ANNEX IV

REPORT OF THE FIRST MEETING OF SCOR WORKING GROUP 36 ON COASTAL UPWELLING PROCESSES

SCOR WG 36 met at the School of Oceanography, Oregon State University, Corvallis, 26 - 29 March 1973. The following members of WG 36 attended the meeting:

Dr K. N. Fedorov (USSR), Chairman
Dr R. C. Dugdale (USA), Chairman of the Biological Panel
Dr K. Yoshida (Japan), Chairman of the Physical Panel
Dr G. Hempel (FRG)
Dr H. Minas (France)
Dr E. Mittelstaedt (FRG)
Dr B. Saint-Guilly (France)
Dr R. L. Smith (USA)
(Dr D. H. Cushing [UK], Dr R. Margalef [Spain], Dr D. Nehring [GDR], and Dr Y. I. Sorokin [USSR] were unable to attend.)

Observers participating in the discussions of the Working Group were: Dr R. T. Barber (Duke University), Dr D. Halpern (NOAA), Dr C. N. K. Mooers (University of Miami), Dr J. J. O'Brien (Florida State University) and Dr L. F. Small (Oregon State University).

Professor H. Charnock (UK) was invited to attend as a representative for ACOMR, but was unable to do so.

The tentative agenda circulated prior to the meeting provided the necessary guidelines for the discussions. The Working Group met partly in plenary session and partly in two panels. The discussions centered around the following major items:

General meeting

(i) Exchange of general information on observational and theoretical studies on coastal upwelling.

(ii) Implications of Coastal Upwelling Experiment (CUE) and other observational results for further upwelling studies.

(iii) Implications of existing theoretical models for the planning and methodology of upwelling studies.

(iv) Physical* information required for biological and fisheries investigations, particularly of a prognostic value.

(v) Optimum ways of combining physical, chemical, and biological studies.

Physical panel

(i) Review of past activities of the panel and the preparation of bibliography of recent work in the physical oceanography of coastal upwelling.

(ii) Discussion of the field observational work and instrumentation.

a. the measurement in the near surface (Ekman) layer made in CUE-1.

b. direct measurements of vertical velocity made in "Auftrieb 1972" and in CUE-1.

c. the measurements made with profiling current meters.

(iii) Review of theoretical modeling

a. success of two-dimensional two-layer models with simple topography in predicting the time scales for the onset of upwelling and the spatial scales for width of upwelling.

b. the necessity for developing 3-dimensional, time dependent models with realistic topographies.

* Term "physical" includes "meteorological".

Biological panel

(i) Biological categories of upwelling systems.

(ii) Intensity of primary production and herbivore feeding in relation to environmental factors and community structure.

(iii) Horizontal processes in relation to upwelling intensity, tongues, patches and fronts.

(iv) Vertical processes related to nutrient supply, phytoplankton re-seeding and zooplankton migrations.

(v) Biological coupling between shelf cells and off-shore cells (at the continental slope).

(vi) Coordination with physical oceanography; international coordination.

The following report was prepared by the Working Group.

1. Introduction

Following the extensive exchange of information on the most recent results of coastal upwelling studies (CINECA, CUE-1, Peru upwelling) and on the outcome of recent theoretical analyses, the Group summarized the present understanding of coastal upwelling as follows:

A) Physical Aspects:

There are well known areas in the ocean where climatological coastal upwelling is occurring on a quasi-permanent basis. Superimposed upon it there are intermittent intensive upwelling events which attract more and more attention from physical oceanographers, marine chemists and biologists.

. The dynamics of a quasi-steady state upwelling in a geometrically and topographically simple coastal region under stationary wind conditions is now relatively well understood.

It is much less clear what effects on upwelling (e. g., patchiness) are to be expected from irregularities of the bottom topography and of the coastline in conjunction with variable wind conditions.

The scale of upwelling in a stratified ocean being essentially determined by the baroclinic Rossby radius of deformation, there should be, and there apparently are, important physical differences between some features of coastal upwellings in the areas of different latitudes, different bottom topography and different stratification.

It now seems to be realized that the offshore width of intensive upwelling zones seldom exceeds 10 - 30 km and the associated Ekman layer is of the order of 10 - 20 m in contrast with the common textbook opinion of 100 km and 100 m scales, respectively.

The longshore jet-like current in the direction of the upwelling producing wind seems to be an inherent feature of the upwelling phenomenon. This view is supported by both theory and observations.

The subsurface countercurrent observed in the upwelling zones is a very important factor both in the dynamics of upwelling and in the associated ecosystem. Physical explanation of this countercurrent may require taking into account longshore variations of wind and pressure (sea level), necessitating three-dimensional theoretical models.

The upwelling phenomenon, being essentially three-dimensional and time-dependent, requires a three-dimensional and time-dependent pattern of observation.

B) Biological Aspects:

Amongst marine ecosystems those of the upwelling areas stand out for their high productivity and comparatively simple food web structure. Certain parts of upwelling areas have a primary productivity which exceeds neighboring areas by a factor of 10 or more. Fishing yields per hectare in upwelling areas and their immediate vicinity are at least thousand-fold higher than in oceanic areas. Upwelling ecosystems consist of rather few species and trophic levels, primary producers and herbivores being of relatively large size. Those ecosystems are liable to produce high fishing yields but they are regarded as less stable compared to other systems. The factors controlling primary and secondary production in upwelling ecosystems are not well known.

The biological effects of upwelling reach far beyond the upwelling proper and influence the productivity of rather wide ocean areas, particularly at higher trophic levels.

Between major upwelling areas, considerable differences exist in primary production but even more in secondary production, ecosystem structure and in fishery resources. The continuity, intensity and geographical extent of upwelling govern these biological differences.

The conventional view of upwelling as bands of nutrient and phytoplankton rich water parallel to the coast has been modified by recent observations, experimentation and the development of computer simulation models. In this new concept, still hypothetical in some respects, production is considered to occur most strongly in discrete relatively stable tongues, communicating through subsurface counter currents. The tongues provide the sites for transfer with high efficiency of organic matter to higher trophic levels.

Upwelling can be considered as occurring at a series of scales, from the local divergence produced by longshore currents passing capes and submarine canyons, to stronger upwelling producing well-defined tongues, and finally to the strongest upwelling in which broad bands of upwelling are found, with much lower productivity. In the latter case nutrient rich water is not conditioned for phytoplankton growth and moves rapidly toward the shelf break and sinks carrying unused nutrients out of the photic zone. In this sense the coastal upwelling ecosystem now appears as more closed than was previously thought. The intermediate upwelling intensity results in the most intense rates of primary production. Intermittency of upwelling is thought to result in the formation of unattached patches. Under these conditions the transfer sites may be extended further offshore and be more diffuse.

2. Concepts of future investigations

Section A. Physical Oceanography

Winds

From theoretical considerations the primary driving mechanism of coastal upwelling is the wind stress at the sea surface. Further ocean-atmosphere boundary studies are recommended to determine the relationship between wind speed and wind stress under variable atmospheric and surface conditions, especially at high wind speeds. The temporal and spatial variations of the wind stress near a coastline are poorly known, and their effects on the coastal upwelling circulation need to be better understood. Wind measurements from ships are clearly not sufficient and should be supplemented by meteorological buoys and coastal anemometers. The predictive quality of any theoretical model will depend critically upon the accuracy and resolution of our wind measurements.

Horizontal field of motion

Upwelling is such a complex phenomenon that it requires many different approaches and measurement techniques for monitoring the same processes. Therefore, both Eulerian and Lagrangian measurements are necessary. Any planning of current measurements should be made with due regard to bottom topography of the shelf and slope in the area of investigations. It is suspected that underwater canyons and banks have particularly strong influence on the upwelling patterns. During the active upwelling phase, particular attention should be paid to finding and mapping (also contouring in vertical plane) the currents near the surface, such as the offshore flow and the longshore jet-like surface current on the seaward side of the principal upwelling front, and the subsurface countercurrent. Measurements should also be arranged to record the onshore flow and, in particular, to verify the existence of the bottom Ekman layer and to establish its offshore and vertical extent. The remarkably pronounced current structure connected with high vertical shears in coastal upwelling areas requires high resolution profiling current meters equipped with temperature and conductivity sensors. These will be useful in determining the dynamic stability in terms of the Richardson number and elucidating the flow in the thin intermediate intrusive layers observed off Oregon and NW Africa. The results of systematic current monitoring from moored stations may be presented on x-t and z-t planes to make time variations and oscillatory components of horizontal motion better visualized and understood by biological oceanographers.

There can be various patterns of moored arrays of current meters depending upon more specific considerations and also upon the instrumentation available, but there seems to be an explicit need to design these patterns in such a way as to attempt to establish the likely coupling between the local upwelling circulation and the general circulation in the area.

Further studies of the response of the field of motion to changes in wind condition are recommended. Eddy-like phenomena in the horizontal field of motion should be a subject of specific attention.

Vertical Motion

Estimation of the vertical advective flux of nutrient rich water is clearly of primary importance. The use of free drifting devices capable of sensing the vertical component of water motion have been used off NW Africa and Oregon in 1972. These measurements showed that the vertical velocity is highly variable and occasionally one to two orders of magnitude greater than earlier estimates. Because of the observed spatial and temporal variations in upwelling, interpretation of these (quasi-lagrangian in the horizontal, quasi-eulerian in the vertical) is difficult. It is recommended that direct vertical velocity measurements be made in conjunction with attempts to calculate the divergence from the horizontal velocity field measured from moored arrays of current meters. Measurements by the biological and chemical oceanographers can be helpful in locating areas of intense upwelling. We encourage development of vertical current sensors capable of making time series measurements of vertical velocity at fixed locations.

Temperature and Salinity Fields

Keeping track of the evolution of three-dimensional temperature and salinity fields in an upwelling area is essential in a number of ways:-

(i) This evolution is indicative of the upwelling intensity and can provide an independent estimate of vertical velocities.

(ii) Salinity stratification and its different character in different upwelling areas may have marked qualitative effect on local horizontal and vertical circulation.

(iii) Temperature and salinity fields and their evolution close to upwelling fronts and shallow coastal areas likely to display some small scale non-steady, intrusive or non-geostrophic manifestations indicative of mixing processes. Frequent occurrence of temperature inversions is one of such manifestations.

There should be several scales of spatial and temporal resolution in temperature and salinity fields monitoring, the use of STD systems being essential for smaller scales together with simultaneous or synchronous current velocity profiling with the same resolution. The precision infra-red measurements from a satellite or an aircraft or even from the bow of a ship are particularly suitable for mapping sea surface temperature. Continuous salinity recording from moored buoys is one of the extremely desirable developments for the future.

Fronts

Fronts, which in an upwelling area manifest themselves especially in the temperature fields, are essential features of upwelling dynamics. They tend to be zones of high horizontal and vertical shear and sharp changes of color, and the boundaries of various biological phenomena. Mapping fronts on the sea surface, determining their vertical extent and slope as well as horizontal T, S and density gradients across the fronts should be an essential part of upwelling studies. It is of interest to find out to what extent the different frontal systems observed in the upwelling areas are in fact density discontinuities. The observed cases of apparent stability of these fronts, their temporal evolution and the processes through which they disintegrate are not yet well understood. Therefore both theoretical and observational studies of frontal dynamics must be encouraged. Biological, optical and chemical observations such as: surface color, slicks with concentrations of various organisms, discontinuities of optical characteristics as well as of oxygen and nutrients may help physical oceanographers to detect and to monitor positions of front.

Theoretical Modelling

Two-dimensional time-dependant numerical modeling of coastal upwelling has advanced to the point where the development of coastal upwelling over regions of simple geometry under steady wind conditions is well understood. These models predict the narrowness of the upwelling band, the time scales for the onset of upwelling and the existence of a longshore jet. Less well understood are the effect of continuous stratification, the development of the undercurrent, and the long time-scale where diffusive effects must be important. Work is needed on the theoretical treatment of frontal zones which are observed to play an important role in physical and biological processes in coastal upwelling. Variations of wind conditions, breaking of internal waves, irregularities of coastal geometry and of bottom topography may be the cause of the patchiness of coastal upwelling. These factors along with a more realistic stratification must be included if the theoretical models are to be predictive.

Section B. Biological and Chemical Oceanography

The following comments refer to the need of better understanding the determining factors related to different trophic levels. The methodological aspects of those studies have only been briefly discussed by the biological panel and need further consideration by the Working Group by correspondence and at the Second Meeting of the Working Group.

The panel emphasized the particular need for studying the following biological factors determining:-

a. Primary production: seeding, species composition, conditioning versus inhibition, grazing.

b. Secondary production: abundance, regeneration rate and size composition of phytoplankton and their variation. Composition and population dynamics of herbivores, their vertical and horizontal distribution relationship to phytoplankton.

c. Harvestable production: abundance and distribution of herbivores exploitable by fisheries, efficiency of transfer into other exploitable resources and their migrations and shoaling.

In discussing the physical background of biological studies of upwelling ecosystems the panel identified the following requirements of biologists for physical oceanographic research:

Since the pelagic components of the ecosystem are embedded in a fluid medium, biologists must obtain from the physical oceanographers a description of the time dependent velocity field in three dimensions.

For those investigations directed towards the ecosystems of upwelling tongues, the urgent requirement is for a detailed understanding of the velocity fields existing in tongues. The mixing processes at the boundaries or fronts of the tongue are clearly important in the re-seeding and concentration of organisms. Understanding the role of the undercurrent in longshore transport of substances and organisms between upwelling tongues or centers requires a quantitative knowledge of circulation and mixing.

Knowledge of the position and nature of fronts will be necessary to understand the role of these features in bringing about aggregations of organisms and in providing clues to food availability to herbivores and to organisms at higher trophic levels.

The effects of internal waves in the distribution and activities of pelagic organisms currently is receiving attention from biologists. It can be anticipated that these effects are likely to be important in upwelling areas and information about them will be required.

Ecosystem Modeling

The techniques of systems modeling should be further applied to the study of upwelling ecosystems, to provide focus in the planning stage and to allow the testing of alternative hypotheses when working models have been established. Process models describing the transfers taking place within a parcel of water are necessary to provide the equations for spatial system simulation models.

Description of the communities

There is a great need for more data on phytoplankton biomass in terms of number of organisms at different size groups and taxa including flagellates. These data should be related to chlorophyll concentrations and to the ratio of live and dead particles at various light levels.

Key species of phytoplankton and herbivores in each area should be identified and cultivated in flow cultures, for measurements of their physiological potentials and requirements.

Dominant species of zooplankton and nekton should be studied for their growth, reproduction and particularly feeding and migratory habits, both diurnal and seasonal.

The vertical distribution of phytoplankton, key herbivores and predators should be studied in order to describe co-occurrences of primary producers, grazers and predators at various depths of photic zone and surface mixed layer.

Continuous culture

The theories of continuous culture processes should be applied to the study of upwelling tongues. For example, these tongues can be divided into zones, analagous to the tandem chemostats used to produce penicillin and other compounds. The population is produced in the first reactor, some additional uptake of nutrients occurs in the second, and product formation occurs in the last. By this analogy the seaward end of a tongue may be the site of excretion of a number of organic compounds including vitamins and water-conditioning substances. The role of these culture systems, operating at high growth and loss rates, in the evolution of phytoplankton species could be investigated based upon previous continuous culture results on mutation rates and population processes in bacteria, and using the knowledge of cellular processes developed for laboratory organisms.

Primary production at low light intensities

In areas with high nutrient supply but high light extinction primary production at intensities below the conventional 1% light level may be important to sustain dense populations of phytoplankton concentrations at the lower part of the photic zone and even below. Further knowledge of primary production at low light levels is required.

Regeneration of nutrients

Special attention to regeneration processes under the photic zone seems necessary in upwelling areas. Sampling along sections normal to the coast covering especially the depth affected by upwelling transport should indicate the regions of enrichment by regeneration of sinking organic material. By this means it should be possible to assess the amount of supplementary regeneration - under the photic zone and the fraction of this in the upwelled water.

Dissolved organic matter and trace substances

High concentrations of organisms and high rates of metabolism cause the production of large amounts of a great variety of dissolved organic matter. The importance of these substances for conditioning the water for growth of phytoplankton and for attracting or repelling zooplankton and fishes is little known.

The role of dissolved and particulate organic matter as food of microorganisms requires further study. Particular emphasis should also be given to the occurrence and accumulation of trace metals and man-made trace organics and their influence on phytoplankton growth.

Section C. General

Multi-disciplinary character of the research requirements specified above calls for tightly coordinated multi-ship operations with the possibility of aid from satellites and airborn oceanography. New types of modern instrumentation and new methodology require new design of these operations, taking into account specific ship requirements of different research groups. This can best be done through international cooperation. CINECA program may be the first international framework for applying the new concepts.

Further Activities of the Group

(i) The group decided to continue its work through correspondence by

(a) reviewing and completing the bibliographies on physical and biological aspects of coastal upwelling.

(b) exchanging relevant reprints.

(c) clarifying terminology used in upwelling studies.

(ii) The group decided to have its 2nd General Meeting during the first half of June

1974, prior to the CINECA planning meeting, preferably in Kiel in the Institut für Meereskunde. An invitation to do so has been extended by Dr G. Hempel.

(iii) The group felt that not less than 5 days is necessary for a productive meeting which would comprise separate panel discussions as well as general sessions.

(iv) The group considers it desirable to hold a workshop on physics of coastal upwellings during the IUGG General Assembly in Grenoble in 1975 and a Symposium on Coastal Upwellings during the Joint Oceanographic Assembly in Edinburgh in 1976.

ANNEX V

SCOR WG 38 (WITH SCAR)
SPECIAL STUDIES IN CIRCUMPOLAR WATERS SOUTH OF 40^{o}S
Report from Chairman - G. E. R. Deacon

Since the formation of the group the Chairman has corresponded with interested scientists of a number of countries and various ad hoc discussions have been held. However, the full membership of the group has not been established and no formal meetings have been held. This is partly because it has not been possible to identify scientists ready to work on new data and reluctance to organize Antarctic supply vessels into undertaking new programmes of measurements without a clear objective in view and immediate prospects of producing results that would demonstrate the value of the work.

This present report was prepared at a small meeting at the National Institute of Oceanography in the United Kingdom on 19 April 1973.

The views expressed and the ad hoc discussions support the earlier emphasis on the need for information on meridional and zonal transport at all depths. SCAR has gathered information on the capabilities of all supply vessels operating regularly in the Antarctic. The possibilities for utilising some of these ships in programmes to monitor currents and sea surface conditions are now developing in conjunction with the GARP need for increased coverage of meteorological data from the southern oceans, and particularly by plans for using satellites to monitor movements of inexpensive drifting buoys.

The promise of an extensive buoy programme during the First GARP Global Experiment [1977] has been increased and made more immediate by the results of the first successful EOLE satellite monitoring of the drift of a large Antarctic iceberg in 1971/72 by expectations of valuable information from a number of the thirteen EOLE transponders placed on icebergs by ships of seven nations in the 1972/73 austral summer and by the plans for a pilot programme in 1974 for monitoring Antarctic oceanographic buoys by the NIMBUS F satellite.

WG 38 will need to examine the proposals for an extensive buoy programme during FGGE to secure the interest and help of appropriate supply ships in setting out the buoys, to formulate proposals for measurements which supply ships can make in direct support of such programmes and recommend how these measurements should be made and utilised. It seems probable that the recommendations for supply ship programmes related to GARP needs should be limited to measurements of sea surface temperatures and possibly bathythermograph observations, although emphasis must also