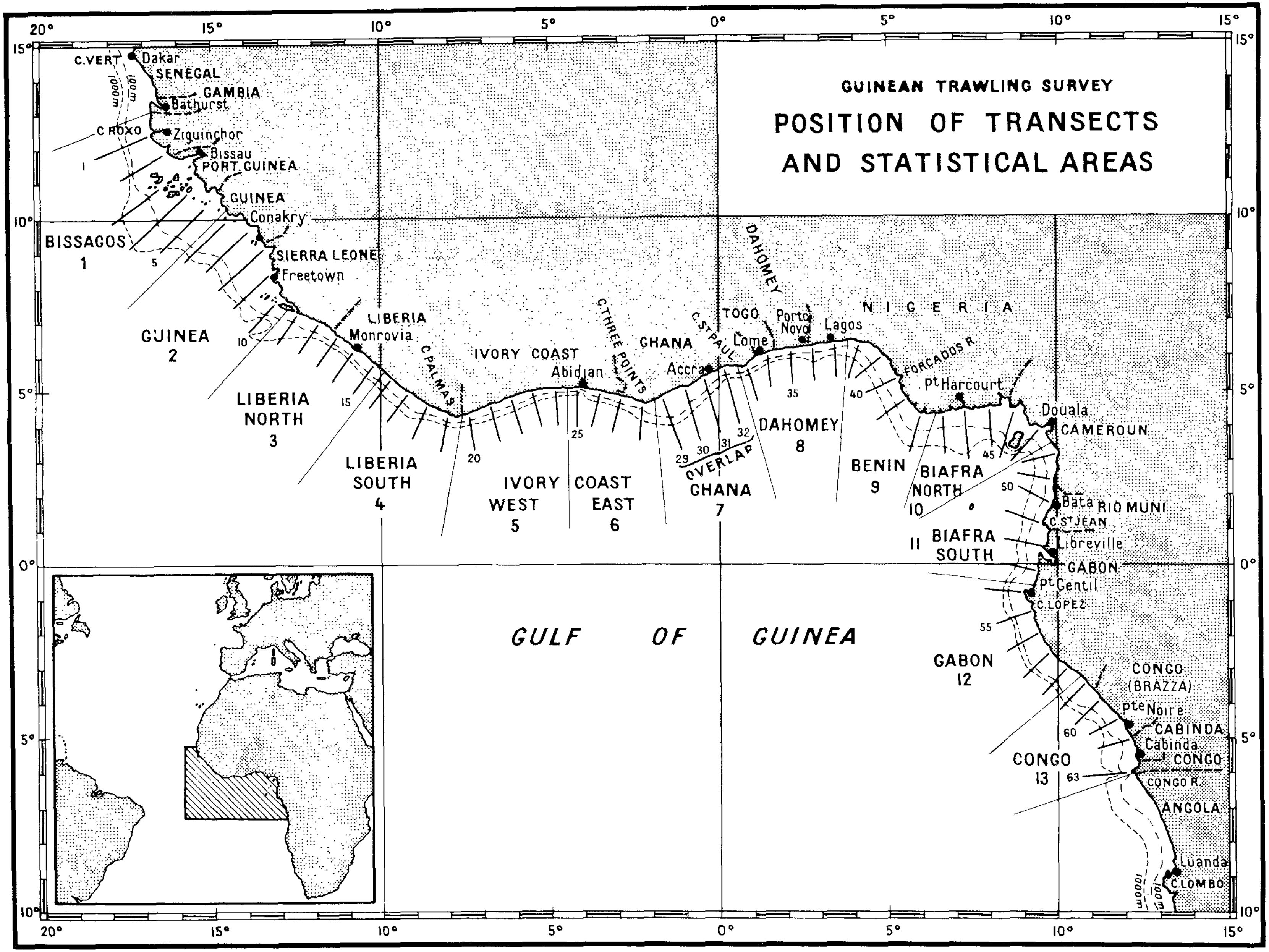

Figure 5. Position of transects and statistical areas used in the Guinean Trawling Survey (after Williams, 1968).

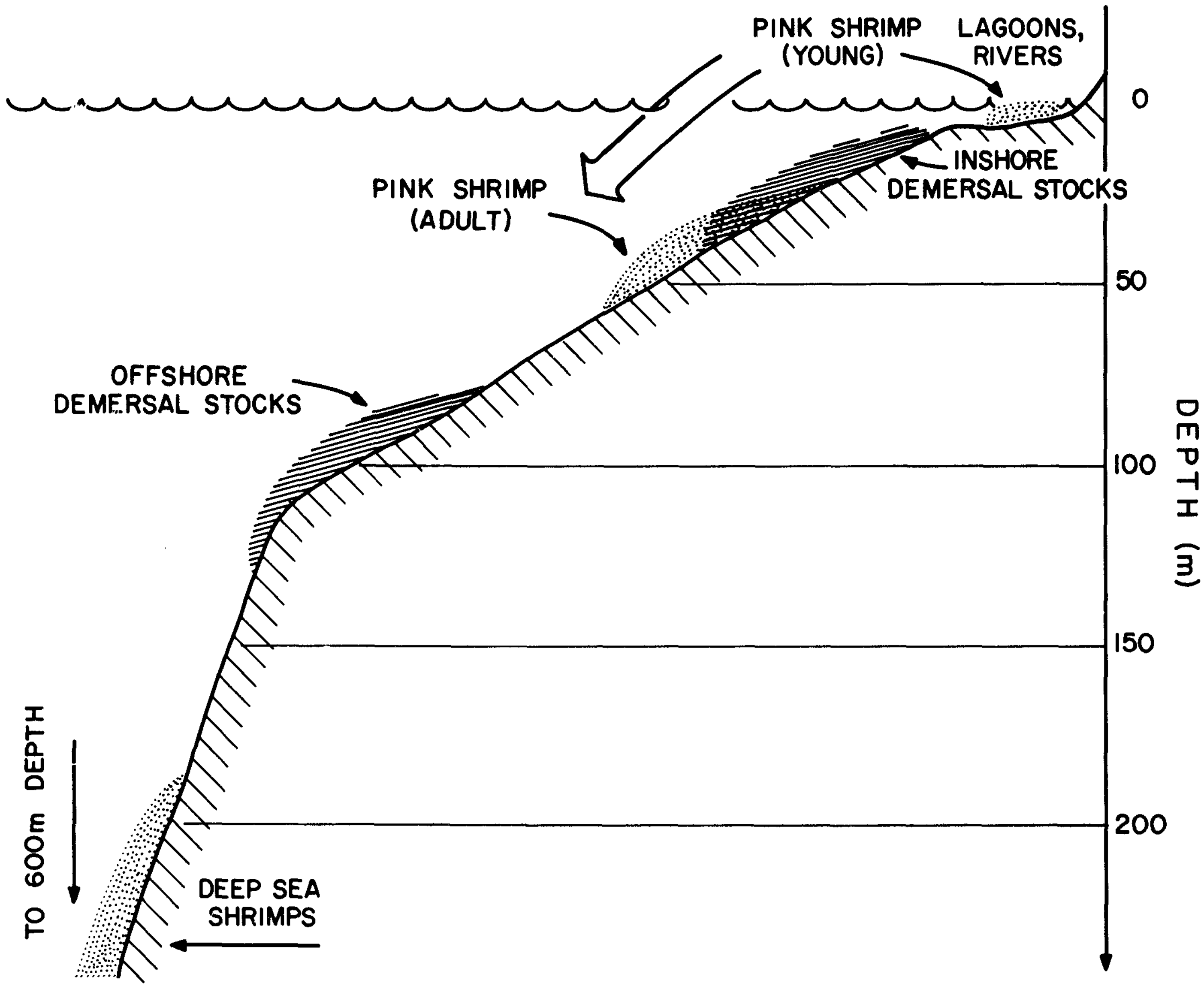

Figure 6. Bathymetric distribution of demersal resources off the tropical west coast of Africa (after FAO, 1971b).

DISCUSSION[1]

D. ROCHFORD

Dr. Williams, you mentioned in the beginning that there was a very close correlation in this area between the environmental features and the distribution of the fish stocks. I wonder whether you could indicate whether it will be possible in the future to utilize effectively this information for a management policy or how do you envisage that management policy is going to make use of environmental oceanographic information?

F. WILLIAMS

I am not sure, Mr. Rochford, that I can entirely answer your question. I am afraid that I have been out of touch with the West African area for a long time but I know that, particularly, in the tuna fisheries for example, the movement of the oceanographic fronts off the Senegal and Mauritania coasts and off the Congo River and their relationship with the fisheries are quite dramatic. However, I do not see how we can put this into a management context at this time.

O. ØSTVEDT

I would like to ask Dr. Williams a question regarding the Guinean Trawling Survey and the ships' time allocated for the survey. I am thinking particularly about whether the number of transects and the trawling stations were sufficient to get a fair picture of the fish abundance. Do you think that in the future planning of a similar survey you would need more ship time or whether one should rather allow time to work together with commercial vessels in such a huge area? Also, have you had any chance to compare the results obtained with the latest fisheries development in that area?

F. WILLIAMS

First of all one never has enough ship time. In this particular case we had 63 transects of eight stations each, which were repeated during two periods of the year corresponding to the major changes in the environment. I think that if I was asked to do the survey again today, I would not have more than 63 eight-station transects. Thus the answer to your question is: No, I would not increase the number of stations if I did it again. I am entirely satisfied that by chance we appear to have picked the right number.

In reply to your second question, I think John Gulland in his Fishery Resources of the Ocean indicated that, at least in the Nigerian area, our estimates of the total standing stock were unbelievably close to the estimates made by Longhurst several years earlier with different vessels, different equipment and with about the same density of stations. This was allowing for the exploitation which had taken place between Longhurst's surveys and our own surveys. I think one of the problems of multi-station multi-vessel surveys such as GTS is the calibration of the fishing power of the vessels. We worked on this for over one month in each survey period and, fortunately, were able to show there was no significant difference in the catching power of the vessels at any given depth or geographic location.

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(1) Names and titles of speakers are found at the end of the publication.

Dr. Emery is Senior Scientist with the Woods Hole Oceanographic Institution, United States of America. He has been involved in geological and geophysical research for the past three decades. He has written extensively about marine geological and geophysical phenomena of the oceans of the world including the Mediterranean Sea, Dead Sea, Persian Gulf, Continental Margins of Eastern Asia, and more recently, as he will discuss with us here today, the Continental Margin off West Africa. He participated in the 1972 and 1973 R/V "Atlantis II" cruises to the mid-Atlantic ridge and to the entire western African Continental Shelf and adjacent regions. These cruises were a part of the International Decade of Ocean Exploration. The research activities under his direction involved seismic reflection, seismic refraction, geomagnetism, gravity, and other types of measurements to provide information about the composition and structure of the ocean floor. One of the primary purposes for seeking this information was to provide a basis for determining the origin and the history of the Continental Margin of Africa as it relates to the adjacent ocean floor and to other continents.
(Biographical note by the Chairman, Dr. T. S. Austin)

REVIEW OF THE RESULTS FROM THE EASTERN ATLANTIC CONTINENTAL MARGIN PROGRAMME OF THE INTERNATIONAL DECADE OF OCEAN EXPLORATION*

K. O. Emery
Woods Hole Oceanographic Institution

BACKGROUND

It is a pleasure to give one of this series of Brunn Memorial Lectures, as I knew Anton F. Bruun well during his last 15 years and because the track of his R/V ATLANTIDE off western Africa in 1945-1946 was repeatedly crossed by our R/V ATLANTIS II during 1972-1973. Although the names of the two ships are similar, their work was rather different, as most of the geophysical equipment aboard ATLANTIS II had not even reached the stage of a gleam in an inventor's eye at the time of the ATLANTIDE cruise. This equipment includes a digital seismic reflection profiler, vibrating-string gravity meter, magnetometer, satellite navigator, and five computers for processing data and plotting the results aboard ship in both map and profile form.

It also is proper that this talk is before the Intergovernmental Oceanographic (though Bruun would have preferred Oceanologic) Commission, because the impetus for the programme came from the Scientific Committee on Oceanic Research (SCOR), an arm of the IOC. At the ninth general meeting of SCOR in La Jolla, California, during June 1968, Working Committee 31 was appointed to arrange a symposium on the Eastern Atlantic Continental Margin. This symposium was held at Cambridge, England, during March 1970 under the sponsorship of SCOR, and it was attended by about 250 invited participants from 20 nations, representing universities, geological surveys, oceanographic institutions and industry. Twenty-eight talks were given by nearly 100 authors from many of the nations bordering the eastern Atlantic Ocean, with results published later in four proceedings volumes (Delaney, 1970-1971). At the end of the symposium there was much discussion about the possible means for conducting a comprehensive study of the continental margin, particularly off western Africa, with organizations of the United Kingdom, France, Germany and the United States co-operating. One result was the funding of geophysical studies of the region by the International Decade of Ocean Exploration through the Woods Hole Oceanographic Institution.

PROGRAMME AND FACILITIES

The programme was designed to learn (1) the date and manner by which Africa became separated from South America and North America, (2) the subsequent history and development of the African continental margin and the adjacent deep-sea floor, and (3) to locate possible economic mineral deposits off the coast. Extensive co-operation of scientists from African and other countries (Emery, 1971) was involved, as well as the integration of data from previous cruises of ships from Woods Hole Oceanographic Institution and from other organizations in the United States, South Africa, France, and Germany. This four-year programme was funded in March 1971, with the first nine months devoted to assembly of background information and construction of a new geophysical system heavily based upon shipboard computers. The first half of 1972 was spent in work aboard R/V ATLANTIS II (figure 1) mainly between Port Elizabeth (South Africa) and the Congo River. During the first half of 1973, the work was continued from the Congo to Lisbon (figure 2). Altogether the ship was engaged for 334 days, of which 293 were spent at sea. The second half of each year was for further processing and distribution of the shipboard data. All of 1974 was set aside for completion of publications.

Continuous seismic reflection profiles were based upon an airgun source, one or two guns fired automatically at 10-second intervals and releasing 1,500 to 2,000 pounds per square inch of air from 10 to 300 cubic inch chambers. Echoes from the bottom and sub-bottom were detected by two hydrophone streamers, amplified, digitized,

* Contribution No. 3218 of the Woods Hole Oceanographic Institution.

and recorded on the ship (figures 3 and 4). The same source also was used for refraction measurements, with the signals received by an expendable sonobuoy that radioed the information to the ship for recording. Gravity was measured with a vibrating-string gravity meter, and the results were computed and plotted as Bouguer and free-air anomalies. Total magnetic field was derived from a proton precession instrument, digitized and plotted as anomalies with respect to the regional magnetic field. Plotting of all of these geophysical parameters was automatic, with the computers adjusting both profiles (figure 5) and map plots according to positions obtained with a satellite navigator.

In addition to the geophysical data, other data that did not require the ship to stop were obtained either continuously or at regular intervals. These included temperature, salinity, colour, suspended sediments, chlorophyll content, and phytoplankton in the surface water. Also obtained were measurements of wind and waves, approximate currents from dynamic topography based upon temperatures from expendable bathythermographs, and counts of sea birds and of larger zooplankton and nekton that could be seen from the submerged bow chamber.

The following totals for geophysical and other data were recorded:

95,800 line km of continuous profiles of 3.5 khz bathymetry,
95,600 line km of continuous profiles of gravity anomalies,
93,700 line km of continuous profiles of magnetic anomalies,
68,100 line km of continuous profiles of seismic reflection,
276 radiosonobuoys for seismic refractions and low-angle reflections,
1,534 samples of suspended matter with surface temperature and salinity,
938 expendable bathythermographs,
650 measurements of wind, swells, and water colour,
87 bottom samples from the continental shelf.

DISTRIBUTION OF DATA

Essentially all of the geophysical data are transmitted to the World Data Centres through the United States National Marine and Solar-Terrestrial Data Center within about six months after the end of the cruises; seismic refraction measurements require a little more time for processing. The data are in the form of profiles compiled into atlases and also as microfilms of the original records. The atlases (Uchupi and Emery, 1972) have the advantage of simplicity of presentation for use by organizations having no computer facilities, and so copies of them are sent directly to the governments and many scientists in each of the west African countries and to interested scientists elsewhere in the world. Copies of the microfilms and eventually of the digital magnetic tapes may be ordered by those who need them from the U.S. National Marine and Solar-Terrestrial Data Center at nominal cost. In addition, copies of the base maps of ocean-floor topography needed for the shipboard programme were compiled into an atlas (Uchupi, 1971) and distributed in the same way as for the geophysical profiles. Copies of all other manuscripts containing data of particular interest to west African countries are distributed to these countries and to others in the form of multilithed reference reports six to twelve months prior to their publication in standard scientific journals.

Many results became evident aboard ship during the construction of maps showing regional variations in gravity anomalies, magnetic anomalies, depth to structural discontinuities, and thicknesses of sediment between the major acoustic reflecting horizons. Some modifications and improvements to these maps occur through the later addition of data from radiosonobuoys, records from other ship traverses, and further considerations of regional geology.

Because the mass of data is so large we decided to concentrate in turn upon sections of the Eastern Atlantic Continental Margin (figure 6) and to prepare each in turn for publication. The first section to be completed is that off south-eastern Africa, where the main features are the Agulhas Fracture Zone, the ancient Orange River delta, and the Walvis Ridge. The second unit is the eastern Gulf of Guinea that is dominated by a long belt of diapiric structures associated with the deltas of the Niger and Congo rivers. The third is the main Gulf of Guinea, which is unique for its numerous fracture zones. Fourth is the large area off north-western Africa, where the main features are the large sedimentary basin off Mauritania and a belt of diapirs off Morocco.

Additional more detailed reports, on smaller areas (such as for the Congo Canyon - Shepard and Emery, 1973) and less detailed ones for the entire eastern South Atlantic Ocean are in various stages of completion. Among the more detailed studies are doctoral dissertations by cruise participants from the Congo, France, Portugal, South Africa, Spain, United Kingdom and the United States. Clearly, still other workers will be able to incorporate data from the ATLANTIS cruises into studies now underway or ones of the future, such as those to be derived from the Deep Sea Drilling Project that is scheduled for the South Atlantic during 1975.

The results for water measurements are less detailed and can be reported in terms of larger areas. Those for the 1972 cruise were presented by Emery, Milliman, and Uchupi (1973), and a similar report for the 1973 cruise will appear during early 1974. Again, later more detailed studies can include data from the ATLANTIS cruise. An example is a study of the suspended sediments in part of the Gulf of Guinea by Bornhold, Mascle, and Harada (1972). Results of analyses of sediments mainly from the continental shelf also shall be published for both large regional and smaller local areas, probably by the middle of 1974.

SOME RESULTS OF ECONOMIC INTEREST

Only two products of economic value are obtained from the ocean off western Africa: petroleum and fish. During 1971 the petroleum production from west African nations totalled 87 x 10^6 tons of oil and 14 x 10^9 m^3 of gas - almost entirely from Nigeria, Gabon, and Angola. These represent 32 and 41 per cent of total production in all of Africa during 1971 (Albers et al., 1973). About 30% (or 26 x 10^6 tons) of the west African oil was produced from offshore wells even though offshore production began only in the late 1960's. An unknown but probably very small percentage of the gas was from offshore, the low production corroborating the shipboard observations of considerable wastage by flaring. As the total use of petroleum products by all west African countries during 1971 amounted to only 21 x 10^6 tons (Southard, 1973), three-quarters of the oil that was produced in the region was exported, providing revenue for the producing countries. A mineral resource that is frequently mentioned in popular literature is diamonds from South West Africa. In fact, however, this offshore diamond mining was conducted at a loss and it now has been discontinued.

The second resource from the ocean is fish. The marine catch from off western Africa totalled 2.4 x 10^6 tons (live weight) during 1971 (90% of which was from Angola, Ghana, Morocco, Senegal and South Africa), a 50% increase over the 1961 catch according to Anonymous (1972). The total value of oil and gas produced during 1971 in the west African countries is estimated at about U.S. $2,000 million, and the value of the marine fish at $200 million. An additional 2.5 x 10^6 tons of fish is caught by ships of other nations (chiefly Japan, Norway, Spain and USSR) and landed elsewhere than in western Africa. These statistics show that the chief opportunity for increasing this region's income from the ocean is through the discovery and exploitation of new petroleum resources from their offshore regions.

Some results of the ATLANTIS II cruises bear upon new potential economic resources even though the cruises were designed mainly to learn about the relationship of Africa to the floor of the Atlantic Ocean and to the continents on the opposite side, and to investigate the general composition, structure, and origin of the continental margin. Broad-scale basic research nearly always produces unexpected economic benefits. An illustration of this is provided by figure 7, a summary of the total thickness of sediments atop oceanic and continental basement.

This map reveals the presence of large basins containing a more than 4 km. thickness of sediments in the St. Francis Basin (south of South Africa), at the mouth of the Orange River (west of South Africa), adjoining Walvis Ridge (west of South West Africa), in a belt associated with the Congo and Niger rivers (off Angola, Zaire, Cabinda, Congo, Gabon, Equatorial Africa, Cameroon, Nigeria, Dahomey, Togo and Ghana), and in a belt along north-western Africa (off Senegal, Gambia, Mauritania, and Spanish Sahara). Sediments are not only thick, but they contain many structural features suitable for oil and gas traps, and their positions off major rivers suggest a high content of organic matter, the starting substance for petroleum.

In addition, the work outlined three belts of diapiric structures (figures 4 and 7) similar to those in and near the Gulf of Mexico, from which are produced about one-tenth of the United States' petroleum. One belt is off Angola, Zaire, Cabinda, Congo and Gabon (Emery, 1972) and parts of it extend onshore where they are the sites of all the oil that is produced from these countries. Another is off Nigeria, and the third is off Morocco (with possible extensions off Spain and Portugal), from none of which is oil presently being produced. All of the diapir belts and all of the sediment-filled basins occur partly beneath the continental shelf (and thus are capable of production after the completion of more detailed geophysical surveys), but most of their areas lie in deeper waters and probably incapable of production for a decade or two.

Highly speculative is the possible future production of methane gas from deep-ocean features, discovered and reported (Emery, in press) for the first time during the ATLANTIS II cruises. The features are revealed on the 3.5 khz. recordings (that basically serve as depth records) as a series of alternating triangles (figures 8 and 9), light ones containing few internal reflections and having their bases upward and convex, and dark ones containing many internal reflections and having their bases downward. Certain reflecting surfaces can be traced throughout a long series of triangles. The poorer internal reflections and the convex upward base of the light triangles are believed to result from cementation of the sediments to a depth of less than 50 metres below the bottom, a cementation that may be due to gas hydrates - a sort of ice composed of gases at high pressure and low temperature. If the features really consist of gas hydrates (and methane is the most likely available gas), shallow penetration of the ocean floor by drilling may permit easy reduction of pressure and consequent production of gas. Note that the pagoda structures lie on the continental rise and the abyssal plains (figure 9), mostly far beyond the 200-nautical mile limit of national jurisdiction over ocean-floor resources that presently is popular at the United Nations.

Lastly, and rather different, is some speculation about potential fishery resources based on the routine collection and analysis of surface waters for their temperature, salinity, colour, suspended matter, and the observation of associated birds. Support was provided by measurements of chlorophyll and phytoplankton, and by observations of larger zooplankton and nekton from the bow chamber of the ship during the 1973 cruise. Results are rather similar to the more detailed study of just the Gulf of Guinea by Zeitschel (1969) presented at a Unesco symposium.

Our data outline areas of coastal upwelling and river discharge and of offshore divergence (figure 10), in all of which primary productivity of phytoplankton can be expected to be great and consequently in which zooplankton and nekton also should be abundant. In these areas were noted schools of fish some of which were tuna that broke the surface. Fishing boats were so abundant in the areas of coastal upwelling that careful manoeuvring was required for ATLANTIS II to pass without interference or possible loss of her trailing geophysical detector cables. We noted rather abundant large tuna in the divergence just south of the equator, but saw very few boats. Perhaps this fishery is close enough to the many countries that border the Gulf of Guinea to justify further exploitation. Most of the fishing in these countries is by short-range boats and canoes that presently cannot reach this area of divergence.

INTERNATIONAL PARTICIPATION

One of the objectives of the IDOE is the transfer of technology and knowledge to developing nations, and so every effort was made during six to eighteen months prior to the cruises to interest and invite participants from African governments of the west coast. Only two countries were not contracted (Togo and Gambia), but only because of their very small size, probable lack of interest, and our lack of contacts within them. The final list of actual shipboard representatives is as follows:

AFRICA (19 people)
- Congo: 1
- Ghana: 6
- Senegal: 1
- South Africa and South West Africa: 11

EUROPE (13 people)
- England: 3
- France: 3
- Germany: 2
- Israel: 1
- Portugal: 2
- Spain: 2

SOUTH AMERICA, CENTRAL AMERICA, CARIBBEAN (9 people)
- Argentina: 1
- Brazil: 6
- Guatamala: 1
- Jamaica: 1

ASIA (1 person)
- Taiwan: 1

NORTH AMERICA (13 people)
- United States (other than WHOI): 13

It is unfortunate that scientists from more African countries did not participate. In at least three instances this is attributed to various administrative difficulties within the governments. In spite of incomplete shipboard participation from West African countries, permission to work in territorial seas was received from all except two countries to which requests were directed: Dahomey and Guinea. Dahomey has only a small coastal frontage, but Guinea claims a territorial sea 130 miles wide that had to be bypassed.

The Africans who participated in the cruises were interested in learning something about the geology of the West African continental margin and about the modern technology of shipboard research. Those from South Africa already had considerable information from their own shipboard operations that they wished to supplement by additional data mostly from areas farther from the coast.

Representatives from half of the six participating European countries (England, France, and Germany) were aboard to compare and supplement results from their own previous cruises with the results from ours. Most of them, plus the representative from Israel, also wished to see the functioning of our geophysical equipment, at least partly in order to be able to consider possible modifications to their own equipment.

The representatives from countries of South America, Central America and the Caribbean Sea were primarily interested in being able to study and compare the geological structures off Western Africa with those of their own countries. This was especially true of the Brazilians, whose country is actively supporting and co-operating in a joint Brazil-Woods Hole study of the Brazilian continental margin. Those from Jamaica and Guatemala were aboard also to see at first hand the shipboard operations so as to aid their planning of a possible future joint Caribbean-Woods Hole study.

The single Asian was present to learn some of our methods for possible transfer to Taiwan's R/V CHIU LIEN. This ship (the former R/V GERONIMO of the former Bureau of Commercial

Fisheries in Galveston) was lent to the Institute of Oceanography, Taiwan National University by the United States Department of State in 1969. Many contacts with Taiwan oceanographers have resulted from my participation in ECAFE work in that region.

Shipboard participants included those from nine organizations in the United States other than WHOI. Those from the Office of the International Decade of Ocean Exploration, Naval Oceanographic Office, and Office of Naval Research were there to view the methods of operation. One from Florida Institute of Technology and two from Massachusetts Institute of Technology wanted to obtain some shipboard experience as graduate students.

The others were aboard for specific work: Middlebury College, Vermont - to collect atmospheric dust samples; Massachusetts Institute of Technology - to enhance the seismic records by digital processing; Scripps Institution of Oceanography - to study the Congo Submarine Canyon; University of Delaware - to quantitatively collect atmospheric dust samples and to measure the content of chlorophyll in surface waters; and the University of Rhode Island - to continue previous work between Monrovia and Dakar.

It was a pleasure to have the shipboard association and co-operation of the many representatives from other countries and organizations. They learned from us, and we learned from them to our mutual benefit. I strongly recommend similar participation, especially from adjacent coast countries, in other oceanographic programmes that are organized in other parts of the world.

This research programme is a good example of the benefits of freedom of scientific research in oceanography. The sponsor, funder, and organizer of the work (the United States and its scientists) learned much about the origin of the South Atlantic Ocean. The African coastal States, especially those which sent scientists to participate in the cruise, learned during or soon after completion of the cruise, the results that have potential economic benefit to them. Countries from which we were not able to obtain permission to enter their territorial waters, of course, learned nothing about the economic potential of their continental margins. This is particularly unfortunate as such countries usually do not have the technological ability to learn about these potential benefits for themselves.

ACKNOWLEDGEMENTS

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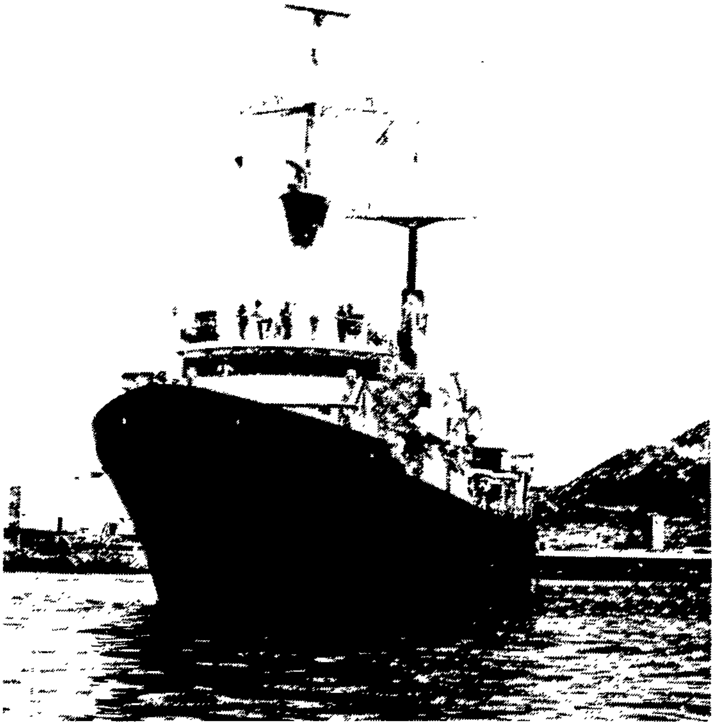

Figure 1. R/V ATLANTIS II at Las Palmas, Canary Islands

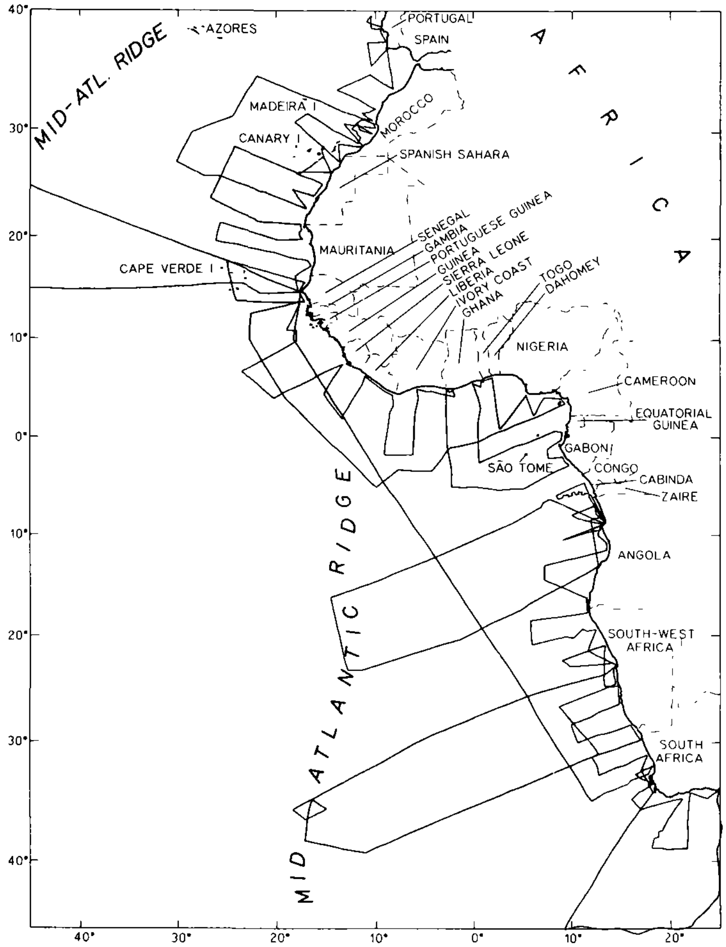

Figure 2. Plot of traverses made by R/V ATLANTIS II during 1972-1973 off Western Africa.

Figure 3. Seismic Center aboard R/V ATLANTIS II.

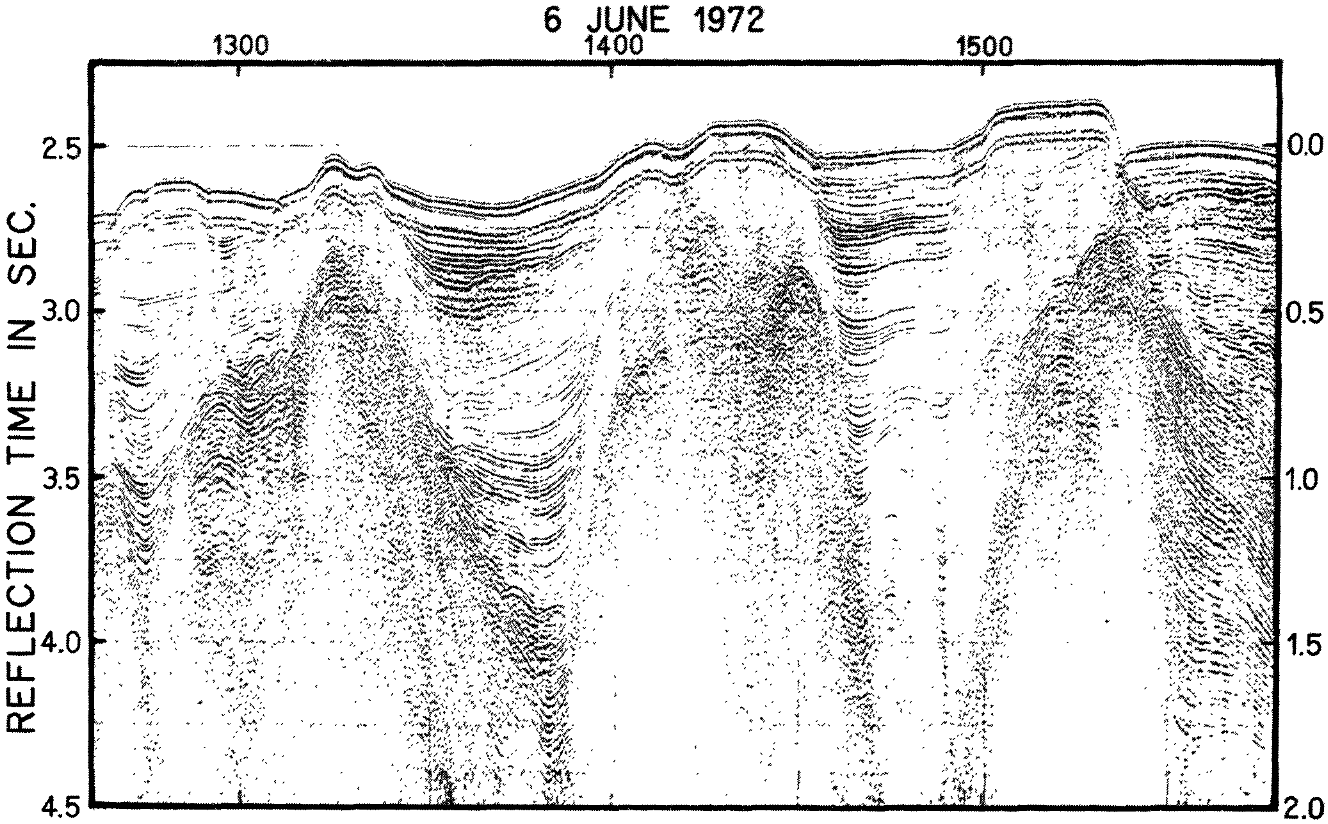

Figure 4. An example of a continuous seismic profile showing salt diapirs off Angola.

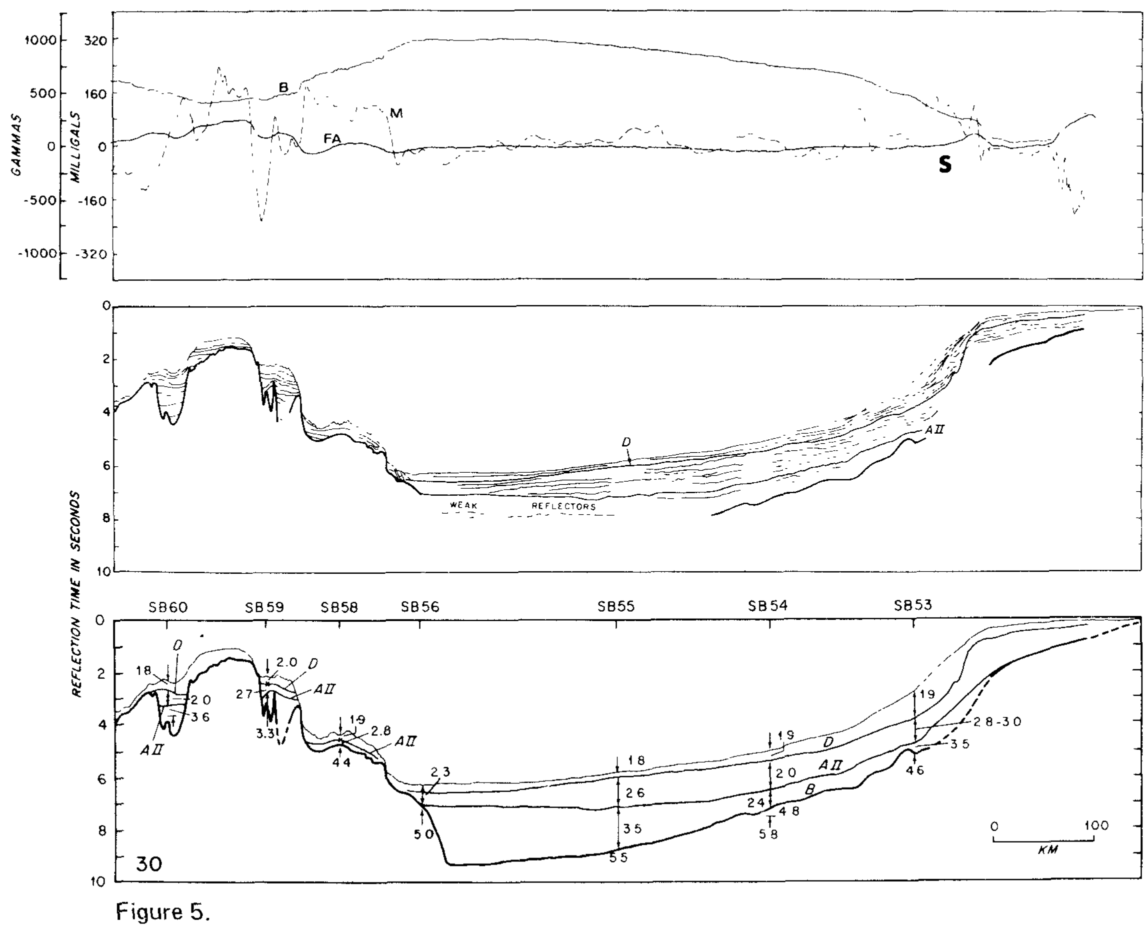

Figure 5.

Typical geophysical profile-off Walvis Bay. The top panel shows the Bouguer and free-air gravity anomalies and the magnetic anomalies. The middle panel has the interpretation of seismic reflection measurements expressed in seconds of reflection time. The bottom panel is an interpretation of the major reflecting horizons based upon seismic velocities from radiosonobuoys as well as upon the top two panels with depth expressed in km by Elazar Uchupi.

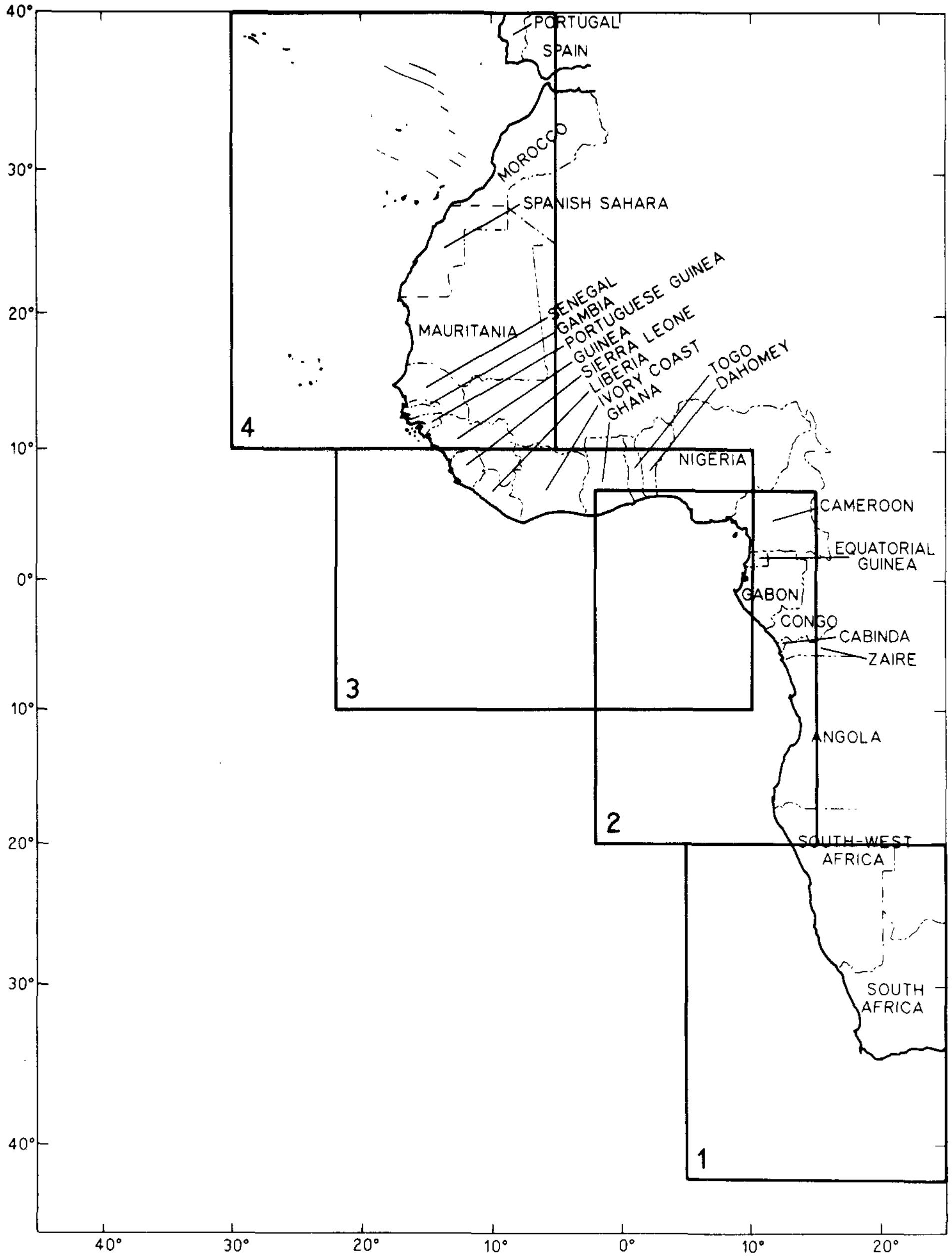

Figure 6.

Subareas selected for detailed geophysical analysis and publication.

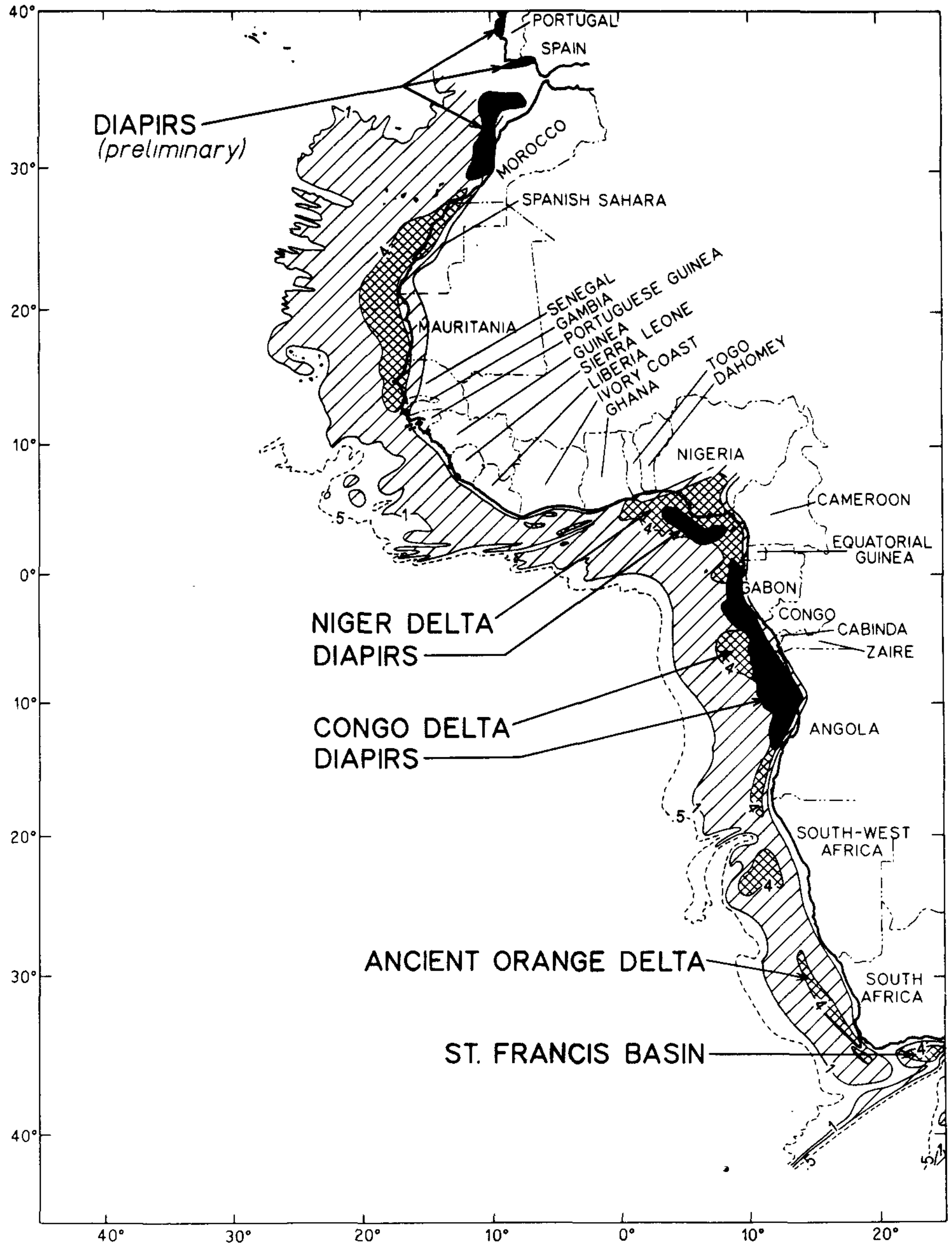

Figure 7.

Thickness of total sediment above continental and oceanic basement expressed in km. The areas of major promise for petroleum resources are indicated for the large sediment-filled basins and the belts of diapiric structures (salt domes). Note that most of these areas lie beyond the continental shelf.

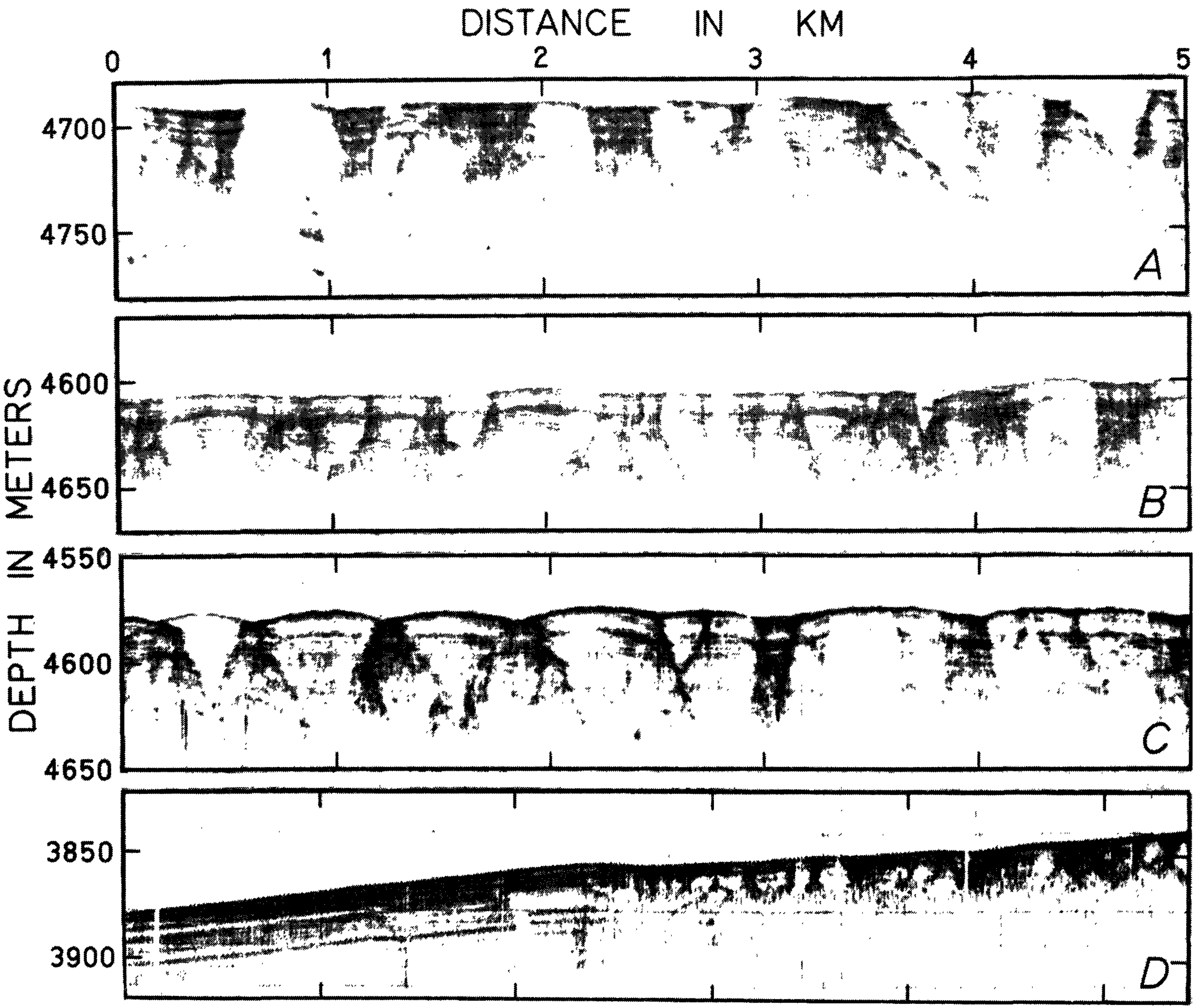

Figure 8. Pagoda structures shown by 3.5 khz recordings made off Sierra Leone and Liberia (A, B, C) and off Southwest Africa (D). See fig. 9 for their distribution on the deep-ocean floor of western Africa.

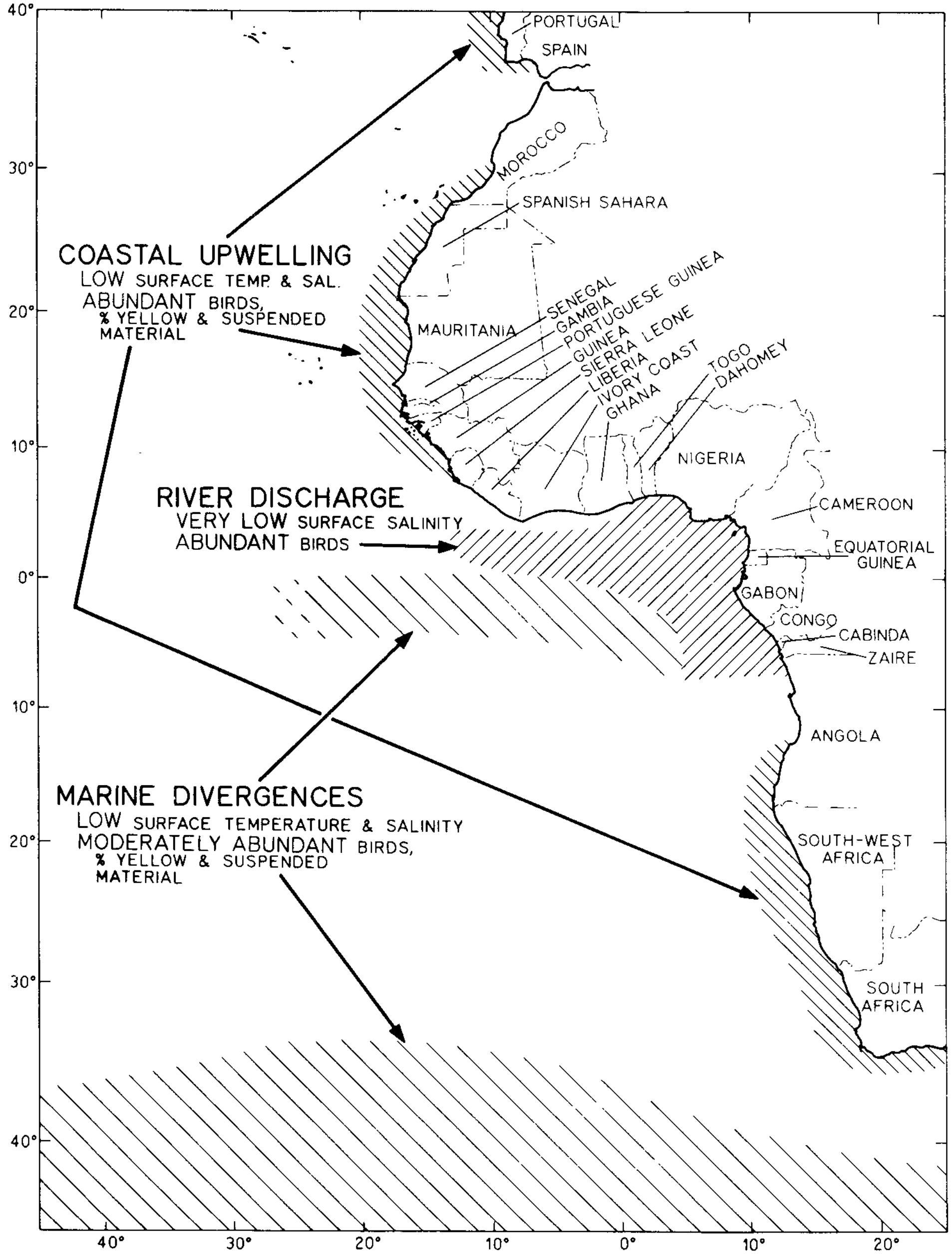

Figure 9.

Distribution of pagoda structures. Note their restriction to the clay-silt floors of the continental rise and abyssal plains. These structures may be due to methane-hydrates, and thus they are a potential source of methane gas for the future.

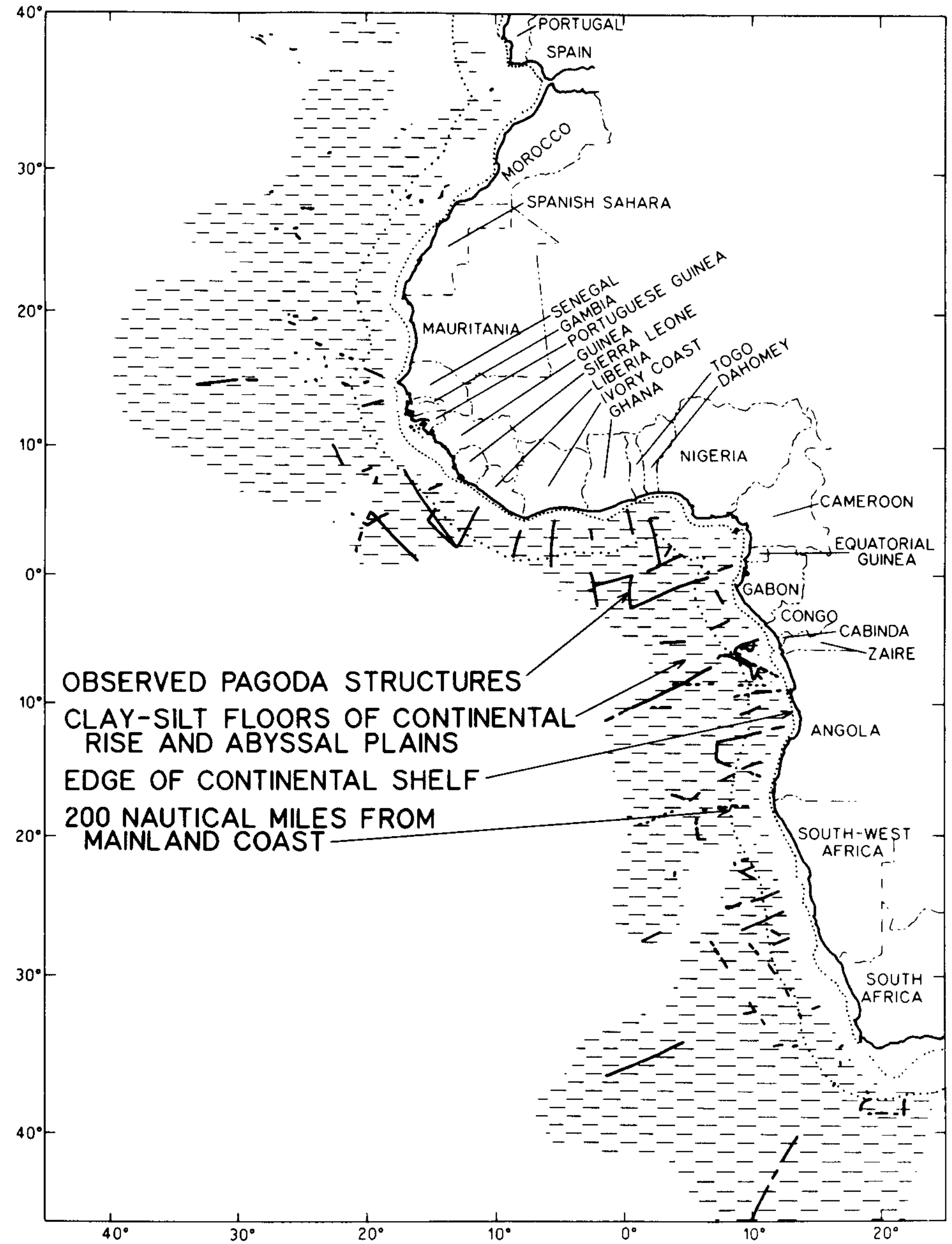

Figure 10.

Areas of high primary productivity in surface waters, as indicated by temperature, salinity, colour, suspended material, and birds. They probably also are the areas of most abundant fish.

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