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International Commission for the Northwest Atlantic Fisheries

Serial No. 5267

ICNAF Res.Doc. 78/VI/80

ANNUAL MEETING - JUNE 1978

Report of the Canadian Planning Group of the Flemish Cap International Experiment Meeting, St. John's, Newfoundland 12-14 September 1977

by

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Abstract

Following ICNAF directives, an international experiment to study variation in year-class strength, as four-year-olds, of Flemish Cap cod has been developed. This report from a group of Canadian scientists comprises a list of hypotheses proposed for the experimental solution of this problem, types of data required to test these hypotheses and some sampling strategies that might be required.

Emphasis on interdisciplinary work between hydrographers and fisheries biologists characterized the meeting; the report is largely descriptional of the working hypotheses of the biologists, and outlines of biological and oceanographic sampling proposed.

After introducing the regime of Flemish Cap, twelve hypotheses are developed to guide a 5-year study. The sampling required is summarized as fish life-stages versus factors influencing them. Oceanographic sections, a biological and hydrographic grid, and 4 current meter locations are now pinpointed.

Because of a 20-day gyre on the shallowest part of the Flemish Cap, 5 days is the estimated time for covering the 56-station grid for acceptable synopticity. The main problems foreseen are environmental patchiness, larval fish behaviour in relation to shearing tidal currents, storm impacts, and the interactions of growth and mortality in larval and juvenile fish.

Preliminary sampling begins in 1978, with a full assault mounted in 1979.

A. Introduction

On 12 September 1977, in St. John's, Newfoundland, twelve representatives of Canadian scientific interests in the Flemish Cap International Experiment met for three days of planning the Canadian objectives and participation in the project. The participants are identified in Appendix 1. In this meeting, our knowledge of the biological and oceanographic events on Flemish Cap was reviewed and criticized. Once some common background among both the physical oceanographers and the fisheries biologists was established, the discussions progressed to include and expand upon the Murmansk, USSR meeting of the Flemish Cap Working Group of the ICNAF Environmental Subcommittee (see ICNAF Redbook, 1976, p. 83). The objective of the meeting was to define the scientific input of Canadian participation, and in particular, to define how the oceanographic and biological regimes might be interacting. A certain part of the project is thus properly interdisciplinary in scope with attendant problems. We began the determination of exactly which parameters measured by each discipline would be required for the 'sub models' of the other. Through conflicts of scale and jargon, a very satisfying communication emerged. C. Ross, A. Clarke and P. Smith of the OAS very generously edited early drafts of this report, and large sections of the oceanographic descriptions are directly lifted from Ross's manuscript describing this area which he prepared for the meeting.

1. Terms of Reference

Recommendation 7 vi of the ICNAF Standing Committee on Research and Statistics in 1975 is as follows:

"that attempts be made to identify relationships between various currents around Flemish Cap and other relevant environmental factors with the year-class strengths of cod and redfish;" (ICNAF Redbook, 1975, pg. 19).

This recommendation came from the recommendation of the Environmental Subcommittee Working Group of the same year:

"that an attempt be made to identify relationships between the various currents around Flemish Cap, the water temperature at appropriate depths and any other relevant environmental factors with the year-class strengths of cod and redfish on the bank, including the role of predation of cod on redfish, and to identify other major gaps which still exist in knowledge of the area as well as research programs needed to fill them;" (ICNAF Redbook, 1975, p. 100).

Reports from 1976 show little progress was made beyond the requested reviews by Hayes, Mountain, and Wolford (1976) and by Templeman (1976). Partly because of the role played by Dr Konstantinov in initiating the project, in April 1976 STACRES recommended:

"that Dr. Konstantinov be asked to convene a meeting of a small group of scientists ... who might be directly concerned with a coordinated international experiment on Flemish Cap, to further examine the data base, to appraise the suitability of Flemish Cap as an area worthy of a special study, and, if the outcome of the appraisal is favourable, to develop a preliminary proposal for consideration by the subcommittee at its meeting in 1977."

At Murmansk, USSR, in May 1977, the project appraisal was favourable, and the Report of the Flemish Cap Working Group (ICNAF Redbook 1977, p. 83) develops the initial proposal and reviews some general ecological and oceanographic considerations of the area. Preliminary plans for work in 1978 were developed, with tentative commitments from the scientists at PINRO, Murmansk, the US Coast Guard, and Poland. Receipt of this report led STACRES to recommend:

"that a coordinated international research project be launched on the factors determining year-class success for Flemish Cap (Div. 3M) groundfish, with emphasis on cod and redfish;" (ICNAF Redbook, 1977, p. 43).

Initial investigations in 1978 should lead to a comprehensive program beginning in 1979. A Task Force Leader, following the structure of the successful Larval Herring Program, was named in the person of R. Wells.

2. Focus of the Experiment on Cod

Although the specifications for the project refer to 'cod and redfish' or 'groundfish', the extension of the sampling period to cover the larval stages of redfish and American plaice is possibly not warranted in terms of costs versus an increase in our understanding of recruitment processes by extensive collections interspecific comparisons. Hence a decision to focus the project upon the factors affecting year-class strength of cod was made during the Murmansk meeting. This does not imply that material concerning Atlantic redfish and American plaice will not be collected and analyzed, but there will almost surely be a truncation of the observations of larval Atlantic redfish since they are apparently most abundantly produced after mid-April, compared to February-March for cod.

3. Outline of the Oceanographic and Biological Regime of Flemish Cap

Most of the available information on Flemish Cap has been examined already and subject to published reviews. Templeman (1976) and Hayes, Mountain and Wolford (1977) provide the biological and oceanographic background, respectively. A conceptual overview, derived from incomplete information, is presented as the first part of the Report of the Flemish Cap Working Group (ICNAF Redbook 1977, p. 83). The following remarks serve only to introduce the more detailed literature which can be entered by the references of the above-cited papers.

(a) Oceanographic Regime

Figure 2 is a schematic diagram of the major currents in the Flemish Cap area. The water mass distribution of Flemish Cap is dominated by the North Atlantic current which carries warm water northward along the deep continental slope of the Grand Bank and Flemish Cap and the Labrador current which carries cold water southward along the edge of the Labrador and Newfoundland Shelf. The Labrador current splits in the region of the northern end of Flemish Pass and a branch flows southward along the western side of Flemish Pass. This branch continues southward to the tail of the Bank by which time much of its transport has turned offshore and mixed with the warmer water of the North Atlantic current. This mixed water is presumed to then be carried northward along the inshore edge of the North Atlantic current. The second branch of the Labrador current flows eastward across the northern edge of the Cap and then southward along the eastern edge. The splitting appears to generally take place in such a way that the coldest water flows through Flemish Pass; the second branch being somewhat warmer. On the Cap itself, there appears to be a fairly permanent anticyclonic flow about the shallowest point. In addition, Soviet investigators (see for example, Serebryakov, 1978) feel that the southwest corner of the Cap is a region of mixing and rather confused and small-scale circulation patterns.

The North Atlantic current would appear to remain well offshore of the Cap and not exert a direct affect on the Cap itself. Occasionally, however, warm cores of water are seen at 300-500 metres depth on the eastern side of Flemish Pass or from 150-200 metres depth in the centre of Flemish Pass. These cores probably consist of mixed water with a larger than normal proportion of North Atlantic current water.

Looking at historical temperature data it would appear that the possibility for the greatest temperature variability lies in the range of 50-100 m. This is the depth of the Labrador current cold core. The temperature in the cold core varies from -0.1 C to -1.7 C on the western side of Flemish Pass and from not present to -1.2 C on the eastern side of Flemish Cap. In none of the Canadian or USCG sections did the cold core cover the entire Cap but this might be a possibility if the anticyclonic gyre were to break down completely. The Soviet literature suggests that this has happened in the past. At this depth range, the temperature over the Cap would appear to be in the range 1-6 C.

In the deeper water, there would appear to be no sources of water of greatly different temperature in the location of Flemish Cap which would cause large temperature fluctuations by moving on-offshore. In the range 250-400 metres, the temperature near the bottom will be in the range 3-5 C.

The available data for Flemish Cap are in the form of standard hydrographic sections occupied seasonally or annually. The literature speaks of cold years and warm years based on these sections. Measurements on the Scotian Shelf suggest that water moves on-offshore with a much faster time scale than a year. The two important time scales for the Scotian Shelf are a meteorological time scale of 3-6 days and a topographic-planetary wave or eddy time scale of 20-30 days. The first time scale arises because storms have this characteristic and winds may cause ocean surface transport on or off the shelf with corresponding deeper off or onshore flows. The longer time scale is associated with the eddy field generated by major currents, such as the Gulf Stream, which may cause large scale mixing between coastal and oceanic water masses.

Some current meter data are available from Flemish Pass. Figure 3 shows the daily velocity vector at 500 and 800 metres at the centre of the Pass from April 14 - July 16, 1976. The daily speed at both meters varies from near zero to 25 cm/s with a time scale of 20-30 days. There would appear to be two alternative explanations for this: either a current is accelerating and decelerating within the Pass or a southward current on the western side of the Pass and a northward current on the eastward side of the Pass are shifting position across the Pass on the 20-30 day time scale. In either case motions in the Pass may generate currents onto and off the Flemish Cap at the same time scale.

Looking at the temperature measured at the same depths (Figure 4), we note (a) that the variation in temperature at a constant depth is quite small (<0.8 C) and (b) that there is variation at the 20-30 day time scale.

Lastly, a surface drifter was deployed on Flemish Cap in May, 1977 for test purposes. This drifter was not drogued and therefore will be affected by the wind as well as the surface current. Its track (Figure 5) suggests that during this period there was an anticyclonic gyre trapped over the shallowest part of the Cap. The drifter required about 20 days to make a circuit and made one and a half complete circuits. Around July 1, the drifter moved off the Cap and was subsequently carried out of the area by the North Atlantic current. No unusual atmospheric events accompanied its departure, but weather charts indicate a period of light WNW winds over the Cap on 29-30 June, which may have been responsible.

The other aspect of the physical oceanographic environment that may be relevant to the fisheries is the internal tide. The Flemish Pass mooring shows that the internal tide is present at the semi-diurnal frequency. The amplitude of this tide might also be expected to be larger as one moves up the slope. An internal tide provides a mechanism by which the upper water might be moving inshore while at the same time deeper water moves offshore. Larvae undergoing diel vertical migrations may be carried either onshore or offshore by being in the upper layer and then the lower layer at just the time when each is going inshore or offshore. Expected internal tidal currents are about 10 cm/s; so that such a mechanism could at best transport organisms perhaps 20 kilometers/day.

(b) Biological Regime

Subjected to major oceanic currents and heavy storms, the reported scarcity of benthic food organisms for fish (Popova, 1962) is not surprising. Cut off from the Grand Bank by Flemish Pass with depths over 1000 meters, the Atlantic cod stocks are reportedly a separate population from those anywhere else (Templeman, 1976; see also Payne, 1977). The extent to which Atlantic redfish (primarily Sebastes mentella) and American plaice, the only other abundant groundfish, are also separated is only implied by the cod separation. The scarcity of capelin as a food source for the predatory groundfish makes the area unique compared to the rest of the Northwest Atlantic. Capelin have occasionally been reported in commercial concentrations on Flemish Cap, with Poland taking 317 tons in the fall of 1973. For both cod and redfish, 1973 produced the largest year-classes on record, by perhaps an order of magnitude.

Cannibalism in cod and cod predation upon redfish are quite important on the Cap, judging from Templeman's review, however Popova (1962) doesn't mention cannibalism in his 1960-61 observations. Quite a bit of unpublished data on stomach contents exists for Flemish Cap in both Canadian and Russian laboratories, and it may be possible to describe the abundance of fish food on the Cap as quite variable year by year.

Larval fish, until they begin to swim, are at the mercy of the oceanography to some extent. Transport from cod spawning grounds in the southwest and northeast into the nursery grounds in the retaining central gyre over the shallows of the Cap is noted by Serebrykov(1978). By his explanation, this was a persistent gyre. The observation that the drifting buoy was retained in small eddies over the presumed spawning grounds of cod is potentially productive. The loss of the drifting buoy may have been related to weak atmospheric winds, or may have been representative of losses of larval fish nursery ground water by a persistant mechanism.

Zooplankton production is vitally important to larval fish, in time and space. Russian work shows an important production area in the (upwelling?) region in the south end of Flemish Pass. Apparently the primary production on the shallows of the Cap is high, due undoubtedly to the Labrador current waters reaching the euphotic zone there. Production maxima correspond to the subsurface flows of the Labrador current otherwise, namely the western Flemish Pass, and deep eastern water (Plekhanova and Rhyzov, 1977). The two major currents have easily differentiated zooplankton associations.

Large intrusions of the North Atlantic current water could lead to lower production, both primary and secondary, reducing the food for larval fish. There is historical data on zooplankton abundance still under-analyzed, including extensive vertical hauls by the Russians from 1959 to the mid 1960's and the British continuous plankton recorder work of the last two decades.

The timing of events on the Flemish Cap appears to be capable of great variation. In 1976 the phytoplankton bloom (mainly diatoms) and attendent Calanus finmarchicus spawning didn't occur until the middle of May (Plekhanova and Rhyzov 1977), while in 1960, zooplankton spawning was underway in March (Pavshtiks, Semjonova and Drobisheva, 1962) These six weeks could be very important to larval fish. The potential for a second generation of zooplankton by July was discussed during the Murmansk meetings. This didn't occur in 1960 in spite of an early start (above cit.). This second abundance of food for larval fish is suggested to account for the prolonged availability of spawning fish on the Cap.

Besides the influence on nutrients and temperatures, the fluctuations of which are still not properly analyzed, the current dominating the Cap also directly influences the abundance of food. As an example, while barracudina, Paralepis rissoi kroyeri, is probably an important food item for adult cod, replacing capelin to some extent, this pelagic fish's distribution on Flemish Cap probably corresponds to the distribution of Labrador Current water on the Cap (Popova, 1962). The extent to which squid (probably predominantly Illex illecebrosus) affect the Cap by their annual migration north, both as predators on young fish and as food for adults is unknown, partly because they would arrive later than the period when most of the biological work has been done.

B. A Systematic Development of Hypotheses

Without clearly defined objectives being firmly laid down in the beginning, and without a commitment on the part of those initiating or later joining the work, any project of a scale of several years and dozens of participants will surely drift into pieces that will resist re-assembly at the time when the project is supposedly completed. Taking this as a background philosophy, the main part of this meeting was concentrated in identifying processes that would be rewarding to study and identifying their connection to the central hypothesis of the Flemish Cap International Experiment.

1. The Central Hypothesis

From the terms of reference earlier quoted from the ICNAF Redbook, and the considered reduction in scope initiated at the Murmansk meeting, there was a clear and testable concept identified, expressable as:

"The year-class strength of the Flemish Cap cod stock varies as a result of specific biological and environmental conditions."

This is regarded as the hypothesis to which all work, done with respect to the initial ICNAF suggestions, should be clearly related so that a cohesive and properly integrated approach might result.

2. Four Main Factors

This central hypothesis can be split into four main divisions: physical environmental conditions, predation conditions, food abundance conditions, and the condition of the cod spawning stock (see Fig. 6).

3. Twelve Hypotheses

Before each of these divisions can be examined, however, there must be a reference to which stage of the life history of cod they are affecting. A simple diagram of the stages of cod development, with an indication of the time spans, is Fig. 7. Of some importance is the definition of 'year-class strength'; for the purposes of this project this was defined arbitrarily to be the number and biomass of fish that became 4-year-olds. More precisely, it is the number and weight of fish alive on January first from eggs spawned three springs previous. These fish would be large enough to begin to appear in the commercial catches.

Grouping the life history stages of Fig. 7 into eggs and yolk-sac larvae (since these are both passive drifting stages), free swimming larvae (mobile and pelagic), demersal juveniles (a change of habitat) and adults (upon whom the production of eggs depends) yielded 12 basic facets to consider as specific hypotheses. Since the response variable in each case is the number and biomass of 4-year-olds, in arguing each hypothesis only the potential modes of action and required variables will be identified.

The strategy behind this dissection is to try to identify those components of the system which appear consistently as potential regulators of year-class strength, thus allowing a rational basis for making them the subject of detailed investigation. As well, certain 'themes' will emerge to provide guidance through the project and upon which to structure further meetings. These themes are concepts such as bioenergetic budgets, sampling, patchiness, and population feed back mechanisms. Table 1 provides a summary of this investigation, which occupied 12 people for nearly 2 days.

Hypothesis (a)

(i) The Size of the Spawning Stock Determines Year-Class Strength.

Since it is the spawning adults that provide the initial charge of eggs to eventually become 4-year-olds, the more spawners, the more eggs, the more four-year-olds. This implies that mortalities are constant, or at worst proportionate to abundance, from egg release onward.

Another way of looking at it is that the greatest potential source of variance in the system is the number of spawning adults, potentially zero to many millions, multiplied by their fecundities. This is the basic stock-recruit relationship, rarely demonstrable, but still influencing our thinking in these matters very strongly.

Countering this argument, only a very few adults would be needed if most of their eggs survived. This is actually believed to have happened on Flemish Cap in 1973 (at least spawning stocks could be said to be depressed due to recent intensive fishing), and is the argument behind the Beverton-Holt model.

Assurance that there is no input of eggs, larvae or juveniles from the Grand Bank is required.

Data required:

- The distribution and abundance of spawning fish.
- The size and age distribution of those spawners, and the maturity ogive of the population, in each year.
- Observations of water entering the Flemish Cap region to try to detect incoming eggs and larvae.

Estimated importance:

This can certainly influence some control over year-class strength, but is likely not critical. The data will be collected as part of following hypotheses.

(ii) The Condition of the Spawning Stock Determines Year-Class Success.

Viewing the adult cod as a machine to produce eggs, if there isn't sufficient food in the environment, the energy stored in the liver throughout the summer will not suffice for high fecundity and egg viability. This hypothesis views the Flemish Cap and stock as being food limited, with the limitation acting through egg number and viability. Besides the gonad energy, the energy of each egg may be a function of the feeding of the parent fish, to the extent that the egg or yolk sac larvae may exhaust its energy supply before it is able to feed from its environment. Since high stock biomass implies an environment that is perhaps 'grazed down', this mechanism represents the declining limb of the Ricker stock-recruit curve; or the $\frac{K-N}{K}$ term of the Lotka-Volterra (hence Schaefer) model. The feeding of adults is clearly critical here, and gets more attention in hypothesis d (i).

An understanding in detail of this mechanism demands a bioenergetic model of cod shunting energy between storage, somatic growth and gonad growth. Mechanisms of egg development in energy limited conditions will be valuable for predicting just how many of what kind of eggs we might expect from a fish with a certain total energy content at some time of the year.

The question just when egg number and size are irreversibly determined must be considered. The mortalities at different stages in egg and larval development must be attributed not only to external influences such as predation, but also to internal conditions intrinsic to an egg from a parent fish in a certain condition. Clearly, this confounds attempts to correlate predation and mortality.

Data required:

- An undetermined series of measurements of the bioenergetic state of fish expected to produce eggs. Gonad and liver weight, lipid content, caloric value are minimal additions to round and gutted weights. There is value in seasonality in this data as well, for Hypothesis d (i). This problem has been reviewed by G.E. Shulman (1962), suggesting that our Russian colleagues may be able to help us here. As well, preliminary work on this is being conducted in the lab by Dr. Ken Waiwood in St. Andrews, and in the field by biologists in St. John's.
- Estimates of fecundity, egg viability, yolk-sac larvae viability. Direct measurements should have a theoretical backing to them, however, that is apparently several years down the road.
- Distribution and abundance of eggs and larvae, ideally with some quite precise idea of how long they have been liberated and in what history of temperature. Observations of the energy content of individual eggs and larvae could go a long way toward resolving the confounding of egg disappearance and predation. To determine an age for eggs more precisely than traditional 'stage of development' work allows will demand detailed knowledge of the drifting of eggs in relation to the spawning grounds.

Estimated importance:

As for number of spawners, since their condition is only a refinement of the stock-recruit relationship. Fecundity and egg viability data would certainly aid in reducing the variance associated with a S-R function.

Hypothesis (b)

(i) Predation Upon Juveniles Determines Year-Class Strength

There were 4 potential sources of predation upon small (5 centimeter to 25 centimeter) demersal juvenile cod: larger cod, "other fish" (including skates, American plaice, anglers, adult redfish), marine mammals (presumably this covers H. sapiens) and invertebrates (especially the squid Illex illecebrosus). "Other fish" and Marine mammals were felt to be unimportant, though no data whatsoever was presented. Templeman's review of published feeding data doesn't mention Atlantic redfish containing juvenile cod in their stomachs, presumably they are separated by chosen depth.

Squid effects on the Flemish Cap, and on the whole Northwest Atlantic ecosystem for that matter, are not ascertained at present. This is partly because they presumably arrive later than when most of the work has been done on the Cap, in late July and August. Due to the warmer conditions on Flemish Cap, squid could quite possibly arrive on the Cap earlier than they do in Newfoundland waters.

In some years, or at least in some seasons of some years, cannibalism is a very noticeable component of the cod diet. Templeman reported "Cod were feeding heavily on the abundant young cod..." in March of 1961, while Popova, visiting in the summers of 1959 and 1960, doesn't mention cannibalism in this region. The effect of hunger on cannibalism (the cod in the spring observations had recently spawned) and the extent to which abundant redfish juveniles as alternate prey would spare juvenile cod, are waiting (as is nearly everything else in this study) for clearer resolution as more data are procured.

It would be quite possible for a moderate stock of large hungry cod to do a great deal of damage to an incoming year-class of 1- and 2-year-old fish. Even if a very low predation rate is postulated (say 1 every week per cod older than 4) the incoming year-class could be extinguished with a quite unalarming rate of occurrence in cod stomachs (this would correspond to one to every third cod stomach roughly, given two days to digest to unrecognizability). Continued for a year, this wipes out 50 times the number of incoming juveniles as there are predatory adults. Of course, seasonal bouts for several years could do the same damage and be even more unlikely to be noticed. Apparently there is plenty of scope for population feedback here. See Hypothesis d (i) again.

A persistent problem in trawl fisheries is the retention and later unreported discarding of small fish, coupled with mortality incurred, directly or indirectly, as a result of passing through (or under) an otter trawl. This can, and apparently has in recent years, destroyed prerecruit cohorts before they can contribute significantly to the landings of the commercial fishery. Although this is a problem that steps above the pure biology of the problem at hand, it is most certainly a fisheries science problem which should be examined on Flemish Cap where, hopefully, we may have a good idea as to the actual abundance of juveniles, a situation that is rare in our fisheries.

Data required:

- The distribution and abundance of predators, and collections of their stomach contents.
- Estimates of the gut clearance rates, or stomach contents turnover time of these predators.
- Temperatures during the above digestion rates and their affect on the rates.
- The distribution and abundance of alternative prey for all predators, for interpretation of selectivity.
- Seasonal changes in predation. This relates to prey abundance only partly, since appetite probably varies seasonably.

- Observations on diet patterns in predators. There is a confounding of diet, appetite, and diurnally migrating prey availability.
- Measurements of discarding from the commercial fleet, and estimation of the survival of unretained, trawled juvenile cod (pre-recruit fishing mortality).
- Distribution and abundance of juvenile cod. This is difficult with our current techniques as will be described later.

Estimated importance:

For the cannibalistic feedback, critical. For the other predators on juvenile cod, probably of relatively little importance. For the fisheries' effects, potentially important but not likely to be critical in this area. This last is based upon a prediction that there will be only moderate fishing intensity on Flemish Cap for a few years after the 1972-1973 year-classes are fished out by 1979.

Hypothesis (b)

(ii) Predation Upon Eggs and Larvae Determines Year-Class Strength

Although a list of potential predators could be made (medusae, ctenophores, arrow worms, pelagic fish, squids, older larvae, juvenile cod and redfish, crustacean zooplankton) no single entry could be agreed upon as being an important destroyer of eggs and larval fish. Defendants and plaintiffs existed for both ctenophores and arrow worms, and apparently those were the only entries that anyone knew anything about. Yet every biologist seemed to feel that predation upon the pelagic stages was of paramount importance to cod year-class strength, and further testified to the difficulties of studying this system.

Even given a distribution and abundance of eggs, cod larvae, and predators, and given the stomach contents and gut clearance rates of those predators, it is still difficult to assess the full impact of the pelagic community's predation on cod. The larval cod are growing rapidly, and entering and leaving the size classes of interest to specific predators. The predators themselves are growing, changing their prey interests. Each predator not only has an individual functional response to an increase in prey abundance, but a population numerical response and particular strategies for optimal foraging. These are potentially confounding intrinsic mortalities in eggs and larvae from maternal effects.

Unless there are theoretical tools from approaches like particle size distributions, the planktonic system on Flemish Cap will have to be quite simple to allow anything more than a bookkeeping exercise of how many eggs and larvae went where, rather than the idealistic result of a model which predicted the extent to which the pelagic community would 'turn on' to varying inputs of eggs. It may be possible to identify some of the predators and to compare their abundance from year to year, and from this may come some confidence as to which, if any, of the list of predators could be held liable for the control of year-class strength of a cohort of eggs and larvae.

Date required:

- Quantitative observations on the distribution and abundance of the potential (later to be trimmed to the demonstrated) predators upon eggs and larvae, for several years.
- Measurements of gut clearance times, stomach contents as spectrums of particle sizes.
- Estimates of the potential for numerical response on the part of the predators. For instance, ctenophores could conceivably get in another generation based upon the energy of abundant larval fish, but squid would not be able to respond numerically.
- Good estimates of the abundance of eggs and larvae at reasonably close intervals.

Estimated importance:

In the same spirit that allows 10 years predictions of yields in fisheries management, this hypothesis was considered "controlling but not critical".

Hypothesis (b)

(iii) Predation Upon Adults (Fishing) Determines Year-Class Strength

The possible effects of fishing were considered to be removal of spawners and the disruption of spawning behaviour. This first effect was an indirect one, and the resultant direct effect is covered as Hypothesis (a) (i). Behavioural disruption was thought unlikely since there is no reason to believe that any mass behaviour is involved and the fish pair in midwater to spawn, out of the reach of bottom trawls.

Although there were no direct effects of any importance anticipated, it was realized that long term changes in the age and size composition of the spawning stocks could have an influence, especially considering the relative viability and sizes of eggs from spawners of different ages. Very heavy fishing pressure could change the size composition of spawners within a single season.

Data required:

- Spawning stock age and size composition, distribution and abundance. Details of the commercial catch, including the proportion spent or ripe in the catch.

Estimated importance:

Very unlikely to be of direct importance, but important over the long term by depletion of spawning stock (see Hypothesis (a) (i)).

Hypothesis (c)

(i) Environmental Influences Upon Adults Determine Year-Class Success

Although a suitable table to specifically answer the question was not prepared, it appeared that the extremes of temperatures likely to be encountered on Flemish Cap were well within tolerable limits and that annual bottom temperature ranged only a few degrees centigrade, from perhaps 2.5° to 4.5°.

The distribution of adult fish is well known to correspond to thermal and to some extent, salinity regimes, possibly to optimize metabolic efficiency. There are several other direct effects of temperature, of course, including the observation that a smaller mean particle size is selected in cold water (cod take small bites in cold water). Indirect temperature effects would include the relative distribution of food items (see Hypothesis (d) (i).

Among the environmental influences, only light and currents were suspected of potential effects. There could well be a change in feeding behaviour in light versus dark conditions, and light certainly is suspected of providing cues for the distribution of fish within the water column, yet the event of any year or season being so significantly different in light regimes as to actually influence year-class strength was not believed possible.

Speed and direction of currents is interesting on three accounts. First, there is always the possibility that an incursion of unsuitable water (extreme in temperature or salinity, perhaps) could reduce the spawning areas or delay or interrupt spawning. Secondly, the orientation of fish on the bottom is influenced by currents since they probably turn into them. This is believed to influence trawl efficiency (Harden-Jones, ICNAF address, 1975) and could possibly bias survey results to an undetermined extent. It is probable that the normal speeds of currents on the Flemish Cap (0 to 25 C/S was suggested) would have little effect, but there is evidence that storms can cause brief but intense currents as deep as 200 meters. Any environmental factors that control the timing of cod spawning could be of potential importance if they were not invariate like photoperiod.

<u>Data required</u>:

- Temperature and salinity measurement over the entire Flemish Cap, as would be collected on routine surveys. Current meters and drifters for estimating the normal current regimes and detecting the movements of masses of water.

<u>Estimated importance</u>:

Very unlikely to be important. Adult cod are capable of tolerating a wide range of environments and can redistribute themselves away from any localized abnormal conditions.

Hypothesis (c)

(ii) Environmental Influences Upon Eggs and Yolk Sac Larvae Determines Year-Class Strength

Temperature and salinity directly influence the development rate and hatching success of fish eggs and early larvae. Since this could affect both the numbers and timing of the entry of swimming larvae into the pelagic community, they must be considered important, given that there is some optimal time for such an entry.

Interpretation of the time since liberation or fertilization of eggs by reading their development requires a knowledge of their temperature (and possibly salinity) history. Incursions of water, or mixings of waters could well complicate this determination. Generally, in discussing the non-motile stages of cod life history, attention is directed to the surface (0-50 meters) water. Cod eggs are almost neutrally buoyant, however, and have been observed to be mixed into much deeper waters (to 125 m in the St. Lawrence estuary; Able, 1976). Whether such deep mixing has any developmental effect is unknown, although it may introduce a new predation regime.

Transport of eggs and non-motile larvae off the Cap into waters where they will never regain it is probably the most important effect. Since there is no mechanism to play the tidal currents off against the residual currents, any loss of surface waters from the Cap gyre probably represents a directly proportional loss of these life stages. Estimating this phenomena is one of the main objectives of the Flemish Cap experiment in the minds of many participants.

At this level of linking the physical oceanography to the biology, the problem is somewhat simpler than in the following discussion of oceanography and motile larvae. Use of a series of current meter arrays could provide information upon which layers of water were moving onto or off the Cap and at what rates. Combining this information with the abundance of eggs and yolk sac larvae at each depth yields a first calculation of transport losses, with some confirmation possible by sampling the off-the-bank waters where water is leaving. Hopefully, such masses of water as are leaving will be recognizable by their temperature and salinity (and if possible, other constituents such as silicates and nitrates) characteristics, allowing a precise calculation of losses to confirm the directly sampled estimates of losses.

The effects of storms with regard to the loss of Cap water in a catastrophic type of event will require examination. Good meteorological observations during research cruises will possibly allow land-based wind stress observations to be used in Ekman transport calculations. In combination with the current meter arrays and survey observations, total losses could be calculated. If it turns out that loss through storms is the main transport loss, it may be possible to use the incidence of storms in March to May (or so) to predict year-class strength.

The possibility of mechanical damage to delicate larvae during high winds was discussed. Besides being difficult to measure, it was not felt to be a problem if such winds resulted in mixing the larvae into waters deep enough that the shearing forces would be very weak.

Other environmental influences, such as light and oxygen, were reviewed and not felt to be capable of exerting any measurable effects in this arena.

Data required:

- The distribution and abundance of eggs and yolk sac larvae, by areas, depths and time.
- Knowledge of the mean water transport and its variability on the Flemish Cap, including the effects of storms.
- Data on the time to different egg and yolk sac larvae development stages as a function of temperature and salinity.
- Hydrographic data over the area, allowing extrapolation of larval density measurements between stations.
- Atmospheric data, both ship- and shore-based; satellite imagery.

Estimated Importance:

Critical. A bad year with low temperatures and high transport losses could certainly decimate this stage of the life history of Flemish Cap cod. Density-independent factors such as transport losses will inevitably be a source of numerical abundance variance. This hypothesis relates back to some very early work in fisheries that suggested currents were a factor in year-class strengths of commercial fish (Hjort, 1914).

(iii) Environmental Influences on Swimming Larvae Determines Year-class Strength

All of the difficulties of dealing with losses of immobile eggs and yolk sac larvae are compounded when the larvae begin to control, however feebly, their own movements. As well, a new dimension is added when they begin to take food from the environment to offset their active metabolisms.

Temperature is an important controller of metabolism and digestion, hence of growth and mortality. As an indirect effect it interacts with food availability. Over the range of temperatures observed in the 0 to 50 m waters (1 to 12 C) metabolic rates must be changed in the order of a factor of 3. In the presence of abundant food, high temperatures could promote extremely fast growth. Alternatively, the same temperatures in a paucity of food could lead to exhaustion of energy reserves through high metabolic rates, and consequent death.

Salinity acts somewhat like temperature, but its mode is probably an energy cost for maintaining an osmotic gradient. The range of salinities on Flemish Cap is so low, however, that generally it can be discounted as important, except in those cases where precipitation lowers surface salinities for a time. Salinity and temperature are the primary definers of water density and vertical stratification of the water column is physically dependent upon density gradients, while biologically dependent upon light and nutrients. The vertical distribution of larval fish is expected to be predictable from density gradients (thermoclines for instance, or depth of the mixed layer).

A more effective predictor of larval fish distribution however, is light; as a regulator of the diurnal migrations observed in larval fish, it leads us to a very important set of considerations. Given that fish larvae can, and from many observations apparently almost always do (although cod larvae may have their own unique behaviour), undergo diurnal vertical movements, they may be experiencing two or more separate current regimes with depth. Vertically shearing currents may result in a variety of ways such as:

1) wind driven surface layers.
2) internal waves, e.g. internal tide.

By vertical migration organisms may exaggerate or oppose residual motion in an oscillating current regime. If we accept this as a potential mechanism whereby an organism can resist being transported by residual currents that would cost too much energy to fight by swimming at one level, the ecology of larval fish from the viewpoint of its interaction with an oceanographic regime becomes a complicated study. Other factors, including predation and food organism patchiness will enter the picture in Hypothesis (d) (ii).

"Playing off the currents" by spending as much time as possible in cyclic currents going in the desired direction assumes four unlikely things. First, the fish must expect to gain something. Unless it would be transported off Flemish Cap as a consequence of not migrating vertically diurnally, there is no reason, outside of predator avoidance, perhaps, to spend energy doing so. Second, a larval fish must know where it is going. This is attributing quite a bit to a creature 3 centimeters long, however evolution argues that only those animals that so utilize the currents would survive to replace the population. Third, there must be an appropriate currents regime and, hard to explain how, the larval fish migrations must be in the correct synchronization and properly phased. Fourth, there can be no overwhelming costs associated with the behaviour in swimming energy, relinquishing food, exposure to predation. The first, third and fourth of these are observable, testable. The second is tautologous.

Given the complications of vertical migration, it may be impossible to ascertain in detail what the thermal history of a larvae has been, so resolution in bioenergetics and the estimate of time since fertilization may be greatly reduced. The topic of larval fish daily growth patterns in otoliths can be introduced at this point, since such rings may be environmentally induced, probably mediated by light controlled feeding activity. Such otoliths can be used to estimate age-at-size relationships for studying the variability in growth within and between groups of larvae.

Beyond the 'catastrophic' effect of large scale events (storms) which would act nearly as described earlier for passive eggs and yolk sac larvae, other environmental effects such as oxygen, nutrients, turbidity, were not considered as potentially important.

Data required:

- Good estimates of the thermal regime especially, in conjunction with food measurements, to determine bioenergetic reasons for growth and mortality.
- Detailed knowledge of the vertical structure of the current field, in conjunction with the vertical distribution over 24 hours of the larvae.

Estimated importance:

While this is an interesting side of fisheries ecology, and certainly has been attracting quite a bit of research activity lately, it is probably not a matter of critical control of year-class strength. The thermal regime and fine structure of currents can possibly have some controlling influence on swimming larvae, but the catastrophic or amplified feed back mechanisms that are required for this hypothesis to be termed critical are missing.

Hypothesis (c)

(iv) Environmental Influence on Juveniles Determines Year-Class Strength

As for adult fish, direct mortality due to environmental extremes is considered unlikely, unless there were inversions of very cold water within a short time. However, indirect effects can be identified from temperature and light. These effects are probably not as important as other influences on this and other life history stages.

Temperature acts through behavioural selection of an optimal thermal regime to affect the distribution of juvenile fish. Undoubtedly, food availability and predation avoidance will modify or override this effect in many situations. Whether temperature effects on distribution are important in predation or fishing mortality deserves attention. The second and most important effect of temperature is as a metabolic rate determiner. Growth of small animals is important, not only since negative growth in weight leads to death, but because of the predation regime the juveniles are in. The faster they grow out of being food for larger cod and other fish, the lower the total mortality of the cohort is bound to be, all else being constant. This effect is another where several variables - food, temperature, predation - are interacting in the ecology of young fish.

Light would be expected to have several inputs to the ecology of juvenile cod, including control of feeding, movements, and possibly through photoperiod, some metabolic actions for preparation for winter. None of these are suitable to cause changes in year-class strength.

Data required:

- Distribution and abundance of juvenile cod in relation to the hydrographic regime.
- Relationships between growth, food, temperature to compare with the observed growth through several different years.
- Distribution and abundance of juvenile cod predators, with special attention to their size selection preferences or abilities and the effect of temperature on predation rates.

Estimated importance:

This hypothesis is very unlikely to yield any effect alone although the ecology of juvenile fish involves the environment in several important interactions with feeding, growth and predation.

Hypothesis (d)

(i) Food Availability for Prespawning Mature Fish Determines Year-Class Success

This hypothesis was referred to several times in earlier discussions of eggs and larval survival. Certainly the earliest factors that can influence year-class strength would be the food energy consumed by parent fish that had the potential of being channeled into gonad and eventually eggs. If, as a premise, one agrees to consider the food of adults as the first 'building block' of a cohort of fish, then variation in food availability, and the bioenergetics of the storage and transformation of food energy, are pertinent to the problems of year-class strength.

The basic approach is one that has been conducted for years, collecting quantitative data on the gut contents of fish. These data are interpreted with the use of temperature and food-type digestion rates, estimates of efficiencies from laboratory studies, and eventually quite complex computer models of energy partitioning, to determine the contribution of various diet items to the production of eggs. By keeping track of the bioenergetic state of a fish through the course of seasonally varied diets by means of as yet unspecified indices, the first estimations of importance to egg production emerge. Comparison of diets from year to year might reveal that certain prey items are related to fecundity many months later, potentially leading to coarse predictions if the availability of such prey items can be ascertained from, say, water mass movements.

As an example, consider the incidence of the white barracudina, Paralepis rissoi kroyeri, in the diet of Flemish Cap cod from the study by Popova in 1959 and 60 (Popova, 1962). One year the Labrador current covered much of the northern banks of the cap, and this item was very abundant in cod stomachs. In the next year, however, the Labrador current water was farther north, and comparatively few Paralepis were eaten (at least in the summers, when the observations were made).

Cod feeding should be viewed from the point of whether assimilation is roughly meeting the metabolic demands, or so far exceeding it that significant storage is possible. Since gut fullness affects digestion rates, gorging may lead to considerably higher net energy gains than frequent small foraging meals. Any physiologist will recognize that the problem is fraught with feed-backs, however, of dynamic actions, changing assimilation efficiencies, activity costs, unbalanced nutrition, etc.

It should be noted as well that fishing activity enhances the supply of food for cod, by having the trawls dig up benthos and cripple fish passing through the codends, and also by returning offal from fish processing at sea. Cod diets are sometimes observed with offal as the main component.

Data required:

- Stomach content data, related to the temperature and size of fish.
- Data of the digestion rates of various types of foods.
- A suitable theory of energy partitioning to determine where the energy from a certain meal is going to end up.
- Seasonal condition factors, related to the previous diets.
- Data on the distribution and abundance of prey, seasonally and from year to year.

Estimated importance:

The importance of this hypothesis is the inevitable problem of whether a few eggs with high survival in a good year will be recognized as a good year-class in the midst of many years when floods of doomed eggs were produced. Certainly egg numbers and quality from adults exhibits some control over year-class strength. The extent of this control, and the extent to which feeding influences eggs, is uncertain enough to forego the label of 'critical', and perhaps settle for 'controlling'.

Hypothesis (d)

(ii) Food Availability for Larval Fish Determines Year-Class Strength

Larval fish and their food are arranged in a patchy environment. The sizes of particles that larval fish take, about 100μ to about 1.0 mm, are not readily able to control their own distribution with respect to the 10 to 50 kilometer patchiness and .2 cm/s residual currents expected. However, as mentioned earlier, vertically migrating larval fish may take advantage of vertical shearing in horizontal current structures, to transport themselves with respect to the surface patches.

This suggests that larval fish are able to continuously sample the surface patches, and if their residence time at the surface is affected by the concentration of food there, the larval fish themselves will form patches (Evans, Steele and Kullenburg, 1977).

How the size and intensity of patches of nauplii and early copepodites interacts with patches of larval fish is unknown. One thing is clear, however, that the system is very dynamic, and animal behaviour and current patterns combine in a complex and poorly understood manner.

There are many reasons to believe that food availability of larval fish is perhaps the most important aspect of the many factors influencing year-class strength. First, we know that there are pronounced seasonal maxima of food items, and that these maxima vary in appearance from year to year, possibly by as much as two months (from late February to early April). If the larval fish begin to search for food at a fixed time in the year, or any time generated from environmental or biological parameters independent of the parameters controlling food, a make-or-break potential exists depending upon whether or not they coincide. Second, the diet of small larval fish appears, from the difficulty of raising them in the lab, to be very particular. If the right particle sizes are not present in some minimum concentration, growth fails. Third, there are reports that the metabolic demands of yolk-sac larvae are very high, especially in relation to their ability to capture and digest food, suggesting that the food concentration threshold for survival is quite high. Fourth, the mortality rates of larval fish are usually several per cent of the population every day, for a period of months. A mortality rate this high has to vary only a small amount to produce wide fluctuations in survivors after some time.

Examination of larval fish distribution in detail will be revealing, especially if stomach contents are examined. Knowing digestion rates and the distribution of the food items could reveal quite a bit about their behaviour as well as environment suitability.

Temperature and food interact in larval fish, coupled through the ratio of total metabolic rate to assimilation rate. If an increase in metabolism through an increase in temperature cannot be met through increased food intake, growth suffers. Alternately, surplus food at low temperatures cannot be utilized at a high rate. Optimal growth is presumably at relatively warm temperatures in high food concentrations. This depends upon the relative temperature functions of metabolism and assimilation. If digestive enzymes increase their rates with temperature more slowly than do the enzymes controlling catabolism, a growth efficiency optimum could occur at relatively low temperatures.

A relationship between temperature and food particles size has been demonstrated in previous larval fish work. Zooplankton sizes decline as temperature increases, forming another dimension to the temperature-food interaction

(Ware, 1977). Whether larval fish prefer a certain temperature because it maximizes physiological efficiencies or because it is most likely to contain the optimal particle sizes should be determined.

Although the preceding hypotheses have concentrated on predation and feeding, the possibility of being out-competed by other organisms exists as a mechanism to affect feeding rates. The disappearance of particles of food at a rate unexplainable by larval fish feeding rates or food particle growth should be examined for the existence of competing macrozooplankton.

As in the discussion of ascertaining which food items in the annual diet of adult cod were most responsible for variations in fecundity, the diet of larval fish holds the same information, expressed through growth rates as measured by the age-length relationship. Larval otoliths and lengths can be used to ascertain growth rates, and it may be clear that some components of the larval diet are not contributing to growth, but only meeting the current energetic demands. As before, there is a cost in mortality to low growth rates.

Movement vertically, in the postulated sampling of the surface waters, involves an interesting trade-off. Supposing that larval cod do use currents to search for a food patch, they presumably forego feeding in order to change depths for some time. When they regain the surface waters where presumably the required concentrations of food are, there may or may not be an acceptable patch. If not, it seems dubious that vertical migration is in order again to find a patch of food. But what if there is a lot of food? How long can a larval fish afford to keep feeding if it is risking being transported off the coastal shallows into unacceptable deep water?. And how little food is worth abandoning to search for a new patch with the risk of not finding one? So here there is a trade-off of transport mortality against reduced growth and ensuing predation and other associated mortalities. Identifying the correct behaviour as a compromise between opposing constraints and being able to say exactly why it is correct would indicate that we had some basic understanding of larval fish ecology.

Data required:

- Elaboration of the problems presented in this hypothesis would be best accomplished by studying a very small area intensively. However, the distribution and abundance of larval fish in relation to their food would be a minimum for "meso-scale" work. Stomach contents and their relationship to the environment and growth rates is required. Vertical distribution of larval fish in relation to the time of day and food concentrations will help to elucidate the utilization of shearing currents by larval fish. Without laboratory data to back up the field work with digestion rates, catabolic rates, assimilation efficiencies, the analysis of the field data will be much less refined than it could be.

Estimated importance:

The availability of food to larval fish was judged as both controlling and critical. It has the capacity for catastrophe and for density dependent feedback by reduction of the standing stock of food. The critical nature of this hypothesized mechanism for determining year-class strength probably diminishes as the larvae get bigger and more able to sustain periods of starvation.

Hypothesis (d)

(iii) Food Availability to Juvenile Cod Determines Year-Class Strength

The role of food for juveniles is very similar to that of larvae. It interacts with temperature to determine growth rates, and there is a cost in slow growth that can be determined by examining loss through predation. Thus it would seem that faster growing fish would be the ones selected. However, there is a drawback. Fast growth may be a result of either improved efficiency or high metabolic rates generally. When there is plenty of food, power at the sacrifice of efficiency is a good policy, but at low food availability, a high metabolic rate is a pronounced deficit since weight loss is faster and starvation so much nearer. As much as possible, it must be presumed, fish that cannot find food would seek water at such temperatures as to minimize catabolic losses. How successful this might be on Flemish Cap with its warm average bottom temperature and potential for incursions of North Atlantic current water, remains to be seen.

Unfortunately, the sampling of juvenile cod is difficult, since they live near the bottom, but not so near as to get into bottom trawls in acceptable sample sizes. Possibly one of the main sampling devices will be their recovery from the stored larger cod, with several attendant biases.

Popova (1962) produced condition factors for size groups of Flemish Cap cod, which suggested that smaller fish were in poorer condition.

Data required:

- Stomach contents, size at age, distribution and abundance of juvenile cod. Knowledge of mortality rates through cannibalism as a function of size. Estimation of the susceptibility to starvation losses of juveniles.

Estimated importance:

Low. The possibility of famine destroying a cohort of animals so physiologically resiliant as cod is low. The influence of growth rate in controlling cannibalistic and other predatory losses is probably not anywhere near to the importance of numbers of predators, water temperatures or alternative prey availability.

B.

4. Summary of Hypotheses

During the discussion of the 12 hypotheses, some 25 factors were introduced as being, alone or interacting with others, important to the production or survival of a year-class of cod on Flemish Cap. Table 2 summarizes the relation of each factor to each hypothesis. It would be possible for an interaction matrix to be developed defining all the interactions for every process affecting year-class strength. When every variable from every important process was listed, however, there would be at least 50, yielding an extremely large matrix of 2500 possible first order interactions alone. This exercise will be valuable only after the initial information begins to come in, refining our ideas about the Flemish Cap system.

C. Sampling

Following an approach similar to the hypotheses breakdown, sampling can be divided into life stages and available techniques for biology. Further divisions would be objectives, scope, participants, scheduling, and program development. For the oceanography, current analysis is somewhat separable from 'classical' hydrography as practised by biologists and details can be organized by scope, etc. as for biology.

1. Oceanographic Sampling

Aims

1) To monitor the temperature and current environment on the Flemish Cap, especially in the upper 50 m and bottom layer where it may be important in the life history of the cod population.

2) To determine the energetic time scales of temperature and velocity on Flemish Cap.

3) To investigate the possible retention mechanism of cod eggs and larvae on Flemish Cap. It is presently suspected to be an anticyclonic gyre trapped over Flemish Cap.

4) To investigate the surrounding water masses to help understand the possible water exchanges that may occur on Flemish Cap.

The division into currents and hydrographics is forced, of course, however they appear to require very different approaches. Certainly the identification and tracking of water masses uses data from both, and important features revealed by one may also be demonstrable by the other.

The valuable confirmation of a suspected gyre over the Flemish Cap by the satellite tracked 'HERMES' drifting buoy illustrates the value of even a single set of measurements. Currently our thinking is limited by the lack of information on the current patterns throughout this entire area.

Two main tools are anticipated in establishing and monitoring Flemish Cap water mass movements. There are drogued satellite tracked buoys and anchored current meter arrays.

C. 1. (a) Current Analysis

(i) Buoys

A program of Lagrangian measurements of near surface circulation on the Cap would best be accomplished by attempting to maintain 2 drogued, satellite relaying buoys in the anticyclonic gyre on the Cap.

It is highly important that meteorological parameters, in particular wind velocity, atmospheric pressure, and air temperature be measured by all research ships at maximum intervals of 6-hours but hourly observations are preferable. Any additional data from the area reported to the standard meteorological network should be collected.

Objectives: To detail water movements so that egg and larvae loss can be demonstrated. To "tag" patches of water and allow other reported sampling.

Scope: The day to day movements of water, only over Flemish Cap, limited by both instrument cost and satellite tracking costs. Their placement for tracking water containing eggs and larvae means that they should be deployed several times in each spring, if possible, until some understanding of the fates of these water masses is reached. Since they are to some extent recoverable (their position, direction and speed are constantly available), they may be captured and replaced if they drift off the Cap.

Participants: This program has been volunteered by the Ocean and Aquatic Science division of the Canadian Department of the Environment. However, capital funds for equipment have not been offered.

Scheduling: To correspond to egg deposition and yolk-sac larvae formation at an earliest date, and to the assumption of demersal life by juvenile cod as a latest. These dates correspond to the end of February and August roughly.

Program Development: Only one or two buoys for use in 1978 due to the limited activity currently planned. In 1979, the first intensive work will begin, and these buoys will be most valuable then. 1980 will perhaps be the first detailed work, possibly involving the need to tag a 'patch' so that it can be found several days later. However, a satellite-tracked buoy is not necessary for this purpose.

C. 1. (a)

(ii) Current Meter Arrays

Four is the minimum number of moorings required to look at the large-scale circulation and variability on the Cap. It is proposed that a mooring (D) be placed at a depth of 400 m in the major spawning area. Three other moorings (A,B,C) would be placed at the 200 m isobath around the Cap. Current meters (Aanderaa) capable of measuring velocity, temperature, conductivity and pressure would be placed at 50 and 180 m on moorings A, B, and C with an additional vector averaging current meter at 20 m and a thermistor chain between 20 and 50 m on mooring C only. Mooring D would have Aanderaa current meters at 50, 180 and 380 m and a thermistor chain between 280 and 380 m. Because of the heavy fishing activity in this area, it is imperative that each mooring be protected by three guard buoys. A guard buoy at mooring C would have a single thermistor mounted under the buoy in order to sense near-surface temperature events.

This array of instruments should be deployed in late January and maintained for six months. Hopefully a much less intensive mooring program will provide adequate environmental information during the remainder of the biological program as well as information about the very low frequency variability. Figure 8 gives the positioning of the current meters relative to the oceanographic sections and bottom topology.

Objectives: To provide information on the rates and volumes of water moving onto and off the Cap. To identify residual currents and to interpret the movement of eggs, larvae and drifting buoys. To provide information on the vertical shearing of currents. To help understand the effects of the two main currents in the area on the movement of Flemish Cap water. To measure the impacts of storms and winds.

Scope: For the elucidation of the biology, the same season as the drifting buoys must be covered. Year round placement would improve our understanding of the relationship of Flemish Cap currents to macro-scale processes. Only Flemish Cap proper needs these instruments for this study.

Participants: Both the Canadian OAS and the U.S. Coast Guard have volunteered arrays and processing. Placement and recovery will be assisted by Canadian vessels if possible and required.

Scheduling: Placement should be in early February, and recovery six months later, in early August.

Program Development: OAS placings will be in 1979. No plans for 1980 are developed. The USCG may have placings in 1979 and later, but not in 1978.

OAS Mooring Positions for 1979

MOORING	DEPTH (M)	LATITUDE	LONGITUDE
A	200	47° 19'N	45° 08'W
B	200	47° 03'N	44° 21'W
C	200	46° 41'N	45° 10'W
D	400	46° 25'N	45° 48'W

C. 1. (b) Hydrography

It is anticipated that this will be done in conjunction with every biological station occupied as well as in independent hydrographic collections. There is a set of hydrographic transects specially developed for the program, involving both new lines and modifications of existing ones. For details, see Appendix 2. Beyond these special lines, the U.S. Coast Guard Ice Patrol will extend its detailed hydrographic surveys to cover more of Flemish Cap, for the duration of the project.

C. 1. (b)

(i) Oceanographic Transects

The objectives of monitoring a set of oceanographic transects on and around Flemish Cap are twofold: first, to continue certain time series that will allow the re-interpretation of past oceanographic conditions in the light of a relatively thorough study of the hydrography; secondly, to understand how the major oceanic currents might be acting as 'driving variables' for the Flemish Cap oceanographic regime.

Three ICNAF hydrographic sections currently are available in the Flemish Cap area: the 47° N Flemish Cap Section, USSR Section 7A (46° 08' N, 51° W to 50° N 45° W), and U.S. Coast Guard Section T (46° 20' N, 49° 10' W to 45° 20' N, 47° 40' W, then east to 45° W). These transects are criticized on the basis of insufficient seasonal coverage (very few observations exist for November to January), and insufficient range, especially the 47° N section which often fell short of observing the eastern branch of the Labrador current.

The OAS oceanographers contribution to this meeting includes a set of transects, diagrammed as Fig. 6 which, if occupied regularly would provide suitable monitoring of the surrounding oceanographic regime. They felt it would be valuable to have observations on the splitting of the Labrador current, which occurs just north of the Flemish Pass, and to observe the North Atlantic current to the southeast of Flemish Cap. Two intersecting sections along with the 47° N section were felt sufficient. Presumably ensuring that these transects extend southeast and west far enough to completely include the two major currents is intended.

The extent of mixing of water masses in the southeast section is not determined.

Monthly occupation of these Flemish Cap sections is suggested. Their positions are shown in Fig. 8.

C. 1. (b)

(ii) Hydrographic Measurements Within Stations

A grid of stations spaced approximately 20 miles apart should be sampled for temperature from surface to bottom as frequently as possible by all ships participating in the experiment. Our present understanding of the dominant time scale on the Cap suggests that a survey of the Cap must be completed within a 5-day period.

Objectives: Identification and delineation of water masses. Data for predicting and understanding the distribution vertically of larval fish and eggs. Computation of water movements by horizontal density gradients analysis. Estimation of primary production. Identification of upwelling regions. Identification of any water entering Flemish Cap from the Grand Bank. Estimating the relative influences of Labrador current and North Atlantic current waters on the Flemish Cap.

Scope: Flemish Cap and surrounding waters as required, especially for tracking the environmental conditions of eggs and larval fish. The following parameters are essential: meteorology, temperature, salinity, chlorophyll. The following are recommended: light, silicate, nitrate and other nutrients, turbidity.

Light, temperature and chlorophyll have some value in estimating primary production once the parameters have been estimated by special experiments.

Scheduling: Dependent upon other aspects of the program to a large extent, except for the routine, established hydrographic surveys of the area. The most valuable observations are from February to September although full seasonal coverage is required, with perhaps monthly intervals during the late fall-early winter period.

Program Development: The hydrographics part of the program is very dependent upon the developments within the biological part. Special hydrographics for patch studies are anticipated, possibly including analysis of light attenuation at different frequencies, dye movement measurements, microstratification observations.

C. 1. (c) Reporting Oceanographic Sampling

All the hydrographic and meteorological data collected are to be transmitted with all possible haste to MEDS. Under certain circumstances, transmission to the St. John's, Newfoundland Biological Station may be preferable. The use of the IGOSS communication facility is being investigated for its application in this project. ROSCOP forms should be completed.

Because of the need to confirm the loss from Flemish Cap of water containing eggs and larvae, hydrographic data have to be analyzed and acted upon in a matter of days. Proper program development in 1978 especially depends upon prompt receipt and sharing of data. The programs for 1979 and later need to be responsive to hydrographic events noted during each cruise.

C. 2. Biological Sampling

The techniques employed to sample, quantitatively, fish and zooplankton depend upon their size (hence mobility and reactivity) and location in the water column. Zooplankton, except for the smallest sizes under 500 microns, are collected by the gear used for larval fish and eggs. Currently no gear is widely accepted as giving a quantitative abundance for larval fish over about 25 mm.

Before giving any faith to any gear, it must be calibrated properly and monitored throughout its operations as closely as possible. This would include comparative tows at different speeds and different mesh sizes, the use of flow meters and depth meters, and analyses for the effect of environmental variables, including light, current direction, temperature.

A basic philosophy throughout a quantitative study of a system with a great deal of variance throughout all the scales of measurement, is to eliminate rigorously all artificially created variance to allow the statistical analyst some faith that the variation he is trying to reconcile is the natural variance that gives the system its emergent characteristics.

A breakdown of the life history stages suggests the gear types required. Their detailed operation and data collected are not the work of this report.

C. 2. (a) Adult and Large Juvenile Cod, Other Bottom-dwelling Fish Sampling

The use of a standardized high operating bottom otter trawl similar to the Russian trawl is being adopted by Canada as well. Standard procedures of this work are widely familiar.

Objectives: - To describe the distribution and abundance of one-year-old and older cod. - To provide specimens for detailed biological observations. - To indicate the abundance and distribution of redfish and other fish. - To indicate the distribution and abundance of squids and other invertebrates that prey upon, provide food for, and compete with cod.

Scope: The entire Flemish Cap to a depth of 450 meters, following the groundfish survey strata described in Wells (1977).

Scheduling: A winter survey of spawning stock and over-wintering juveniles is required, and the time-series of juvenile abundance done by the USSR should be continued. Details of seasonality in diet, condition, abundance and distribution, will require at least one other cruise each year. Table 4 indicates current scheduling.

Program Development: Beyond the two minimum winter and summer cruises, the cruises to suggest seasonality should be staggered through the months of the year for good coverage.

Participants: Canada and the USSR have committed themselves to surveys in 1978 and are in the process of scheduling a program for 1979. Participation by the F.R.G. and Poland has not been confirmed. No responses by other countries have been received.

C. 2. (b) Small Juvenile Cod, Large Larval Cod, Pelagic Fish Sampling

Of the many pelagic trawls available (IKMT, NIO, capelin trawl, 2 meter plankton nets, commercial trawls) none are reputed for their quantitative sampling, at least to those present. Only comparing indices of large larvae abundance from one year to the next in relation to the abundances of other, more quantifiably sampled life stages will be possible.

Experimental trawling with IKMT's was suggested by the group, for information on growth rates and distributions. As far as a quantitative fall survey for eight month larvae goes, there are no commitments.

Objectives: Analysis of growth in small pelagic cod. General ecological information on the larger species of the midwater community. Information on the occurrence of pelagic fishes of value as food for demersal cod. Potential index of comparative pelagic cod abundance.

Scope: Unplanned, but of more value to cod life history after July.

Program Development: Unplanned, may be further developed if pelagic fishes or squids appear to be important after the first year or two of the project.

Participants: None formally.

C. 2. (c) Cod Eggs, Yolk Sac Larvae, Swimming Larvae, Large Zooplankton

A great number of gears with different objectives exist for sampling .5 to 20 mm organisms quantitatively. None are very comparable and all are a trade off of the three problems of avoidance, clogging and extrusion. High speed samplers with extremely shallowly tapering nose cones, in the order of seven degrees, very large filtering ratios, and slow filtering speeds opening are required. The Jet-Net (Clarke, 1964) appears correct but is rarely used for some reason. The current Lowestoft samplers are heartily recommended by scientists from Lowestoft. Standardizing on the 61 cm Bongo just because it is commonly used in North America is begging the question. Vertical hauls appear to be hopeless as a quantitative tool for this project. The Sameoto 10 net multiple opening and closing sampler represents the state of the art for sampling with vertical resolution. The Boyd sampler, based on the principle of the Coulter counter (displacement of the seawater electrolyte), provides detailed data on the size and incidence of .5 to 25 millimeter particles, but also entertains the basic net problems. The total sample costs are high, in the order of $200.00 to $300.00 per sample for ichthyoplankton alone, including preliminary reports. Discussion of zooplankton sampling handling is deferred to section 2. (d), following.

It is suggested that 1978 sampling be conducted using paired 61-cm Bongos, both with 333 micron extra long nets towed to 200 m depth at 3.5 knots in a careful double oblique haul, following the techniques of Paul Smith's anchoveta larvae sampling (Smith and Richardson 1977). Further investigations may produce a more satisfactory gear for 1979. Paired samples give benefit not from an estimate of station variance (which is extremely small) but by doubling sample size for accuracy at low abundances and providing back-up samples in case of damage or error. Flow meters inside and outside, and a bathythermograph are basic calibration equipment for every tow.

It was the suggestion of the group that Canada supply the gear for foreign ichthyoplankton sampling, presumably including technicians.

Objectives: Quantitative ichthyoplankton samples. Material to describe growth, mortality, food and feeding of larval cod. Distribution and abundance of eggs and larvae. Quantitative zooplankton collections. Details of the ecology of the larval fish in the plankton community over a six month period. Details of the vertical distribution and transport of eggs and larvae. Collection of arthropod and predators.

Scope: A grid of 50 stations to be sampled within 5 days is required. Extra stations to gain precision at high densities may be required, and special stations for demonstrating loss of eggs and larvae may occasionally be required. Preliminary sampling to determine the vertical distribution and migration of larval fish should be conducted throughout the 1978 sampling; the vertical strata would be determined by hydrographic parameters if possible. Sampling in 1979 may be more complex. Two vessels each doing 25 or more stations in only 48-56 hours may have to be arranged to provide maximal synopticity. Since water transport rates should be known from current meters, such synopticity would result in the collection of eggs and larvae of known age and thermal history.

Participants: Plans for 1978 include commitments from the USSR for two cruises in April-July. Canadians hope to have at least one cruise in this period as well as a cruise in March. Poland indicated support would be possible for a short period in 1978 at Murmansk, however no details are known.

Scheduling: Every two weeks from March to June is ideal. The report of the Murmansk meeting details the expected season and intensity of sampling. For 1979 and later, a 30-day period without samples would be 'uncomfortably long', however, no firm commitments of vessel time are known in detail.

Program Development: The 1978 sampling is preliminary to the development of a 1979 program. Changes in every aspect may be expected if equipment funding is supported, however the bongo sampling may have to be accepted. Because the plankton sampling will be the subject of a meeting with USSR scientists October 17, 1977, details of program development are deferred to the report of that meeting.

Ichthyoplankton Sample Processing and Reporting

Standardization of sorting protocols is as important as standardizing gear. The development of a preliminary report form for visual assessment immediately upon collection is recommended, to be exchanged immediately. Details from laboratory counting of samples should not be delayed, and should be summarized into maps and tables of value for survey scheduling in the next year.

C. 2. (d) Small Zooplankton Sampling

As a measure of prey abundance for cod larvae, a mesh size of less than 80 microns is required to retain zooplankton naplii and small copepodites. Since the avoidance behaviour of these animals is minimal, a modified Miller sampler with a very small mouth opening is suggested as appropriate. It can be attached to larger gear conveniently. Vertical distribution of prey items may be important, since a minimal density on a volume basis is required by larvae, and this may not correspond to areal density. Dispersion of a thin stratum of prey throughout a thicker stratum of water may result in larvae starving while areal estimates of food available remain unchanged.

For 1978, total vertical hauls with a 1 meter net, 80 microns will suffice.

Objectives: Estimation of the distribution and abundance of larval fish food, to help explain variations in growth and mortality.

Scope: In conjunction with ichthyoplankton sampling.

Program Development: (Not yet determined)

C. 2. (d)

(i) Zooplankton Sample Processing

To be consistent with the objectives of the entire program, it isn't required that the dynamics of the zooplankton be understood or studied. Only the quantities and distributions of zooplankton size categories are needed. There may be important differences in the utilization of different species of zooplankton by larval fish. If so, gut contents analysis should suggest the appropriate detail required.

To simplify sample processing, it is suggested that sieving zooplankton into different size classes be undertaken. The dry weights of a sample so fractionated should be enough to demonstrate the importance of food in larval fish ecology.

Correlations of zooplankton size and decreasing temperatures as noted by Ware (1977) reveal again the extent to which temperature interacts with larval dynamics.

Zooplankton predators of eggs and larvae should be counted separately, although they will usually constitute the largest size fractions. Ctenophores and jelly fish do not preserve well, and it may be necessary to count them or estimate them volumetrically at sea.

As for other sampling, preliminary reports should be distributed very quickly.

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Table 1. Coding of the Twelve Hypotheses

	Spawning Stock	Predation	Environment	Food
Adult	A1 A2	B3	C1	D1
Eggs		B2	C2	
Yolk Sac Larvae				
Larvae			C3	D2
Juveniles		B1	C4	D3

Table 2. A matrix of hypotheses and some of the factors involved

	Hypotheses											
	Spawning stock		Preparation			Environment				Food		
	Number	Condition	Juveniles	Eggs & Y.S. Larvae	Adults	Adults	Eggs & Y.S. Larvae	Larvae	Juveniles	Adults	Larvae	Juveniles
Factors	A1	A2	B1	B2	B3	C1	C2	C3	C4	D1	D2	D3
Number and biomass of age 4	X	X	X	X	X	X	X	X	X	X	X	X
D/A Age/Size classes (adults)	X	X			X	X				X		X
Spawning stock biomass	X	X										
D/A cod eggs & Y.S. larvae	X	X		X			X					
D/A larvae								X			X	
D/A Juveniles												X
Quality of eggs		X										
Condition factors		X								X		
Stomach Contents) Size spectra			X	X						X	X	X
Gut clearance time) Predation rates			X							X	X	X
Food preference		X								X	Particle size	X
Digestability (rates)		X								X	X	X
Competitors											X	X
D/A prey species			X	X						X	Patchiness	X
D/A predator species			X	X								
Active removal of spawning stock	X				X							
Disruption of spawning behaviour		X			X							
Light								X	(X)			
Turbidity						X				X		
Currents						X	Surface	X	X	X	X	X
Wind and Met.						X	X	X				
Salinity							X	X				
Temperature			X			X	X	X	X	X	X	X
Growth rates		X		X	X	X	X	X	X	X	X	X
Diel vertical migration								X	X		X	

Table 3. Methodology

Adults		Eggs and Larvae		Juveniles	
Biomass and number of age 4		Biomass and number of age 4		Biomass and number of age 4	
D/A age & size classes (adults)		D/A age and size classes (E & L)		D/A age and size classes (Juveniles)	
Spawning stock biomass	(A1)				
Number of eggs	(A1)	Number of eggs	(B2)		
Quality of eggs	(A1)	Quality of eggs	(B2)		
D/A prey species	(D1)	D/A prey species	(B2) (D2)	D/A prey species	(B1) (D3)
Condition factors	(D1)	Condition factors	(D2)		
Stomach contents		Stomach contents		Stomach contents	
Food preference	(D1)	Food preference	(D2)	Food preference	(B1) (D3)
Gut clearance time		Gut clearance time		Gut clearance time	
Digestability					
Competitors	(D1)	Competitors	(D2)	Competitors	(D3)
		D/A predator species	(B2)	D/A predator species	(B1) MAN
		D/A alternate prey species for predators	(B2)		
		Growth rate	(B2) (D2)	Growth rate	(D3)
Temperature	(B3) (D1)	Temperature	(D2)	Temperature	(C4) (D3)
Currents		Currents		Currents	(C4)
Wind and met		Wind and met	(C2)		
Turbidity	(C1)				
Salinity		Salinity			
Light				Light	(B1) (C4) (D3)

Table 4. Biological and Hydrographic Sampling Schedules, 1978

Type	Country	Dates	Comments
Groundfish	Canada	Jan. 25-Feb. 15*	GADUS, biomass survey
	"	Nov. 6-24	A.T. CAMERON biomass survey, biological oceanographic data
	USSR	April	Juvenile time-series continued
	Poland	April 15-25	Condition factors samples only, WIECZNO
Plankton	USSR	April-May	Canadian gear suggested PROTSION, PERSEY III.
	Canada	Nov. 6-24	During groundfish cruise
	Poland	Apr. 15-25	With Canadian scientists, WIECZNO
Hydrographics	USA	March-May	U.S. Coast Guard Ice patrol.
	Canada	July-August	Standard hydrographic time-series continued

*This is to become a regular survey for the duration of the project.

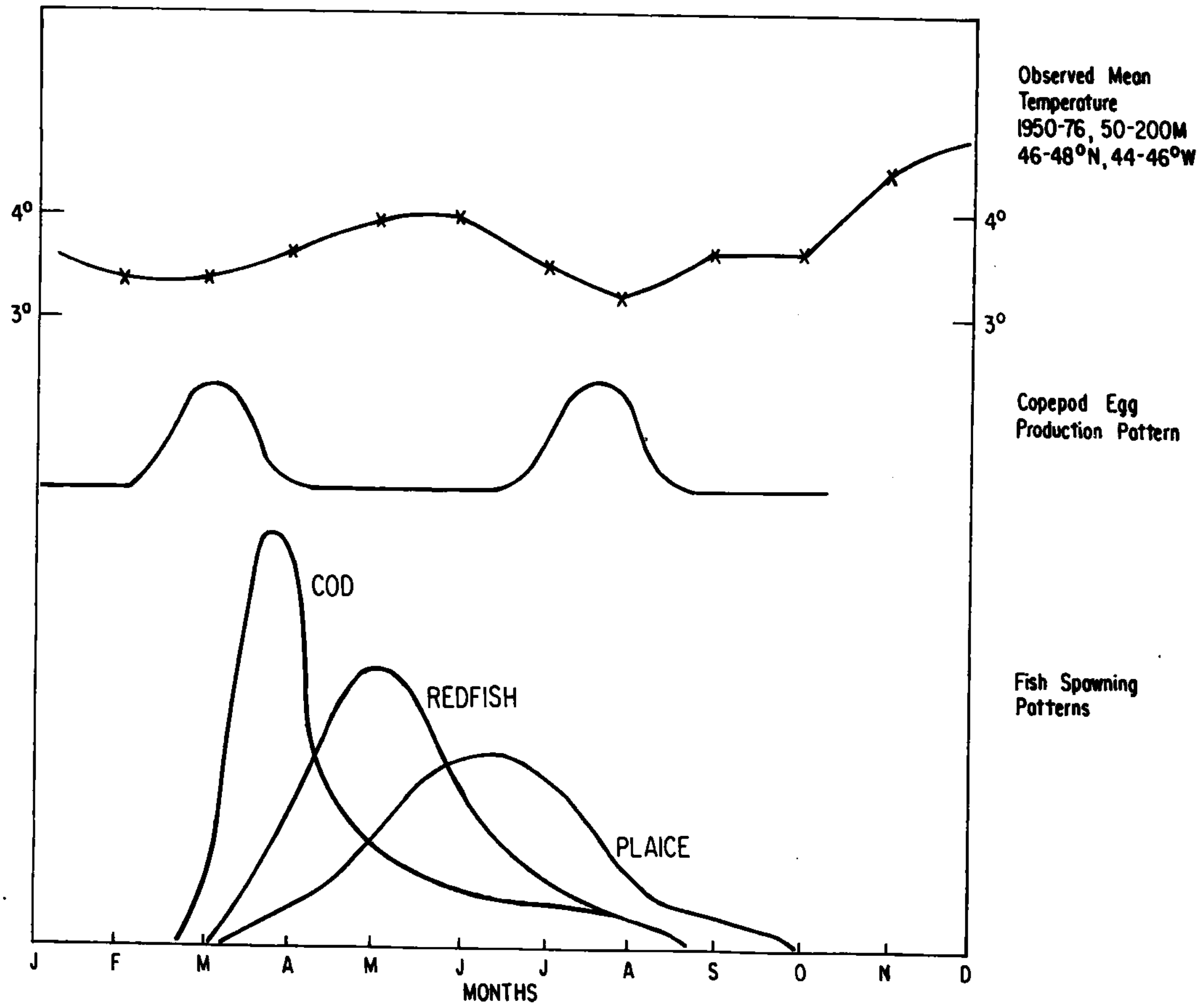


Fig. 1. Conceptual Summary of the Spawning Sequence of Flemish Cap Groundfish in relation to Biological and Environmental Events.

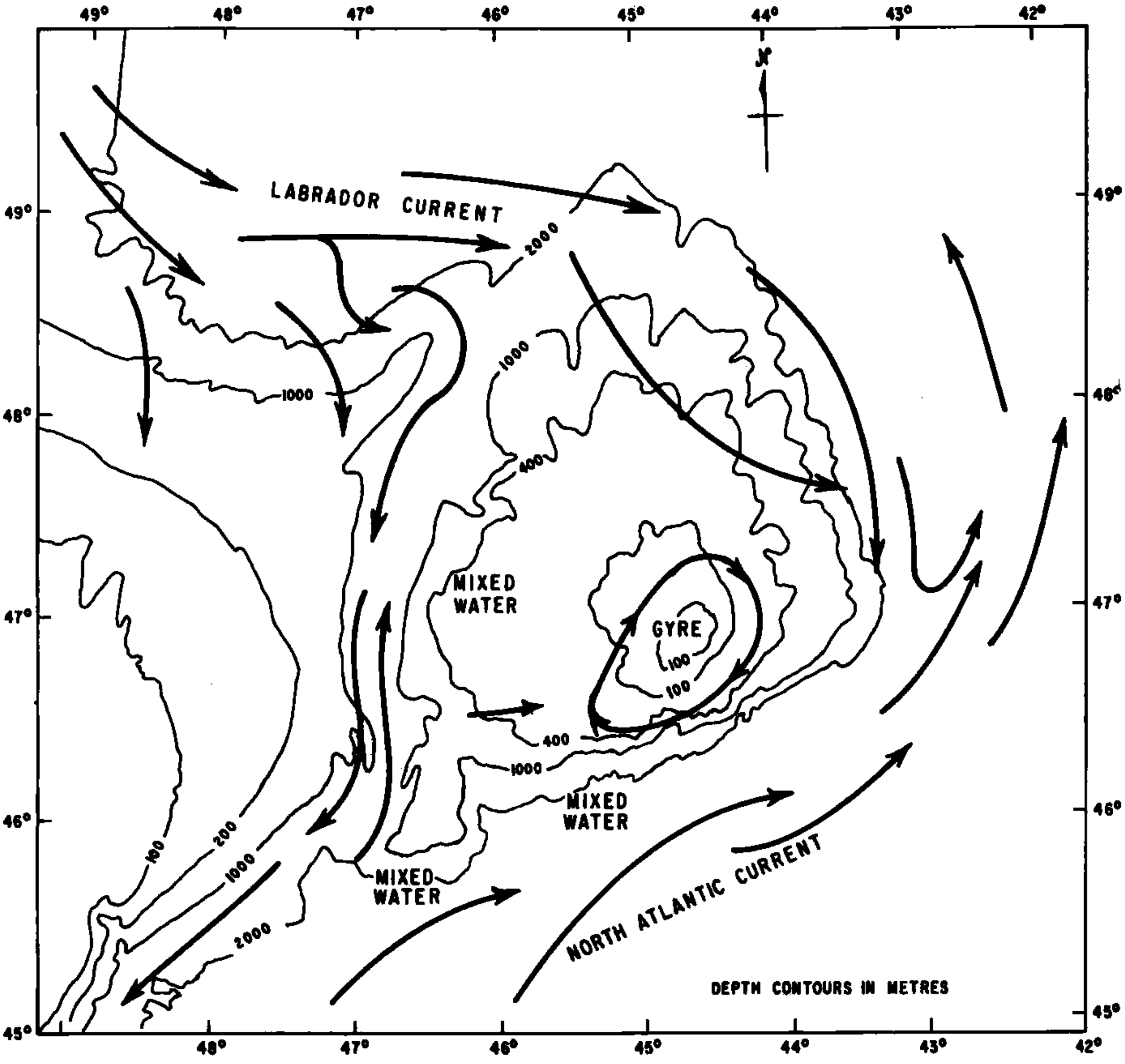


Fig. 2. A Sketch of the Suspected Current Regimes of the Flemish Cap Region.

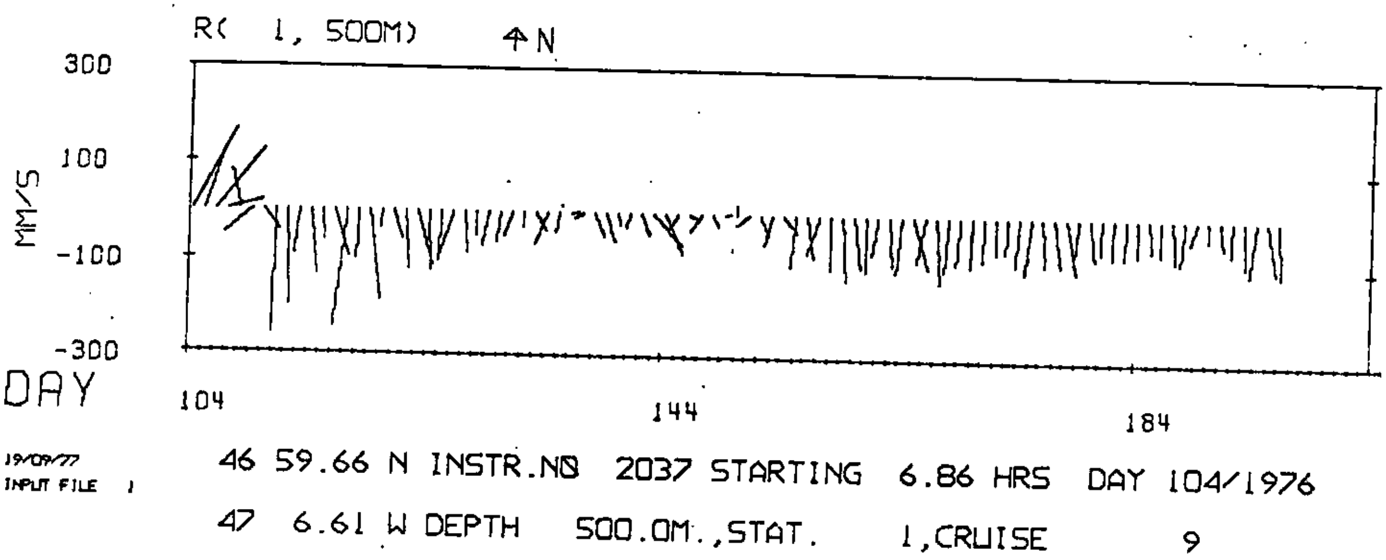


Fig. 3. Daily Current Velocity Vectors at 500 meters, Center of Flemish Pass, April 14 - July 16, 1976

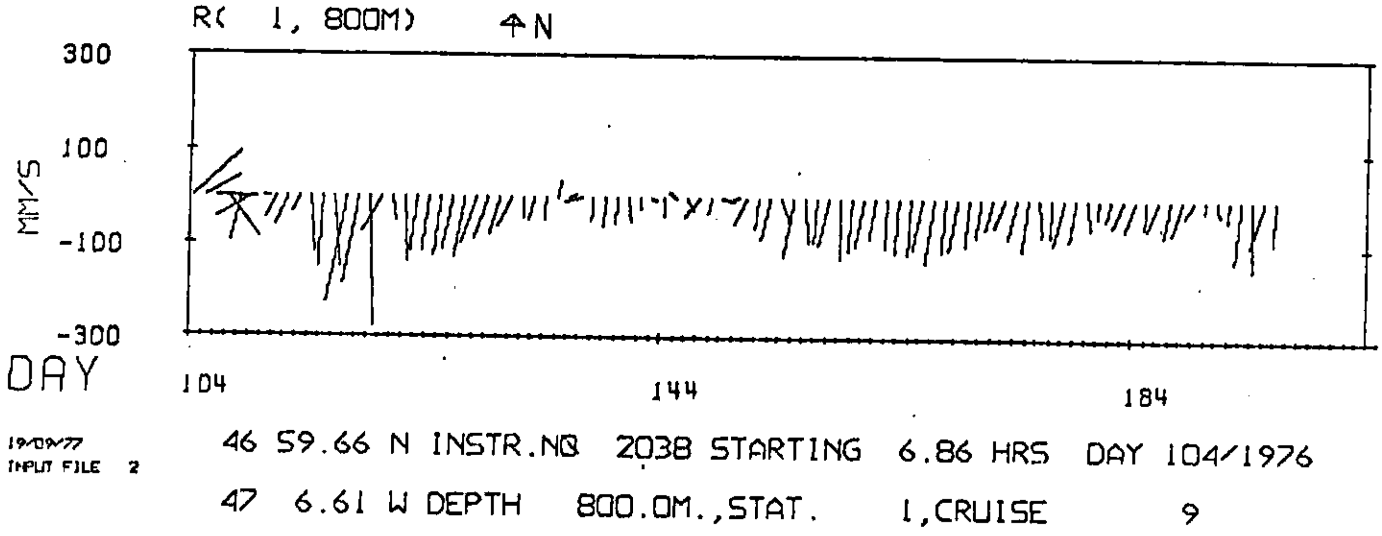


Fig. 3(a) Daily Current Velocity Vectors at 800 meters, Center of Flemish Pass, April 14 - July 16, 1976.

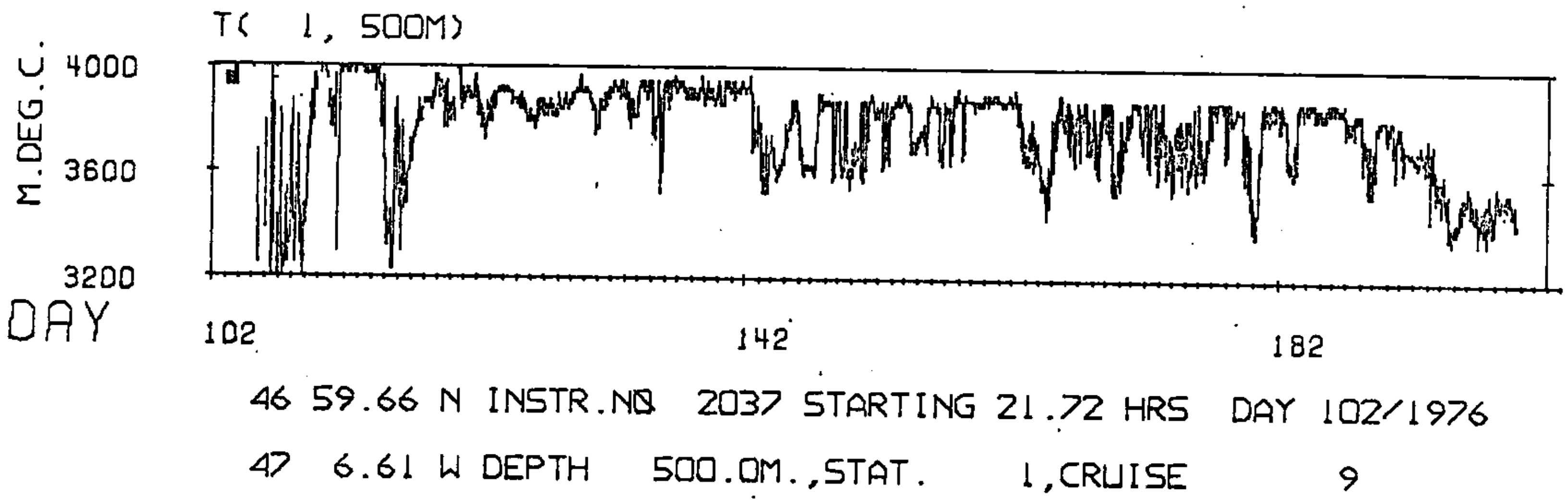


Fig. 4. Temperatures Associated with the Velocities of Fig. 3 (500 m).

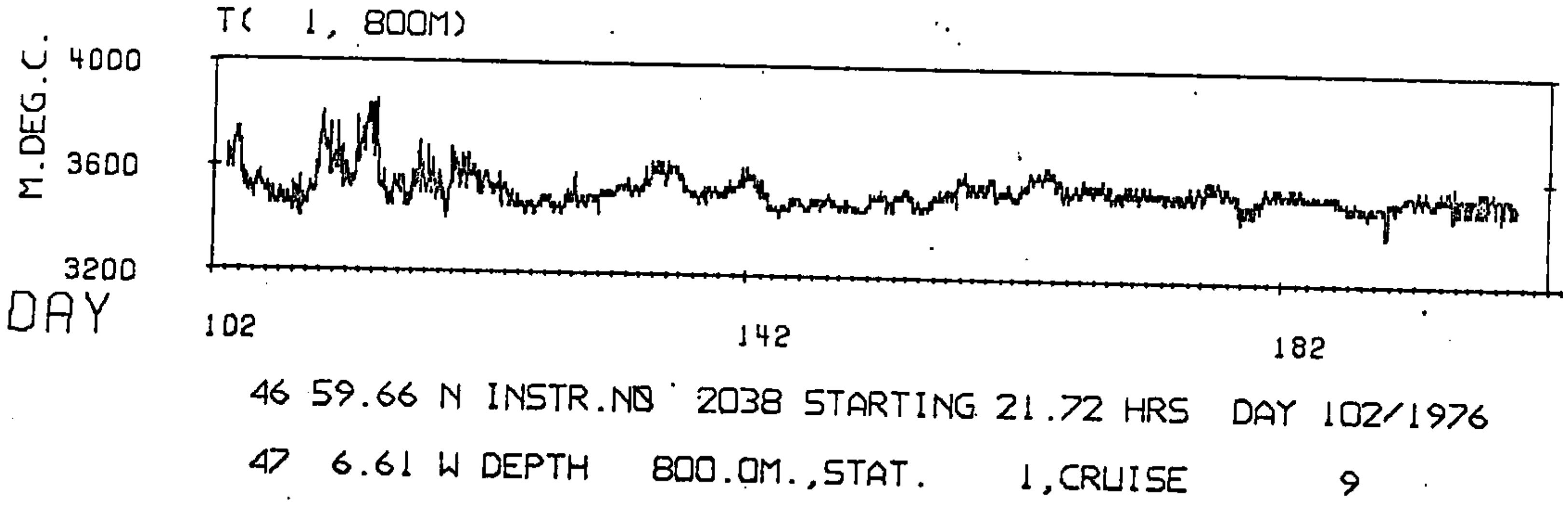


Fig. 4(a). Temperatures Associated with the Velocities of Fig. 3(a) (800 m).

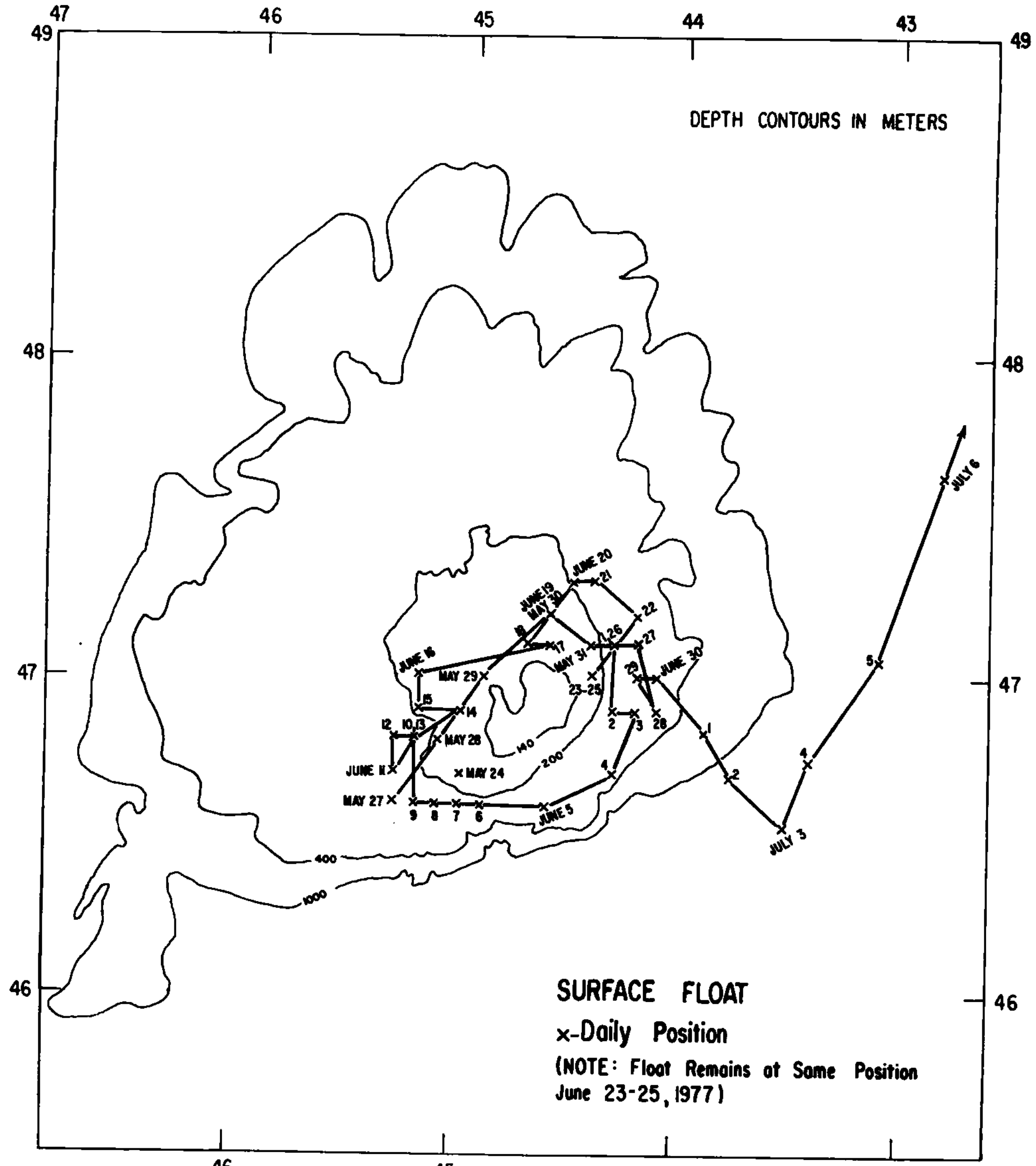


Fig. 5. Track of HERMES Satellite-Tracked Drifting Buoy, May - June, 1977.

Fig. 6. The First Division into Four Subhypotheses

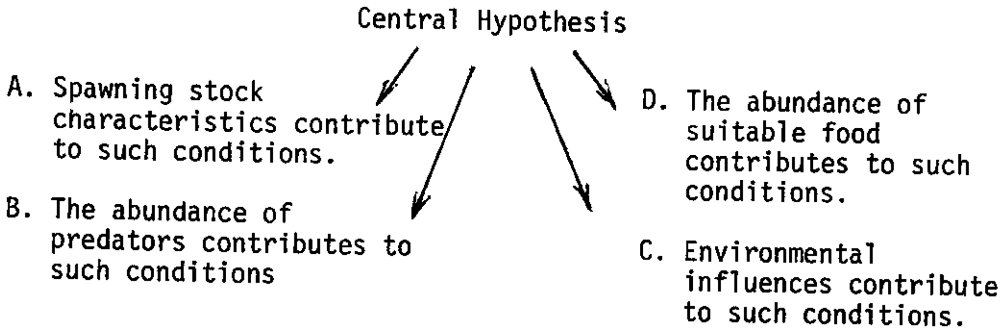
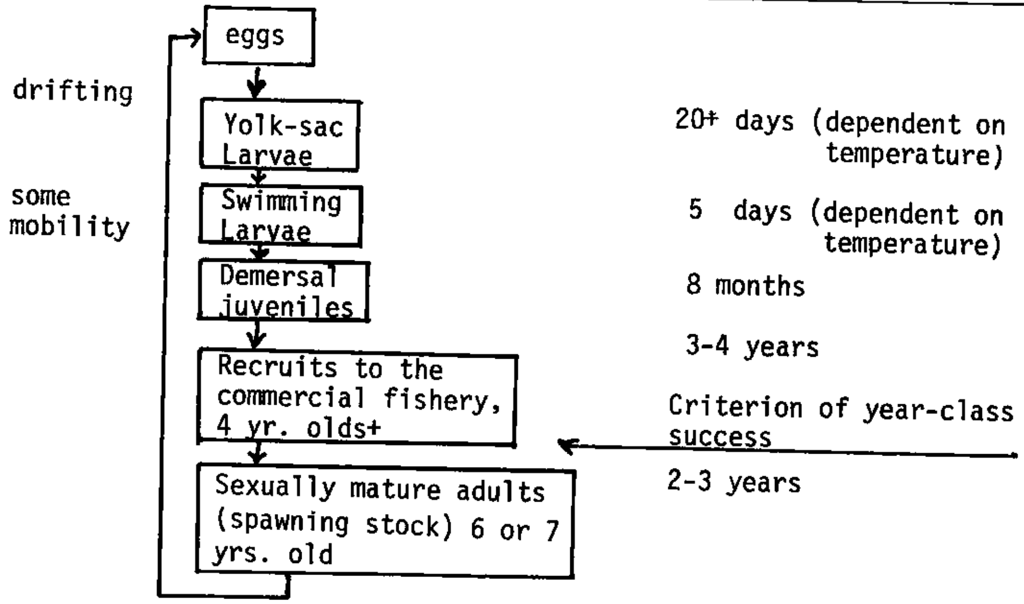


Fig. 7. Cod Life-History Stages



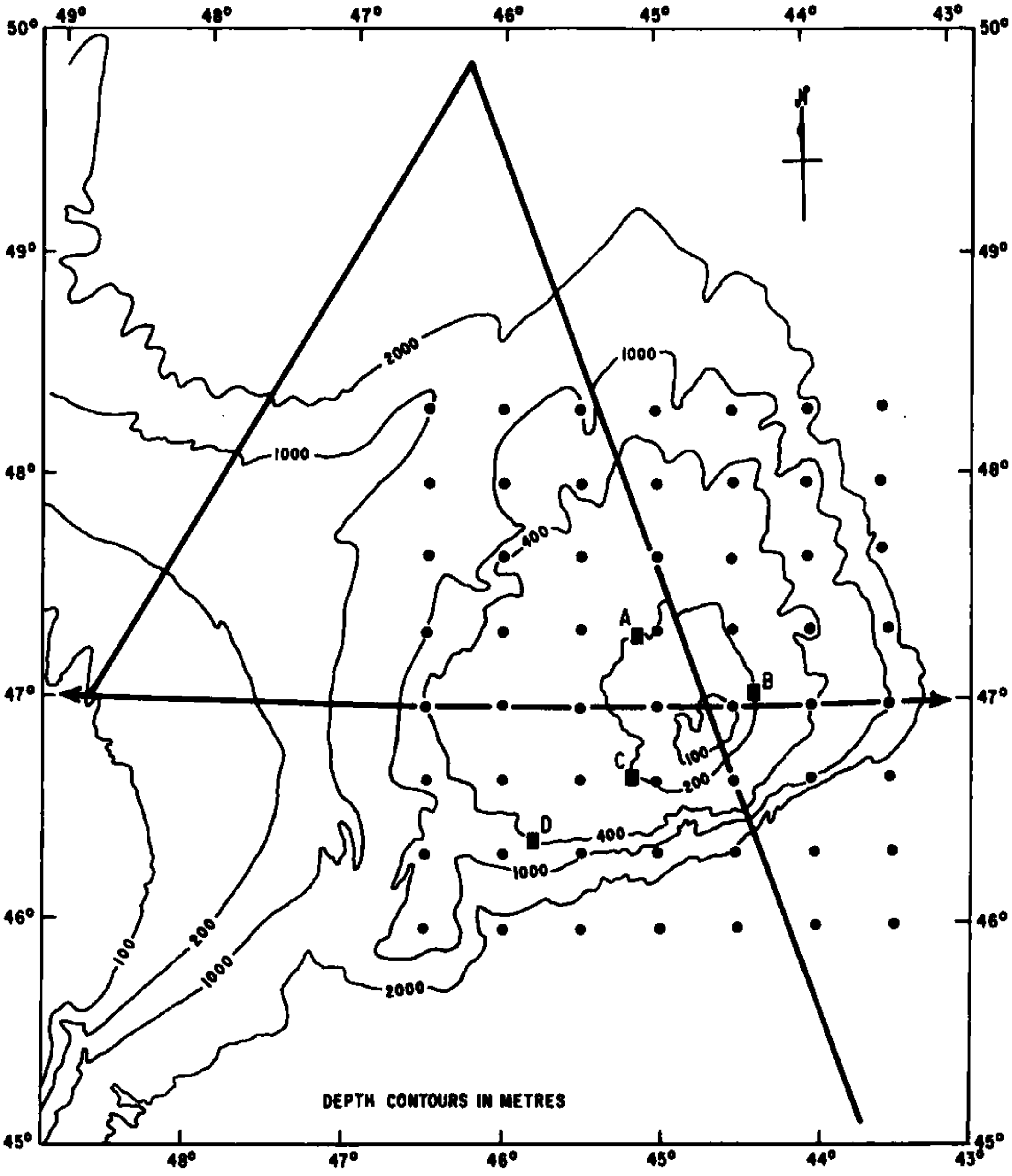


Fig. 8. Current Meter and Oceanographic Section Positions.

Appendix I

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Appendix II

Station Positions for the Flemish Cap International Experiment

STATION	POSITION		PROPOSED ORDER	DEPTH
5,A	47°00'N	52°00'W	1	145
5,B	"	51°00'W	2	108
5,C		50°00'W	3	90
5,D	"	49°00'W	4	95
5,E		48°00'W	5	145
5,F	"	47°30'W	6	225
5,G		47°15'W	7	414
5,H	"	47°00'W	8	1145
5,J	"	46°45'W	9	
5,1	"	46°30'W	10	365
5,K	"	46°15"W	11	350 (XBT only)
5,2	"	46°00"W	12	305
5,3	"	45°30'W	13	254
5,4	"	45°00'W	14	155
5,5	"	44°30'W	15	141
5,6	"	44°00'W	16	400
5,7	"	43°30'W	17	1000
5,8	"	43°00'W	18	3620
5,9	"	42°30'W	19	3750
5,10	"	42°00'W	20	4000
1,7	48°20'N	43°30'W	21	3000
2,7	48°00'N	"	22	3000
3,7	47°40'N	"	23	3000
4,7	47°20'N	"	24	1500
6,7	46°40'N	"	25	3000
7,7	46°20'N	"	26	4000
8,7	46°00'N	"	27	5000
8,6	46°00'N	44°00'W	28	5000
7,6	46°20'N	"	29	3500
6,6	46°40'N	"	30	1245
4,6	47°20'N	"	31	400
3,6	47°40'N	"	32	570

Appendix II. Station Positions for the Flemish Cap International Experiment (Continued).

STATION	POSITION		PROPOSED ORDER	DEPTH
2,6	48°00'N	44°00'W	33	965
1,6	48°20'N	"	34	1750
1,5	48°20'N	44°30'W	35	910
2,5	48°00'N	"	36	460
3,5	47°40'N	"	37	265
4,5	47°20'N	"	38	207
6,5	46°40'N	"	39	145
7,5	46°20'N	"	40	3060
8,5	46°00'N	"	41	4000
8,4	46°00'N	45°00'W	42	3000
7,4	46°20'N	"	43	1530
6,4	46°40'N	"	44	184
4,4	47°20'N	"	45	195
3,4	47°40'N	"	46	250
2,4	48°00'N	"	47	355
1,4	48°20'N	"	48	620
1,3	48°20'N	45°30'W	49	735
2,3	48°00'N	"	50	365
3,3	47°40'N	"	51	280
4,3	47°20'N	"	52	265
6,3	46°40'N	"	53	246
7,3	46°20'N	"	54	1160
8,3	46°00'N	"	55	2500
8,2	46°00'N	46°00'W	56	2000
7,2	46°20'N	"	57	560
6,2	46°40'N	"	58	326
4,2	47°20'N	"	59	349
3,2	47°40'N	"	60	625
2,2	48°00'N	"	61	925
1,2	48°20'N	"	62	1165
1,1	48°20'N	46°30'W	63	1000
2,1	48°00'N	"	64	1170
3,1	47°40'N	"	65	1185

Appendix II. Station Positions for the Flemish Cap International Experiment (Continued)

STATION	POSITION		PROPOSED ORDER	DEPTH	
4,1	47°20'N	46°30'W	66	980	
6,1	46°40'N	"	67	300	
7,1	46°20'N	"	68	800	
8,1	46°00'N	"	69	486	
T,27	44°56'N	43°42'W	70	3200	
T,26	45°16'N	43°52'W	71	4720	
T,25	45°35'N	44°01'W	72	4620	
T,24	45°54'N	44°10'W	73	4325	
T,23	46°14'N	44°19'W	74	3600	
T,22	46°33'N	44°28'W	75	600	354
T,21	46°52'N	44°37'W	76	135	
T,20	47°11'N	44°46'W	77	158	
T,19	47°30'N	44°56'W	78	226	
T,18	47°48'N	45°05'W	79	260	
T,17	48°08'N	45°14'W	80	390	
T,16	48°26'N	45°23'W	81	760	
T,15	48°44'N	45°32'W	82	1145	
T,14	49°02'N	45°41'W	83	2600	
T,13	49°20'N	45°50'W	84		
T,12	49°38'N	46°00'W	85		
T,11	49°57'N	46°09'W	86		
T,10	49°41'N	46°25'W	87		
T,9	49°25'N	46°41'W	88		
T,8	49°09'N	46°57'W	89		
T,7	48°53'N	47°11'W	90		
T,6	48°37'N	47°27'N	91	2450	
T,5	48°21'N	47°42'W	92	1920	
T,4	48°05W	47°58W	93	472	
T,3	47°49'N	48°13'W	94	280	
T,2	47°33'N	48°29'W	95	175	
T,1	47°17'N	48°45'W	96	110	
STA 27	47°32'05"N	52°35'10"W	97		