SCOR WORKING GROUP 36 (WITH ACMRR & ACOMR)

COASTAL UPWELLING PROCESSES

Report of 2nd Meeting, Kiel, FRG, 24-28 June 1974

SCOR WG 36 met at the Institut für Meereskunde, University of Kiel; Federal Republic of Germany, 24-28 June 1974. 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 D. H. Cushing (UK)
Dr G. Hempel (FRG)
Dr R. Margalef (Spain)
Dr M. Minas (France)
Dr E. Mittelstaedt (FRG)
Dr D. Nehring (GDR)
Dr B. Saint-Guily (France)
Dr R. L. Smith (USA)

Prof. H. Charnock (UK) was invited to attend as a representative for ACOMR/WMO, but was unable to do so.
Dr Y. I. Sorokin (USSR) was unable to attend.

Observers participating in the discussions of the working group were: Dr R. T. Barber (USA), Dr R. Boje (FRG), Dr J. J. O'Brien (USA), Dr K. -H. Szekielda (USA), Dr M. Tomczak (FRG).

The tentative agenda circulated prior to the meeting met with general approval and was adopted with the addition of a few relevant items.

Most of the items of the agenda were discussed in plenary sessions. Separate meetings of the two panels were organized to discuss:

Items 3, 5 and 9b (Physical Panel)

Items 3, 4 and 6 (Biological Panel)

1. <u>Review of the progress achieved over the past year</u>

There was the general feeling of a considerable progress achieved during the past year in the following fields:

i. Observational programmes in all the three major areas of coastal upwelling:

<u>NW African area</u> (CINECA - France, Ghana, GDR, FRG, Mauretania, Morocco, Poland, Senegal, Spain, UK, USA and USSR participating;

<u>Oregon area</u> (CUE-II - USA);

<u>Peruvian area</u> (Instituto del Mar del Peru, USSR expedition of R.V. <u>Akademik</u>

Kurchatov).

ii. Interpretation of CINECA data of 1970-1972

iii. Theoretical modelling (both analytical and numerical)

The accumulated new knowledge helped considerably to widen the present understanding of coastal upwelling phenomenon so that quite a few important stepts forward have been made from the position reflected in the 1973 Report of WG 36. The opportunity to compare the information on different upwellings played a substantial role in this progress.

2. Comparison of different upwellings

Scientific results of various expeditions in different upwelling areas conducted during 1972 - 1974 were reviewed. Depending upon specific conditions (wind, coastal configuration, bottom topography) coastal upwelling exhibits great variety of patterns. The occurrences of quasi-two-dimensional upwelling along parts of the NW African coast were referred to as contrasting with the long-shore variability and intermittent character of upwelling near the Oregon coast and quasi-permanent patchiness of upwelling in some areas off Peru and NW Africa.

3. Visualization of three-dimensional patterns of circulation at different stages of upwelling

It is possible now to suggest several basic patterns of circulation depending upon the width and form of the continental shelf and slope, the intensity and variability of the wind field and the stratification and latitude.

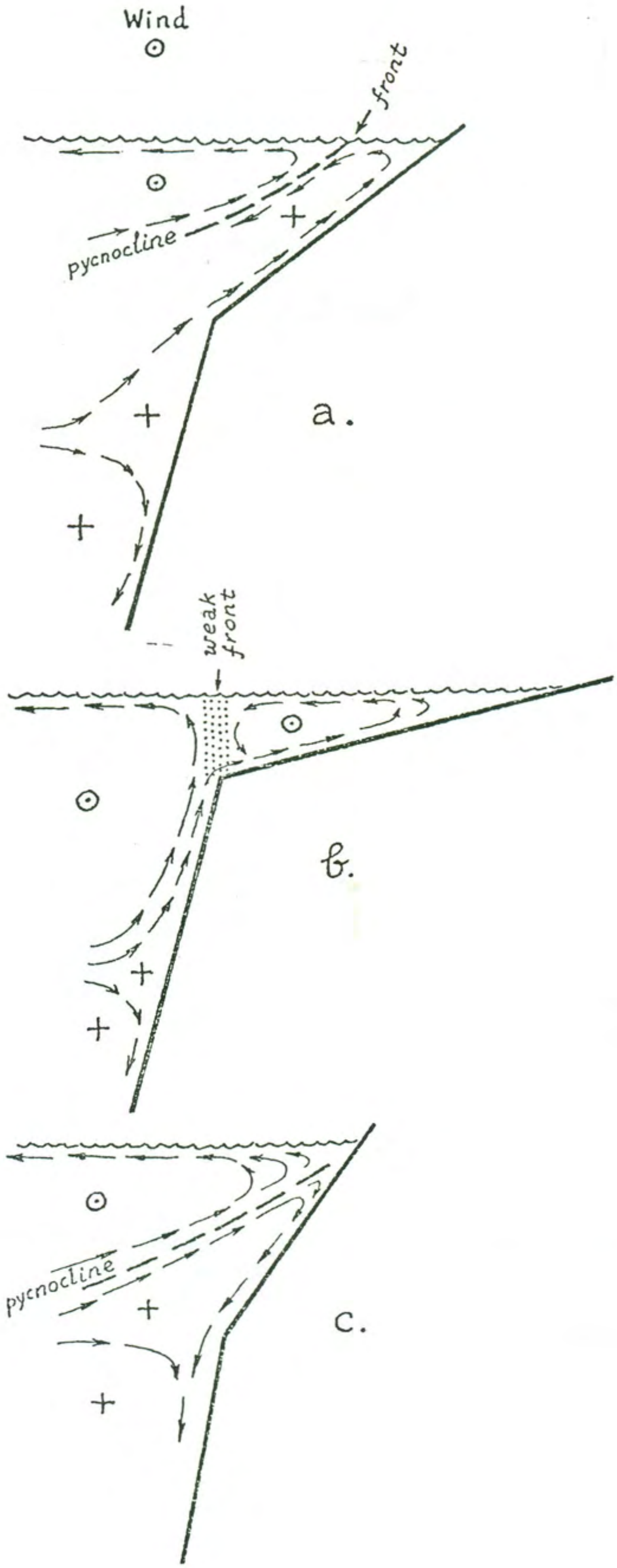
a) Two cells of upwelling over the shelf with onshore flow and ascending motion from both above and below the pycnocline, but with the flow below the pycnocline being part of a poleward flow. Sinking occurs near the front formed by the pycnocline intersecting the surface.

b) Upwelling over the slope with a second weak cell of upwelling over a wide and shallow shelf being fed from the slope upwelling.

c) A single cell of upwelling over the shelf and slope but with sinking associated with deeper on-shore flow. The sinking cell may extend close to the coast depending on local effects.

In all the schemata there exists a deep poleward flow (undercurrent). This undercurrent and the downwelling cell associated with the deeper onshore flow, may be part of the large scale eastern boundary current system and common to all major eastern upwelling areas.

The suggested patterns come as a result of recent observations off Peru, Oregon and Northwest Africa and theoretical models. The patterns may represent stages of development, or states of intensity of the upwelling processes. The following parameters relevant to ecological considerations can be identified for patterns of circulation:


Wind
front
pycnocline
a.
weak front
b.
pycnocline
c.

1) the depth from which the upwelled water comes
2) the characteristic vertical velocity
3) the width and position of the upwelling zone
4) the ratio of flow normal to and parallel to the coast
5) the existence and location of fronts
6) the residence time of upwelled water in the euphotic zone.

Although the schemata are two-dimensional in presentation, emphasizing the vertical and onshore-offshore flow, they are part of the three-dimensional circulation. Even for the case of two-dimensional upwelling (by which physical oceanographers mean a mass balance by the onshore-offshore flow alone) the characteristics of the alongshore flow will affect the biological scales. On the other hand, the addition of the third dimension will not necessarily close the circulation within the upwelling region.

We wish to encourage observational and theoretical oceanographers to provide estimates of relevent parameters to these patterns of circulation.

4. Chemical and biological significance of upwelling circulation patterns

An analysis of the expected residence times in the inshore cell of upwelling may be based upon the following velocity estimates provided by the physical panel for average conditions based on measurements off Oregon and in the Cap Blanc area off NW Africa:

	velocity in cm/sec
longshore v	10 to 25
upward limb w_1	2 to 4 x 10^{-2}
downward limb w_2	-1 to -2 x 10^{-2}
offshore and onshore u	4 to 8

The offshore vertical dimension may be taken to be 100 m and the inshore vertical dimension may be set at 50 m. The offshore horizontal dimension, x = 20 km. Using these values, a hypothetical helix could be constructed, giving the following time scales in the various phases:

ascending 1.5 - 3 days, offshore 3 - 6 days, descending 6 - 12 days, shoreward transport 3 - 6 days, total of 13.5 - 27 days. The longshore transport in average conditions would then be roughly 300 km. The mean euphotic zone half-cycle is a useful concept and would be about 10 days in this model. These estimates are, of course, extremely crude and may be regarded as some minimum values of the time scales involved.

The euphotic zone half-cycle appeared to be too short to generate sufficient grazing capacity within its own system unless it circulated more than once. If the material is to be transferred to secondary production, a grazer must be present before the cycle starts.

The euphotic zone half-cycle should be long enough to allow regeneration in faecal pellets, zooplankton liquid excretion and bacterial regeneration. The first two imply grazing. If there is none, phytoplankton and zooplankton are not connected dynamically, and there must be a sedimentation of dead algal cells; there is some evidence of such sedimentation off Cap Blanc.

Off Northwest Africa an inshore and offshore cell sometimes becomes established with a front between the cells; because of the shear there may be transfer across the front by entrainment and mixing. There may be an association between strong winds and the establishment of two cell circulation pattern. If the lower estimates are taken one can argue that although algae are produced within 7 days, the grazers cannot be generated within such system. If the material can be transferred across the front it is vulnerable to attack by small zooplankton and by euphausids. The generation time of the small zooplankton may be of the order of two to three weeks whereas that of euphausids is of many months to two years.

As the trades shift to the north the wind stress weakens and a one cell system may replace that of an inshore and offshore one, then the production over the shelf is advected offshore over the slope. Smaller zooplankton can then be generated within the whole cycle in addition to the euphausids that are present in any case at the shelfbreak and beyond it. Off NW Africa, the two cell system appears to separate algae and the smaller grazers whereas the one cell system may link them. However, the distinction between the two biological systems may become blurred due to the transient nature of circulation patterns.

The several cell models of coastal upwelling are explicative of many biological phenomena. The two cell system helps to explain segregation of zooplankton: species of small size and with irregular migration in the inshore cell where mixing may be more important than circulation; larger species with more defined or persistent migratory behaviour in the offshore cell. The contact between the inshore and offshore cells proprovides a mechanism for transfer between the cells. The alongshore undercurrent (counter current) provides a mechanism for the return for migratory animals and for the reseeding of phytoplankton. Decay of the two cell systems into a one cell system, either in time, or in space along a coast, may pass through a stage with a single cell in the surface and, with a horizontal eddy on the edge of the shelf. There is some evidence for the occurrence of such structures and a physical model of this decay or transition would be welcomed by biologists. Biological exploration should provide a sufficiently detailed picture of events (production and transport) on scale commensurate with phenomena affecting, at least, a width twice that of the shelf.

Until now it is not known whether the existence of two cells of upwelling separated by a convergence zone over the shelf break is a very common feature off NW-Africa. The sets of data obtained by the CINECA multiship surveys in February and August 1973 may contain the necessary information on this question. The CINECA Coordinating Group may consider taking early action in the analysis of the data for possible indications of convergences at the shelf break.

Horizontal extension of the system analyzed by biologists as a quasi-closed ecosystem must be a function of the intensity of upwelling. Recognition of this relation may be essential in scaling biological programmes, in order to produce meaningful results. It seems impossible to understand upwelling in a narrow spatial frame, and in this biology and physics pose similar requirements.

5. Effects of coastal configuration and bottom topography on the intensification of coastal upwelling.

Observations carried out in the areas off Oregon, off NW Africa and off Peru gave new evidence that the irregularities of coastal configuration and bottom relief in the longshore direction influence substantially coastal upwelling patterns. Observations tend to confirm some of the outcomes of the recent theoretical modelling according to which patches of intensive upwelling should be located close to the heads of underwater canyons and on the equatorward sides of significant capes. Theoretical modelling has still to develop further by taking into account more realistic features of bottom topography, coastal geometry and stratification. In parallel more observations should be made of the three-dimensional motion field in the upwelling areas.

6. Effects of frequency, intensity and duration of upwelling events on the average large-scale productivity in major upwelling areas

Intense upwelling, although transporting very large quantities of primary nutrient into the euphotic zone, may result in reduced rates of primary production through a variety of effects related to a reduced time scale and turbulence. For example, under strong upwelling winds, a two-cell circulation is expected to develop and under these conditions, the time available for phytoplankton to grow and consume all of the primary nutrient may be too short. The problem is compounded by the effect of turbulent mixing in reducing the probability of long periods of exposure to the high light apparently required to "shift-up" the ability of the phytoplankton to take up nutrients and to grow at an enhanced rate. The requirement for strong light and high nutrient concentration for bloom formation can be met at lower rates of upwelling (accompanied by decreased turbulence) or by complete cessation of upwelling. It seems likely that intermittency of upwelling may result in higher rates of productivity. This is an area in which biological modelling based upon physical and meteorological observations made in the major upwelling areas may help attain an understanding of the primary processes resulting in the heirarchy of production and the pattern of ecosystems observed.

7. Field methods of following time-history of upwelled water

Our present understanding of the phenomenon of upwelling is such that it seems hardly possible to select a representative volume of upwelled water and to follow its evolution in time and space from the biological and physical point of view under the real conditions found in coastal upwelling regions.

Instead both physical oceanographers and biological oceanographers are inclined to visualize this evolution in terms of the "residence time" of the upwelled water in the euphotic layer of the upwelling zone. To estimate the residence time, however, it is necessary to understand fully the physics pertaining to the particular upwelling occurrence.

Although the basic concepts of the desirable future investigations are well understood and had already been formulated (cf 1973 Report of the WG 36), there are always some practical constraints both in time and facilities available which require certain priorities to be observed when expeditions are being planned. These priorities are easier to specify for the NW African area, for which the planning of further field studies (for 1975 and 1976) is already in progress.

7.1 Obtaining three-dimensional information on motion field in the upwelling area (Direct current measurements from anchored buoy arrays; current profiling, drogues,etc.). Consideration of the offshore, alongshore and time scales involved may be based on the discussion under items 3 and 4. There is a definite necessity to go to larger longshore scales (100 - 1000 km) of observations in view of the possible role played by continental shelf waves and biological scale associated with the longshore advection. The basic three-dimensionality of the coastal upwelling will be also probably revealed by studies extending over these scales. Estimates of vertical velocity of upwelling may be based upon small-scale buoy arrays

(10-30 km) and use of natural and artificial tracers. There is still need to improve methods of direct measurement of vertical velocity and utilize them more widely. Particular attention should be paid to current measurements in the Ekman layer. Tracing drogues from an aircraft may be one of the desirable methods.

7.2 Biological problems which require special action

Distribution of demersal fish in relation to depth contour under different conditions of upwelling. Special attention should be given to the shelf break and to the deeper parts of the continental slope (> 800 m). Echosounder surveys have to be coupled with experimental bottom trawling and with analysis of catches of commercial vessels, taking into account results of earlier surveys, particularly of Poland and GDR. The joint operation of a fishery research vessel together with one or two oceanographic vessels would be most desirable. The fish survey should also be combined with benthos studies and with the examination of the stomach contents of demersal fish.

The trophic position of necton and macrozooplankton is not yet well known. Studies of the stomach contents of pelagic fish could be most profiterably carried out in collaboration with the commercial fisheries and with fisheries surveys. For studies in micronecton and macrozooplankton catches at day and night in hydrographically well defined layers are required. Special attention should be given to euphausids which are considered to be the major predator of phytoplankton.

The poleward undercurrent as well as the onshore lower, aphotic limb of the upwelling cell(s) should be studied for its contents in phyto- and zooplankton and its microbial activity. For sampling micronecton and macrozooplankton selectivity in those layers, new closing nets might be needed.

7.3 Multi-ship approach. Multi-ship approach is fully in line with the interdisciplinary nature of the upwelling studies. Distribution of disciplines and scientific staff between participating ships is naturally a function of compatibility of different shipboard measurements and observational programmes. Biological and physical measurements which require synchronization (e.g. biological and chemical sampling and STD casts) or those which can not be separated in space may be more conveniently carried out from one vessel. However, for the fullest possible realization of physical and biological experiments, separate ships may be assigned to carrying out simultaneously the major elements of the biological and physical programmes.

7.4 Statistical significance and comparability of sampling

Wherever possible sampling techniques in physics, biology and chemistry should be brought in line with each other so that they give fully comparable and statistically significant information.

8. Long-term plans of upwelling research

As discussed under various items of the agenda plans for a future upwelling research should emphasize a coupling of theoretical and observational work and a close link between physical and biological studies.

The WG regards it as natural and desirable that major emphasis is given in

CINECA to the study of upwelling processes rather than to regional surveys. However, the WG recognized the need for surveys particularly in the field of resource assessment and fishery forecasts.

The close similarities in the physical processes in coastal and equatorial upwelling in combination with the striking biological differences call for detailed studies of equatorial upwelling which might also help to understand better some of the phenomena in coastal upwelling ecosystems.

Long term plans along those lines are under consideration in various institutions engaged in upwelling studies. Members of the WG reported briefly on some plans for field work for the years 1975/76. The full success of several of the programmes largely depends on the strengthening of the exchange of personal and equipment between countries. Recent cruises have already greatly benefitted from the input of foreign scientific and technical personal and of scientific equipment. Beyond this exchange it seems necessary to modernize and augment in quantity the equipment (e. g. current meters, closing nets) available for upwelling studies to cope with the increasing demand and expanding the temporal and spatial scales of future studies.

9. CINECA Coordinating Group Meeting

The WG took note of the report of the 3rd meeting of the CINECA Coordinating Group and referred to it at various occasions in the course of its discussions.

After about 5 years of increasing oceanographic research activities in the Canary current system, the area off NW Africa can be considered as one of the better-known areas of the oceans. The picture arising from the investigation seems now to be sufficiently clear and consolidated to build on it programmes of applied research and resou ces appraisal needed to advise fisheries and other kinds of ocean use. Strengthening of contacts of the scientists participating in CINECA with the interested institutions in the coastal states might help to utilize the scientific results of CINECA. Taking note of SCOR's growing interest in assisting the promotion of marine science in developing countries, the WG feels that careful consideration of the creation and strengthening of efficient oceanographic research units within the coastal states of the CINECA region would be most desirable.

10. Symposia

(a) IAPSO/IAMAP Symposium on Upwelling Generation, Grenoble, France, 5 September 1975

A symposium entitled "Generation of upwelling and vertical motion in the sea" is planned for 5 September 1975 during the IUGG General Assembly in Grenoble, France.

A member of this Group (R. L. Smith) has been appointed convenor. This Group discussed the symposium and recommended that 12 papers be invited. The convenor asked members to correspond with him offering suggestions as to invitees.

(b) El Niño Workshop of the IOC, Guayaquil, December 1974

The Group took note of the El Niño workshop scheduled for December 1974 in Ecuador, and that several members of this Group have been invited to attend the workshop. Those members will report on the workshop at the next meeting of this Group, bringing to the Group's attention those scientific issues and problems appropriate for consideration by this Group.

(c) The Third International Symposium on the Analysis of Upwelling Ecosystems.

This will be held in Kiel, Federal Republic of Germany, 24 to 28 August 1975 prior to the IAPSO/IAMAP Symposium. This Symposium is open for contributions in all fields of upwelling research. A report of the Symposium will be provided at the next meeting of this Group.

(d) Joint Oceanographic Assembly, Edinburgh, September 1976

A General Symposium on upwelling and a Special Symposium to include CINECA results are planned for the JOA. For the General Symposium the Group agreed to recommend to SCOR two possible convenors:

Dr David Cushing and Dr Gotthilf Hempel. A paper on the application of upwelling research to the needs of coastal states should be invited. On the other hand, the Group felt that the Special Symposium on scientific results of CINECA during the JOA might be less desirable in view of the proposal of the CINECA Coordinating Group to hold a Symposium on the results of CINECA in the first half of 1977 at a place within the CINECA area.

11. Future activities of the Group

There was a general feeling that in dealing with the phenomenon of coastal upwelling it is difficult to avoid drawing parallels with the phenomenon of equatorial upwelling, both in physical and biological sense. In the Pacific area the close link between the two phenomena can be traced through the El Niño events. Therefore the Group felt that SCOR should consider the necessary adjustment of the Group's terms of reference to cover the equatorial upwelling phenomenon. Another point which SCOR might wish to consider is inviting an oceanographer from the Instituto del Mar del Peru to be a member of the WG 36. This would provide the Group with the first hand information and expert advice on the Peruvian upwelling area and will facilitate to Peruvian scientists the access to scientific information on coastal upwellings.

The Group decided to have its 3rd General Meeting in France from 8 to 12 September 1975 after the IAPSO/IAMAP Symposium on Generation of Upwelling and Vertical Motion in the Sea scheduled to take place in Grenoble on 5 September 1975 in conjunction with the IUGG Assembly. Prof. B. Saint Guily was requested to explore possibilities for holding the Group's meeting in either Banyuls-sur-Mer or Villefranche-sur-Mer, or in UNESCO, Paris.

The Group should continue its work through correspondence in the interval between meetings.