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Biological Oceanography Committee

REPORT OF THE WORKING GROUP ON LARVAL FISH ECOLOGY

Lowestoft, England 3-6 July 1981

This Report has not been approved by the International Council for the Exploration of the Sea; it has therefore at present the status of an international document for Working Group review purposes only and does not represent advice given on behalf of the Council.

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1. INTRODUCTION

1.1 Participants

The Working Group meeting was convened in Lowestoft, England 3-6 July 1981. The Group was welcomed by Dr. A. Preston, newly appointed director of the Laboratory, who kindly provided the use of a large conference room in a recently completed new addition to the Laboratory. Attendance included representatives from 11 ICES countries: CANADA, R. O'Boyle; DENMARK, P. Munk; FEDERAL REPUBLIC OF GERMANY, D. Schnack; FRANCE, N. Lacroix, D. Halgand; ICELAND, J. Magnusson; IRELAND, R. Grainger; NETHERLANDS, J. Zijlstra; NORWAY, P. Solemdal, S. Tilseth; SCOTLAND, J. Gamble; UNITED KINGDOM, D. Harding, J. Nichols, B. Thompson, J. Riley, S. Coombs, S. Lockwood, J. Pope, J. Shepard; and UNITED STATES, K. Sherman. Although no representative from Poland was present we were pleased to receive a written status report on larval fish research from Mr. S. Grimm of the Sea Fisheries Institute, Gdynia.

1.2 Terms of Reference

The meeting provided a forum for scientists studying larval fish ecology to discuss the various strategies employed by ICES countries for investigating larval fish distribution, abundance, growth, and survival in relation to fish stock assessments.

The first half of the meeting was spent reviewing ichthyoplankton studies in the member countries, followed by subgroup discussions and drafting recommendations addressing the following terms of reference:

- Evaluate the present sampling designs of ichthyoplankton surveys taking into account differences in the mesoscale and microscale distributions of larvae of different species and areas,

and

- Review results of ongoing research in patch and enclosure studies in conjunction with experts in biological and physical oceanography.

2. NATIONAL REVIEWS

Considerable effort is underway in ICES on mesoscale studies of ichthyoplankton that contribute to fish stock assessments, and microscale and experimental studies that focus on the underlying ecological processes controlling the growth and survival of fish eggs and larvae in the sea. The following reports provide mini-reviews of ichthyoplankton studies in 11 of the ICES countries:

2.1 Canada

Ichthyoplankton studies in Canadian waters can be readily divided into broad scale surveys, process studies and laboratory studies.

Broad-scale Surveys

The multi-species ichthyoplankton surveys in the Newfoundland coastal area continue with focus shifted from Fortune Bay on the south coast to Trinity Bay on the northeast coast to moniter herring and capelin spawning.

The Scotian Shelf Ichthyoplankton Survey is now subject to a major review in the light of four years' results. The initial aim was to identify spawning areas and stocks and to that end an overall coverage of at least two surveys in each month will be achieved by 1982. The review in October 1981 will examine whether this type of survey can be used in support of stock size estimates and for studies of multi-species interactions. Problems produced by varying sampling methods and strategies will also be reviewed.

The annual March Bay of Fundy herring larval surveys continue and are used in support of stock assessment. Similarly there have been mackerel egg surveys in the Gulf of St. Lawrence since 1976, which are used to calculate spawning stock biomass.

Process Studies

The Flemish Cap project, begun in 1979, has concentrated on understanding the mechanisms which operate during the egg and larval phase to produce fluctuation in year-class strengths to a fishery. Of particular interest were the cod, plaice and redfish stocks. The declaration of a 200 mile fishery limit by Canada brought increased fishing pressure to the Flemish Cap resulting in a serious depletion of the cod stock which has, thus, affected the programme. The increased fishing effort also resulted in a high equipment loss for independent systems such as current meter networks. Despite these setbacks, work has progressed well on redfish larvae.

Results in 1979 indicated high mortality in redfish larvae while cod eggs and larvae were all but absent in our samples. Recent ground trawl data indicate a 1979 cod year-class does not exist on Flemish Cap. It appears 1979 was a poor year for Flemish Cap larvae. Now, in 1981, our preliminary results indicate a comparatively good year for larvae. We have extensive oceanographic, chlorophyll, nutrient, zooplankton, larval feeding, condition and otolith ageing data to supplement these observations. These data are now being analyzed to determine possible causes for differences in larval abundances observed in 1979 and other years. Future work will concentrate on comparative observations on cod spawning concentrations, maturity and fecundity to estimate eggs spawned versus egg and larval abundances estimated from ichthyoplankton surveys.

In the Emerald Bank area of the Scotian Shelf a process study on silver hake has begun. The variability of different sampling gear has been examined and some feeding studies conducted.

In the Banquereau Bank area a process study involving both cod and haddock larvae is planned.

Laboratory Studies

Ageing fish larvae using growth zones on the otoliths is being developed as a routine technique for cod, redfish, silver hake and herring larvae.

Embryonic deformity in early stage mackerel eggs is a common feature in fixed plankton samples, and can affect the accuracy of the stage I egg production estimate. Possible reasons for these deformities such as death before capture, net death and osmotic hazard of fixation are being investigated.

Equipment for *in situ* particle size analysis is being developed in support of the ichthyoplankton process studies. Similar equipment is being developed for egg counting in the laboratory.*

2.2 Denmark

Ichthyoplankton studies have been confined mainly to experimental work and modelling in recent years. The emphasis has been to examine the relationships between fish larvae and their prey organisms in order to produce a feeding strategy model for herring larvae. A number of experimental methods are under development, including the storage of fish gametes by deep freezing, cultivation of copepods and *in situ* scanning of plankton at sea.

Laboratory facilities at the institute in Charlottenlund have been improved and are equipped for small scale experiments. A laboratory is under construction at the Hirtshals Sea Center, where large scale experiments

*A more complete account of ichthyoplankton research in eastern Canada is given in Appendix 4.1.

in large tanks and concrete basins will be conducted. In addition, the recent completion of a new research vessel RV DANA has opened up new possibilities for field studies. One of the first ichthyoplankton surveys for the RV DANA will be the ICES herring larvae survey in the autumn of this year.

2.3 France

Most of the ichthyoplankton surveys by France in the ICES area are along the French Channel coast. They are undertaken in order to assess the impact of both planned and operational nuclear power plants.

Bongo nets fitted with 315 µm and 500 µm nets are used on oblique tows at two knots, sampling in each area at bi-monthly intervals. The observations made since 1975 have resulted in a picture of annual ichthyoplankton cycles, which can be related to hydrographic and biological changes, such as secondary production.

At operational nuclear plants the entrainment effects on fish eggs and larvae are assessed. The eggs and larvae of sole and sprat are particularly vulnerable in the Channel and the field studies on these species have been augmented by laboratory studies of thermal, mechanical and chemical shock.

The RV THALASSA took part in the international mackerel egg survey of the Celtic Sea and Biscay in June 1980.

In 1982, five surveys of the bay of Biscay for sole eggs will be conducted at monthly intervals between January and May. They are aimed at determining the spawning distribution and assessing the spawning stock size for sole in the area.

France will also participate in 1982 in the international herring larvae surveys in the North Sea and Channel.

2.4 Federal Republic of Germany

Considerable effort is underway in laboratory and at-sea studies in the North Sea, the Baltic, and the California Current regions.

Experimental Work

Hatching success.--Studies of hatching success related to gonad contamination in the Baltic flounder are conducted at the Biologische Anstalt Helgoland by H. Westernhagen; studies of hatching success in relation to parent size of Pacific herring are conducted in cooperation with the Pacific Biological Station, Nanaimo, Canada; and studies on mortalities associated with egg densities are carried out by A. Hourston, and on mortalities associated with the influence of substrate by H. Rosenthal.

Ecophysiology, bioenergetics.--Raising flounder and turbot from eggs to beyond metamorphosis, studying related ecophysiological problems, and studies on energy transfer within an artificial food chain from phytoplankton through larval fish are being carried out at the Institute für Meereskunde, Kiel, by W. Nellen.

At-Sea Studies

Participation in cooperative ichthyoplankton survey programmes: ICES Joint Larval Herring Surveys in the North Sea and adjacent waters and surveys on eggs and larvae of mackerel south and west of Ireland are being carried out by the Institut für Meereskunde, Kiel, under the direction of G. Joakimsson.

Special studies on the ecology and distribution of eggs and larvae including studies on mackerel in the North Sea focusing on distribution, growth, feeding, and variability in abundance on different scales (tenths of meters to miles) using the Meshai-System. These studies are conducted at the Institut für Meereskunde, Kiel, by H. Grave.

Studies on vertical distribution of eggs and larvae in the CalCOFI-area related to the time of day and the stage of development have been completed. Sampling was carried out in spring 1980, based on the Meshai-System supplemented by a series of other methods in Cooperation with the SW Fisheries Center, La Jolla, and Institut für Meereskunde, Kiel, by T. Pommeranz.

Studies of the interrelation between invertebrate and ichthyoplankton development in the Schlei Fjord, western Baltic are being carried out by the Institut für Hydrobiologie und Fischereiwissenschaft, Hamburg, under the direction of D. Schnack.

2.5 Netherlands

Eggs and Larvae

Netherlands vessels will continue to participate in the ICES herring larvae surveys in the North Sea and around the British isles in late summer and autumn and also in the surveys of late larval clupeids in the North Sea in February.

In 1980 the Netherlands took part with a moderate effort in the patch study on plaice eggs and larvae in February-March.

In addition, monitoring the immigration of herring and plaice larvae into the Wadden Sea, underway for more than 10 years will be continued.

A special programme has been launched to follow the immigration of plaice larvae into the Oosterschelde (southern delta) to assess the effect of large engineering works in that area including a semipermeable dam.

Participation is considered in a mackerel-egg survey in the North Sea for 1983.

During zooplankton studies in the southern and central part of the North Sea, attention is and will be given to fish larvae as agents causing zooplankton mortality.

Late Larval and Early Postlarval Stages

Special studies on the immigration of plaice larvae, and their settlement, growth and mortality in the western Wadden Sea will be continued. Although the emphasis of these studies is on plaice, other flatfishes will be considered also. Special attention is devoted to food and predators of late larvae and early postlarval plaice.

Experimental Work

Laboratory experiments are mainly directed to the effect of temperature on egg development and on the effect of food and temperature on the growth rate of larvae and early postlarval fish. Experiments are concentrated on sole and plaice but include other species as well.

In addition, experiments are carried out to assess the possible effect of predators (e.g., brown shrimps, *Pleurobrachia*) on mortality of juvenile plaice.

2.6 Iceland

The annual ichthyoplankton surveys, conducted for the past 6 years in Icelandic waters between April and June, have been terminated to allow time for the material to be analysed. The analysis is progressing well and as a result the emphasis on future surveys will be toward more detailed studies of larval feeding competition and environmental influences on this factor. These types of studies will utilise a modified version of the fish pump sampling gear developed for scientific use by Norwegian scientists.

Since 1976 Iceland has continued to conduct the 0-group survey, previously carried out around Iceland and in the Irminger Sea by several nations. The emphasis is on producing abundance indices for cod, haddock, capelin and redfish.

Some ichthyoplankton studies are conducted on the annual plankton and hydrographic survey around Iceland. This study in May-June has continued for almost thirty years.

An annual survey of the distribution and abundance of redfish larvae around Iceland and in neighbouring waters has been conducted since 1976 with the exception of 1979.

2.7 Ireland

The Fisheries Research Centre has conducted surveys for herring larvae for the last four years (October-February) off the south coast of

Ireland for the purpose of monitoring the Celtic Sea herring stock. These have shown a continuing decline in spawning stock biomass since their inception in 1978/79 (ICES CM 1981/H:44).

Multispecies egg and larval surveys have also been conducted off the south coast at monthly intervals between February and August in 1979 and 1980. The sprat egg abundances were used to assess the spawning stock biomass of the sprat population spawning in the area (ICES CM 1981/H:43). Mackerel egg distributions were also described (ICES CM 1981/H:13).

A further multispecies egg and larval survey with cruises between March and August 1981 at monthly intervals was carried out in the western Irish Sea.

A new series of herring larval surveys was started in 1981 off the west and northwest coasts of Ireland with three cruises in October and November.

The University College, Galway, is involved in ichthyoplankton research off the west coast of Ireland, and in particular, Galway Bay. This work is mainly descriptive but vertical and horizontal distributions are examined in relation to physical and chemical oceanographic data collected concurrently.

2.8 Norway

In recent years research on the early life history of fishes has concentrated on enclosure studies relating larval survival to varying food densities. This type of study has ranged from small plastic bags and large tanks to open basins as well as the Lofoten area. Most of the process studies in enclosures have used cod larvae, but some work has also been done with capelin larvae, where data on food uptake, growth and survival were collected over a period of 127 days. In addition to these process studies, there have also been attempts to mass produce post larval cod in enclosures, harvesting 0-group cod in the autumn from newly hatched larvae introduced in the spring.

The enclosure studies are continuing, but more effort is put into field studies using the knowledge gained in laboratory and enclosure studies. For these to succeed it is necessary to develop new and quicker sampling methods to provide a synoptic picture over a large area. To this end an *in situ* particle size analyser has been developed and used at sea, and a plankton pump, based on a purse seine pump, has been developed as a plankton sampling pump. The particle size analyser based on the HIAC-PC 320 particle analyser will count and size particles in the range of 100-600 μm. The pump used in sampling cod larvae delivers at a rate of 3 m^3 per minute and produces larvae in a condition suitable for qualitative feeding studies.

Annual ichthyoplankton surveys for mackerel eggs in the North Sea and the coastal surveys between Bergen and the Lofoten Islands are continuing. In addition a post larvae survey of commercially important species from Lofoten to the USSR border and a survey to examine capelin spawning sites have begun.

Experimental work on eggs and larvae has included genetic studies on the separation of the Arcto/Norwegian and Norway coastal, cod stocks. Similar studies have also been made on plaice. An electrophoretic method to separate individual cod and haddock eggs has been successfully developed. Successful rearing of two halibut larvae to metamorphosis from a batch of artificially fertilised eggs has been achieved at the Flødevigen Laboratory.*

2.9 Poland

The Polish ichthyoplankton studies in the ICES area have been centered on participation in the Georges Bank herring larval surveys, and some work in the southern Baltic.

Involvement with the Georges Bank surveys has included the establishment of a Sorting Centre in Szczecin to analyse all the material collected, as well as to participate in the field work.

Work in the Baltic during the last three years has been confined to tows with bongo nets at random stations within the Polish fishery limits. From 1982 these studies will receive new impetus as effort is directed through both meso- and micro-scale sampling towards specific objectives. These objectives will include description of fish egg and larval distribution, attempts to calculate egg and larvae mortality and to use egg or larval abundance as an index of stock size. The main emphasis in these studies will be on cod, sprat and herring and it is hoped that they will provide a better understanding of the recruitment processes for these species.

In July of 1981 an ichthyoplankton survey of about 100 stations in the southern Baltic was conducted in relation to the environmental effects of pollution in that area.

2.10 United Kingdom

A report and summary of the results of the ichthyoplankton surveys off the northeast coast of England throughout 1976 is now in press (Harding and Nichols, MAFF Tech. Rep. 1981). The report includes descriptions of all the major spawnings in the area, predation studies on fish eggs and larvae and the results of replicate hauls done on each survey.

A patch study conducted in the Southern Bight of the North Sea in February/March 1980 demonstrated that plaice eggs and larvae could be successfully sorted and staged at sea and the patch of larvae tracked. Five consecutive grids over the larvae patch were completed and larvae mortality rates for the period calculated.

Opportunities have been taken during 1979 and 1980 to collect both plankton and hydrographic data in the vicinity of known fronts. These data are being reviewed in relation to the importance of fronts to fisheries in the North Sea.

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*A more detailed report on ichthyoplankton research in Norway is given in Appendix 4.2.

The UK participated with RV SCOTIA and RV CIROLANA in the mackerel egg surveys to the west of Britain and in Biscay in 1980. The spawning stock size estimate calculated from these surveys will be reported at the 1981 ICES meeting (Lockwood et al., CM 1981/H:13).

UK vessels have participated in the ICES herring larvae surveys of the central and southern North Sea and eastern English Channel. Larval abundance in the eastern English Channel has risen dramatically to the 1951-52 levels, but in the central North Sea larval abundance has continued to decline, and there is no evidence of an increase in spawning stock biomass in spite of the absence of a directed fishery.

One survey of the plaice egg patch in the southern North Sea was undertaken in January 1981. The spatial and vertical distribution of newly spawned eggs was examined in relation to the spawning behaviour of the adults.

Three ichthyoplankton surveys of the English Channel have been completed between April and June 1981. The initial aim was to examine the distribution of sole (Solea solea), sprat (Sprattus sprattus) and bass (Dicentrarchus labrax) spawnings. On the first survey artificially fertilised sprat eggs were successfully reared to hatching at nineteen different temperatures between 4°C and 19°C.

A HIAC particle size analyser has been developed for continuous monitoring of particle size at sea. The equipment is used to support frontal zone studies and can also be used in the laboratory for fecundity estimates.

Some studies of lobster and Nephrops larvae distribution have begun with the aim of using larvae abundance for stock size estimates. The diurnal variation in the vertical distribution of lobster larvae has made quantitative sampling impracticable and that part of the project has been suspended. Some qualitative work on lobster larvae is continuing in Scottish waters. Nephrops larvae are, however, sampled quantitatively with high speed nets and their seasonal abundance can be calculated. A survey of the western Irish Sea for Nephrops larvae is planned for 1982.

In Scotland the programme to examine whole ecosystems in enclosures is continuing using herring larvae, hatched within the 300 cubic metre plastic bags, fed on a natural population of phytoplankton and copepods. This study is partly related to the environmental effect of "production water" a waste product from the offshore oil exploration industry, made up of sea water and hydrocarbon.

The Clyde herring larvae surveys have now ceased because the spawning stock has become too small to justify any further effort.

The Institute for Marine Environmental Research at Plymouth continues to collect data on fish egg and larvae distribution using the continuous plankton recorder surveys in the North Sea, English Channel and North Atlantic ocean. This long-term data series on fish eggs and larvae in relation to the environment will be enhanced in the future by the continuing development of the undulating oceanographic recorder. This is now in experimental use on some shipping routes and on research vessel surveys.

The Longhurst Hardy plankton recorder is being used to examine vertical distribution of fish eggs and larvae in relation to environmental parameters and their survival strategy.

2.11 United States

MARMAP Ichthyoplankton Surveys

The MARMAP survey unit of the National Marine Fisheries Service (NMFS) at Sandy Hook, New Jersey, in 1981 completed the fourth consecutive year of ichthyoplankton surveys in shelf and slope waters off the middle Atlantic and northeast coast of the United States, an area of some 260,000 km^2. Mesoscale surveys of shelf and slope waters were underway during 10 months of the year. They utilized 238 vessel days, collected 2,000 plankton samples and recorded nearly 50,000 observations of temperature, salinity, dissolved oxygen, chlorophyll a, nutrients and ^{14}C. Analyses of ichthyoplankton samples over the past four years reveal marked seasonal differences in the abundance of eggs and larvae but several consistent patterns emerged. Among the most noteworthy were: the high abundance of sand lance larvae during the winter months, especially off Southern New England; the continued low abundance of Atlantic herring larvae during autumn on Georges Bank; and the recurrent overlap in areas of high chlorophyll a concentrations, zooplankton biomass; and dense patches of fish eggs and larvae. Based on the distribution and abundance of eggs and larvae, initial spawning success during the peak spring and summer period was greater in 1977 and 1979, when spring warming began in April, than in 1978, when an unusually cold spring delayed warming by several weeks. Although sand lance (*Ammodytes* spp.) larvae continued to dominate our ichthyoplankton collections during the winter of 1980, their overall mean abundance (64 larvae/10 m^2 surface area) was drastically reduced from the record high level observed in 1979 (417 larvae/10 m^2 surface area). The center of their abundance in 1980 remained off Southern New England, in the vicinity of Nantucket Shoals, where they had been most abundant since shifting from Georges Bank in 1976. Whereas the three winters of 1977 to 1979 produced record cold conditions, the weather moderated during the winter of 1980. During the autumn of 1979 Atlantic herring larvae increased in abundance over 1977 and 1978 levels along the western part of the Gulf of Maine, but for the third consecutive year, herring larvae were scarce to absent on Georges Bank where they were most abundant during the 1960's. In addition to monitoring seasonal and annual changes in the distribution and abundance of fish eggs and larvae, we have been directed to obtaining spawning-stock estimates based on fish eggs collected on MARMAP surveys. Work is currently in progress on yellowtail flounder, silver hake, bluefish and haddock. Taxonomic studies on the early stages of *Phycis* and *Urophycis*, *Sebastes*, and *Liparis* are underway, and the guide to the identification of early stages of marine fishes from the northwest Atlantic is under review.

At the Woods Hole Laboratory of NMFS, the analyses of larval Atlantic herring data from 39 surveys have been completed. The surveys were conducted by the International Commission for the Northwest Atlantic Fisheries in the Georges Bank-Nantucket Shoals area over the 1971-1978 spawning seasons

(October-February period). Seasonal abundance estimates by one-millimeter length classes and their confidence intervals were made using the delta-distribution to account for the high proportion of empty hauls on these surveys. For the fully vulnerable length classes, length-specific instantaneous mortality rates were estimated by log-linear regression for each season. Age specific mortality rates were estimated similarly after adjusting for length-class duration using a Gompertz growth model based on otolith daily growth increments. The mortality curve also provides a series of initial larval abundance estimates by extrapolating back to size at hatch. Mortality rates are being compared within each season and from year to year in relation to: the initial and subsequent abundance of larvae; their spawning time and location; larval size, growth, condition, and prey selection; recruitment; and changes in hydrographic and climatic patterns. The larval herring time series includes a wide range of initial larval abundance estimates, mortality rates, and other conditions in which to examine some of the leading hypotheses controlling larval survival and eventually their recruitment. It appears that high larval survival is associated with the high abundance of their prey, Pseudocalanus minutus. Larval herring prey selection and morphological condition from three contrasting spawning seasons (1974, 1975, and 1976) are being examined in detail. Studies are also in progress on the composition, abundance, and distribution of the total ichthyoplankton and zooplankton from the same series of surveys.

MARMAP Microdistribution and Process Studies of Ichthyoplankton Growth and Survival

Experimental studies by NMFS staff at Narragansett including a preliminary study of the effects of water temperature on the timing of yolk absorption and first feeding in haddock and winter flounder larvae were completed along with studies of the effects of water temperature on the relationship between RNA-DNA ratio and growth rate in haddock, winter flounder and summer flounder larvae. RNA-DNA ratio was found to be a good estimator of growth rate in these species. A study of the effects of existing contaminant burdens on the viability of striped bass eggs and larvae from selected east coast river systems was undertaken in cooperation with the U. S. Fish and Wildlife Service, Columbia National Laboratory.

In the first year of the proposed three year study larvae from females taken from five river systems were reared in "clean" water at the Narragansett Laboratory. Growth and daily mortality was monitored together with selected classes of biochemicals including RNA and DNA. Analysis of tissue contaminants is being conducted at the Columbia Laboratory. A nitrogen budget for larval summer flounder was estimated using measurements of growth rate, and ammonia and primary amine excretion. The budget includes an estimate of the daily cycle of nitrogen excretion and allows the estimation of the changes in daily ration and growth efficiency with growth and development during the larval stage.

In Situ Studies on Georges Bank

The ability to predict early life stage survival and relate it to recruitment requires three main components: (1) seasonal population abundance estimates or indices of egg and larval stages, (2) quantitative estimates of larval growth and feeding parameters, and (3) predictive models. Ichthyoplankton surveys are conducted by NEFC, at least bimonthly, in the MARMAP mode over a broad area of the Northwest Atlantic continental shelf, and provide timely abundance estimates of all larval fish. For several of these species larval fish growth and survival models exist, some of which have population predictive capabilities. Larval trophodynamics, physiology, and behavior have been studied extensively in the laboratory and at sea, and several factors controlling growth and survival have been identified and quantified. An important missing component is a physical-mathematical description of the spatial-temporal bounds of larval prey organisms. Once this is known, prey encounter rate functions in the existing models can be used to predict larval growth and survival on the individual and population level based on the abundance estimates of the eggs or early larvae from ichthyoplankton surveys as an initial starting point. In the case of the target species, the haddock, predicted estimates of larval survey can then be correlated with data from subsequent autumn juvenile survey estimates as a validation test.

In the Georges Bank study, the focus is on the haddock, *Melanogrammus aeglefinus*. This is a species for which a good data base exists on the "O-group" stage, and fecundity and spawning population biomass data. In addition, there is a considerable amount of background field data as to the location of the spawning grounds on Georges Bank and the general movements of the eggs, larvae and post-larval stages (to "O-group" age) on Georges Bank.

The general plan for 1981 included completion of a series of process-oriented cruises beginning in the spring on Georges Bank, concentrating on the feeding dynamics of larval haddock. Special emphasis was given to a three-dimensional description of the spatial-temporal variability of the distribution of larvae and their prey (copepods) food and factors affecting their production. A field program of this nature attempting to cover at least three trophic levels simultaneously requires sampling on spatial scales ranging from centimeters to kilometers and temporal scales from minutes to weeks.

The basic field strategy compared and contrasted fine-scale distribution of haddock larvae in the well-mixed waters on the crest of Georges Bank with the stratified waters on the southern flank using electronically-controlled opening/closing plankton nets (MOCNESS), plankton pumps, electronic particle counter, STD-continuous fluorometry, and other conventional biological and hydrological sampling gear, instruments, and techniques in a multidisciplinary mode. Observations were also made on the potential predator field of larval fish by sampling the macroplankton and micronekton components on the same cruises. Broad-scale MARMAP ichthyo-zooplankton-primary productivity surveys of the Georges Bank area and contiguous waters were monitored during the haddock season to provide the mesoscale distributions against which it was possible to relate the more intensive fine-scale studies. A summary of the results of the spring surveys is given in the paper by Lough and Laurence in Appendix 4.3.5.

Larval fish research continued at the Beaufort Laboratory, Southeast Fisheries Center of the National Marine Fisheries Service in 1980 with both field studies and laboratory experiments on the growth and survival of Leiostomus xanthurus (spot), Micropogonias undulatus (Atlantic croaker), Brevoortia tyrannus (Atlantic menhaden), and B. patronus (Gulf menhaden). Field studies were conducted off the North Carolina coast and in the northeastern Gulf of Mexico. The North Carolina cruises, conducted during the winter, collected specimens for age and growth, distribution, and predation effects analyses. Larval ages were determined for spot and croaker using otoliths and were used to calculate age and entry into the estuary. Chaetognaths associated with ichthyoplankton collections are being sorted and identified and their role as larval fish predators examined. In the Gulf of Mexico, sampling and analyses were directed to evaluate the impact of pollutants in the Mississippi River plume on fish larvae and their food supply. Using a multiple opening and closing net system (MOCNESS), larvae and zooplankton were sampled at several depths both day and night. Fish were taken to determine food preference and age. The study objective is to identify and describe the potential pathways of energy transfer and the effects of pollutants on the food web which supports larval croaker and menhaden, two species of prime importance in the northern Gulf. This research in the Gulf of Mexico on larval fish, their food and trace metal effects is being conducted cooperatively with scientists from NOAA's Atlantic Oceanographic and Meteorological Laboratory in Miami, Florida. Laboratory studies complementary to the above field work continued describing morphological indicators of starvation for spot and Atlantic menhaden, two species we routinely spawn in the laboratory. In situ experiments with Atlantic menhaden larvae held in an enclosure were initiated to determine growth rates under natural conditions of known age and size fish larvae.

During 1980 the Miami Laboratory, Southeast Fisheries Center of the National Marine Fisheries Service conducted a biological oceanographic cruise in the Gulf of Mexico in February and March. The cruise covered the entire Gulf with the chief purpose being an ichthyoplankton survey. The samples collected from this survey were sorted and identifications completed in 1981.

3. REVIEW OF CURRENT RESEARCH AND RECOMMENDATIONS

The Terms of Reference were addressed by four subgroups that considered the following research activities--(1) Estimations of spawning biomass; (2) *in situ* studies; (3) comparisions between continuous sampling of ichthyoplankton and point sampling; and (4) ichthyoplankton ecology and recruitment. Reports of the subgroups include specific recommendations for ICES with regard to ichthyoplankton research strategies.

3.1 Estimation of Spawning Biomass by Mesoscale Sampling

(D. Halgard, N. Lacroix, R. O'Boyle, D. Schnack, K. Sherman)

The generation of spawning stock biomass estimates based on mesoscale ichthyoplankton surveys is a complex process which involves consideration of several interacting factors. The process, in general terms, is based on the backcalculation of abundance indices of early life history stages (either eggs or larvae) to the adult spawning population. As such, four steps are required in the calculation:

- Estimation of early life history stage (egg or larvae) abundance.
- Estimation of development and mortality rates between the surveyed ELH stage and spawning.
- Estimation of the spawning stock biomass and age composition.
- Estimation of fecundity.

The precision and biases of population parameter estimates generated in each step are affected by various factors which must be taken into consideration in a systematic manner.

Estimation of ELH Stage Abundance

The adequate description of ELH abundance depends upon: (a) efficient sampling with respect to distribution of the stage in question, (b) the proper choice and calibration of sampling gear, and (c) the minimization of sorting errors.

Considering component (a), sampling frequency in space and time must be adjusted according to the specific distribution of the ELH stage for the stock in question. Design of multispecies surveys is difficult in this regard on account of the variability in time-space distributions of the different members of the ichthyoplankton community. Nevertheless, the broad scale multispecies programs on the North American east coast have produced some encouraging results. Due to fairly smooth production curves, bimonthly mesoscale surveys appear to provide adequate abundance estimates for at least three species. Other species may require more intensive sampling. In these cases the sampling strategy needs to be tailored to the distribution of the species in question.

Component (b) calls for standardization of sampling gear, both equipment and usage. This is particularly important in international cooperative survey programs. Effort needs to be expended on calibrating the sampling operation to the ELH stage of the stock being studied. Although this has been said before, these basic requirements have in many instances still not been attained. Special attention needs to be directed to this problem.

In general, then, ichthyoplankton surveys should be based on a standard sampling scheme, adjusted to the average distribution patterns of those species and ELH stages under consideration. They should be arranged with the flexibility for an extension of the sampling effort as required, according to yearly changes in the distributions. Within this framework, sampling effort should be concentrated when and where major adult spawning activity or egg hatching is observed. In this regard, the use of ocean frontal systems in the stratification of sampling must be considered seriously.

Estimation of Development and Mortality Rates

The growth and mortality of fish eggs and larvae figure prominently in the backcalculation of ELH abundance to the time of spawning. Therefore, the reliable estimation of these parameters is important.

With respect to the egg stages, the main factors acting during their development are temperature, predation and cannibalism. While much laboratory work has reasonably well defined the effect of temperature, the mortality due to predation and cannibalism is less well understood. The importance of these two factors as sources of year to year variation are still to be assessed for many stocks and further investigations are necessary.

Larval estimates of growth and mortality are dependent not only on temperature and predation but also on the concentration of food items, i.e., prey. Understanding the biotic and abiotic factors controlling growth of larvae in the ocean is important to advancing the ability to handcast spawning biomass success. Additional studies of the growth process at sea are needed and should be encouraged.

Estimation of Spawning Stock Biomass

The main point to consider here is the proportionality between the estimated egg production and the spawning stock biomass. Fecundity, maturity and sex ratio of the adult population are important in this regard. Not enough attention has been paid to these factors in the past and further basic investigations are required. In the case of largely reduced stock sizes and closed fisheries, ichthyoplankton surveys provide one of the only methods of estimating spawning stock size. It has been pointed out that under these conditions, the proportionality between egg production and spawning size may be quite different from that existent in an optimally exploited population. Therefore, studies on the adult population need to be carried out in tandem with ichthyoplankton surveys to account for this variability.

3.2 In-situ Studies in Relation to Growth and Survival of Fish Larvae (J. Gamble, P. Solemdal, B. Thompson, S. Tilseth)

There are two main areas of study:

- Bags, enclosure and laboratory programmes
- At-sea programmes.

We have commented on the results obtained from these studies and made recommendations for future lines of research.

Bags, Enclosure and Laboratory Studies

Bag and enclosure studies are successful in providing larvae in good condition in fairly large numbers.

Limited feeding studies can be carried out, and it must be remembered that the larvae are in an artificial situation. They are being held in a patch in which there is little or no water circulation apart from convection currents except when net bags are employed.

The mortality curves obtained must be treated with caution. Patches of larvae and patches of food organisms occur, particularly near to the bottom of the bags and enclosures and this presents a sampling problem.

However, despite these limitations there are advantages in studying enclosed systems:

1. Both larval and prey populations can be studied simultaneously in enclosures. This provides potential for studies on interactions at different trophic levels and insight into food preferences of larvae in relation to available food.

2. Despite the artificiality of the bag and enclosure situation it is possible to rear larvae beyond metamorphosis without having to supplement the prey populations.

3. The concentration of organisms in enclosures/bags, though larger than average open water concentrations, are not unrealistically high.

4. Replicate bag systems provide the opportunity to study effects of pollutants, different stocking densities etc. within a large multitrophic system.

Laboratory studies of ageing larvae using the otoliths have met with some success. The otoliths of some species are still impossible to study due to their shape and thickness. Results should be treated with caution. Morphometric methods of ageing larvae have been studied, and although successful, only apply to the temperature and food conditions of the experimental rearing procedure.

The effects of temperature on the development rate of a number of species of fish has been determined.

Recommendations

1. That there is a need to link laboratory and enclosure experiments more closely.

2. That emphasis be put on both identification of predators and evaluating the importance of predation on young larvae as a significant factor in mortality.

3. That efforts be made to study larval behaviour in enclosures/bags, in relation to predators and particularly in relation to microdistribution patterns of larval prey.

4. That studies be continued to attempt to make larval otolith reading a rapid routine process so that it can be used to age larvae from preserved samples.

5. That otolith reading of larvae of known age reared in bags and enclosures be compared to morphometric characters so that these morphometric characters can be used to age larvae from field samples.

6. That there should be a standardisation of the parameters used to describe the conditions of larvae, especially those from field samples. Published literature should contain a definition of the "index of condition" used by the research worker.

7. Further temperature and development studies should be carried out on eggs and larvae of important fish species.

At-sea Programmes

Comment here is confined to larval surveys involved with understanding the ecology and population dynamics of larvae with respect to small scale distribution of larvae and their prey. We have not considered larval surveys made for stock assessment.

Patch studies have been carried out to try to ascertain hatching success of eggs and subsequent larval condition and feeding success. High capacity pumps have been used in the study of small scale vertical distribution of cod larvae, however, there has been a difficulty in obtaining larvae in good condition and this problem is being studied.

Recommendations

1. That field studies should, if possible, have a built-in flexibility of timing and of ships used. There is a need for an interdisciplinary approach, physical and biological parameters must be studied simultaneously before the biological observations can be fully interpreted. There is a need for a pre-knowledge of physical conditions before the surveys begin,

e.g., temperature because this is the major influence on the hatching period of a patch of eggs.

2. That studies be made of the way in which the physiological condition of spawning females and eggs may affect the successful hatching of larvae and their subsequent survival.

3. That studies of predation on fish eggs be continued, particularly with respect to temperature.

4. That studies of larval feeding be continued, to find out whether food is a limiting factor on survival in the wild.

5. That there is co-development of projects between different groups of workers studying similar problems, e.g., cod feeding and food. There should also be an attempt to standardise methods.

3.3 Comparisons of Continuous and Discrete Sampling for Ichthyoplankton (S. H. Coombs, R. Grainger, J. H. Nichols)

A Comparison of Continuous and Discrete Sampling for Ichthyoplankton

The conventional strategy for estimation of abundance of ichthyoplankton is by net hauls at discrete stations taken to be representative of larger area (Fig. 1a). An alternative approach using continuous sampling throughout the survey area offers a combination of the following advantages:

- The possibility of reducing sample size, and hence analysis time, and of eliminating the errors due to sub-sampling in the laboratory.
- Reducing the variance associated with taking a single sample as representative of a large area (see table 1a).
- The potential for using small high-speed samplers to give a more synoptic picture of the survey area and resultant savings of research vessel time.

Three sets of data were available:

1. The study of Ahlstrom et al. (1958) in which results were compared from sampling for fish eggs and larvae off the Californian coast using a 1.0 m net at individual stations and continuous tows with high speed samplers at several constant depths for part of the distance between stations. Both types of gear were equally effective in delineating the distribution of eggs and larvae but the continuous high speed method was thought to give a more representative estimator of mean density. It was not possible to make a statistical comparison between the samplers because of differences of mesh size and lack of information about the strata unsampled by the high speed samplers.

2. Sampling for mackerel eggs in the Celtic Sea on four cruises in 1977 by means of TTN at station positions based on a 30' x 30' grid (Lockwood et al., 1981) and using a CPR towed at 10 m depth between stations on the same cruises (Coombs et al., 1978). Vertical distribution studies carried out on the same cruises were used as the basis for raising numbers of eggs taken by CPR at 10 m depth to numbers throughout the water column. Approximately 400 m^3 of water was filtered by TTN at each station compared with 15 m^3 for each CPR tow between stations. A similar pattern was obtained for both the overall distribution of eggs (Fig. 2) and egg production (Fig. 3) by both methods; however, a comparison of the standardised numbers of eggs taken in individual 30' x 30' rectangles (Fig. 4) showed a high incidence of occasions when no eggs were recorded by CPR but were taken by TTN. This apparent deficiency in CPR sampling is largely attributed to inefficiencies of the collecting system when deployed for the short tows undertaken in this exercise.

3. Sampling for mackerel eggs in the Celtic Sea in May 1981 by Undulating Oceanographic Recorder (Undulator) along a horizontally and vertically integrated path (Coombs et al., 1981) and by TTN hauls at discrete stations (Lockwood et al., 1981) based on a 30' x 30' grid (Fig. 5). The Undulator was towed at $\sim$ 10 kn along a saw-tooth sampling profile typically between depths of 7 and 67 m, measured every 15 s, over an undulation cycle of about 3.7 km. A single net sample of $\sim$ 15 m^3 was taken on each Undulator tow and a small adjustment of $\pm < 5\%$ any bias in the sampling profile arising from unequal time spent at different depths. A further allowance of ca: + 15% was made, based on a preliminary analysis of the vertical distribution of the eggs for the unsampled proportion found below the 67 m sampling depth of the Undulator compared with the 120 m sampled by TTN. The water volume filtered at each TTN station was $\sim$ 200 m^3. A comparison of numbers of eggs taken by both methods gave a significant correlation at 0.1% (Fig. 6).

On the basis of the above studies it is apparent that the continuous sampling method described offers the possibility of quantitative sampling with the advantages of small sample size and the saving of analysis and research vessel time.

The trials in 1981 were limited by operational difficulties with the UOR and the planned programme was not achieved. A more complete set of data are required before a thorough comparison, subjected to rigorous statistical analysis, can be made. The reliability and sampling performance of the Undulator, which offers the most promising approach, must be improved and subjected to further development. The potential benefits of such an improved sampling strategy justify a continuation of effort directed to assess its performance; the most important areas in which further work is required are:

a. Comparative trials with conventional samplers,

b. An estimation of sampling error compared with conventional samplers,

c. Improved reliability of control and data acquisition systems,

d. Flume testing of filtration system,

e. Fairing trials to improve depth capability.

Estimates of Point Sample Variance

Replicate hauls with the Lowestoft 30" high speed plankton sampler (Beverton and Tungate, 1967) were made during a series of ichthyoplankton surveys off the north east coast of England in 1976. Harding and Nichols (in press) have described the results of these tests and the relevant section of their report and the two tables are reproduced below.

> "Replicate hauls with the 30" plankton sampler
>
> "One aspect of sampling error was examined, as part of the general routine on most surveys. The sampler was fished normally for ten consecutive hauls in the same discrete body of water, to test the repeatability of a single sampling haul, by obtaining an estimate of haul to haul variance. These replicate hauls were performed on eight of the surveys and were normally done in areas of high egg or larval density. The samples thus collected were processed with the standard samples for fish eggs and larvae, in the normal way. Numbers of each species or stage per replicate haul, were converted to numbers per square metre. The mean number per square metre and the coefficient of variation for each series of replicates was calculated and are presented in Table 1a (eggs) and Table 1b (larvae). The estimates of haul to haul variation generally lie within the range 30%-60% for the abundant species and stages. These data can be used to provide an estimate of the error on seasonal production curves of eggs and larvae.
>
> The consistently high variation for both eggs and larvae in these results, indicates an unavoidable level and source of error inherent in this type of plankton sampling. It is probable that the major contributing factor is plankton patchiness. The effects of this can be minimised by increasing the concentration of sampling points, particularly in areas of known egg and larval abundance. This concept was incorporated in the original design of the 1976 surveys."

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Coombs, S. H., Aiken, J. A. and Lockwood, S. J., 1981. Mackerel spawning in the Celtic Sea: a survey with the Undulating Oceanographic Recorder. ICES, C.M. 1981/H:32 (mimeo).

Legends to Figures

1. Alternative strategies for ichthyoplankton surveys.

2. The distribution and abundance of stage I mackerel eggs taken by TTN and CPR in the Celtic Sea in March, April, May and June 1977; results are plotted as figures for daily egg production m^{-2} in each rectangle of 30' x 30' and are represented by symbols showing three categories of abundance.

3. Production curve for mackerel eggs taken in the Celtic Sea in 1977 by CPR and TTN; the development stages of the eggs are represented by Roman numerals.

4. The relationship between numbers of mackerel eggs taken in each 30' x 30' rectangle in the Celtic Sea in March, April, May and June 1977 by CPR and TTN sampling.

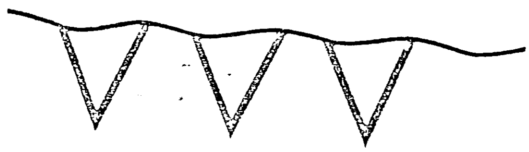
5. Sampling completed in 1981; the vertical distribution hauls are indicated by the symbols for LHPR.

6. The relationship between numbers of mackerel eggs taken by Undulator (UOR) and TTN sampling in the Celtic Sea in May 1981.

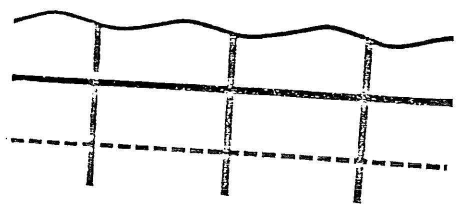
Legend to Table

1. Results from replicate hauls made with the standard plankton sampler on selected surveys in 1976

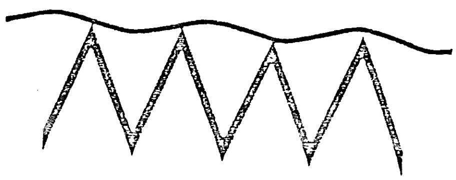
   a) Fish eggs   b) Fish larvae and Nephrops larvae



a) Conventional double oblique hauls at single stations



b) Horizontally integrated at one or more depths and vertical distribution at discrete stations



c) Fully integrated vertically and horizontally

fig 1

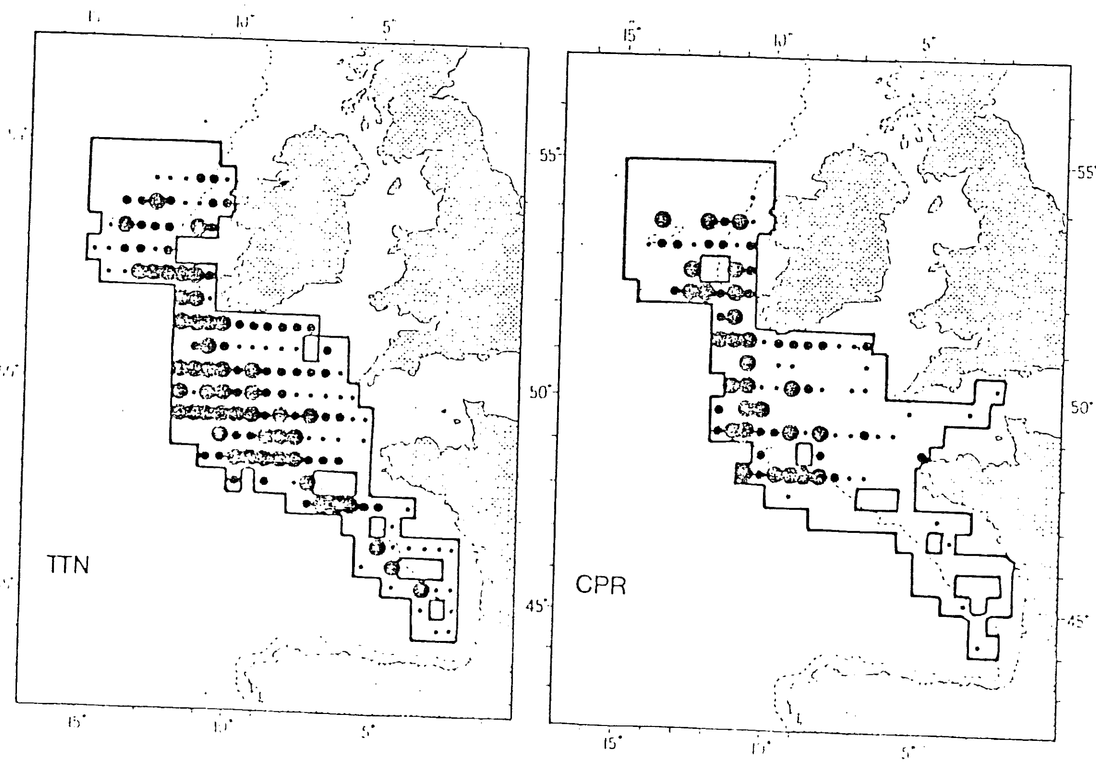


fig 2

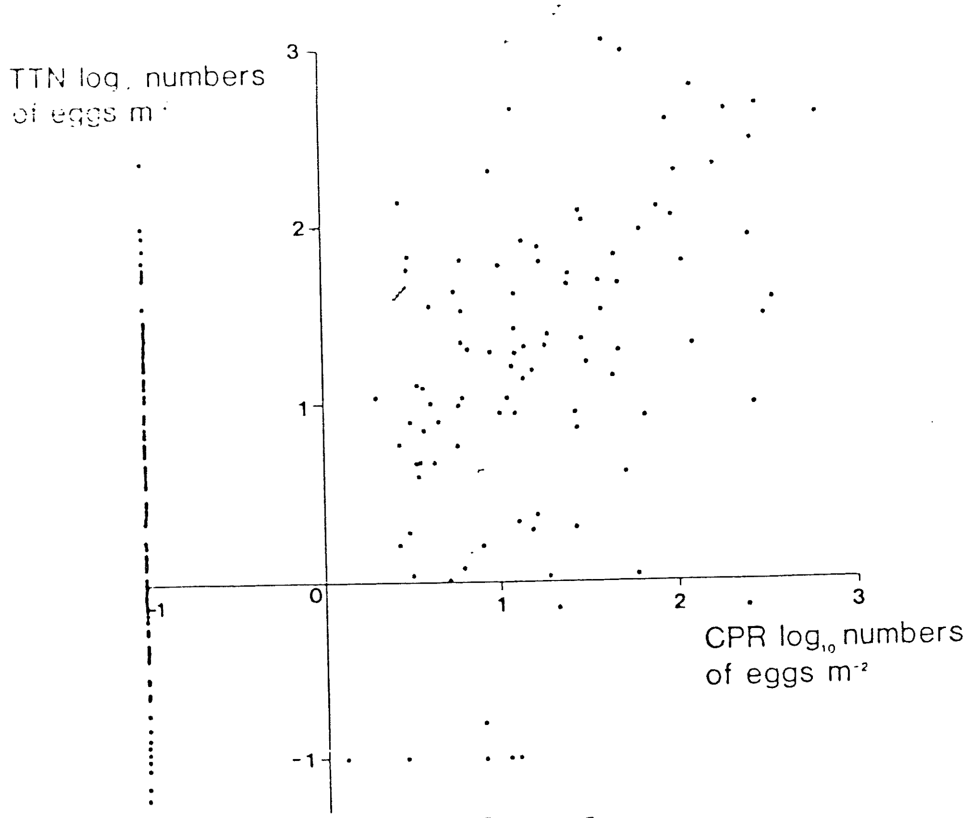

TTN log. numbers of eggs m
CPR log$_{10}$ numbers of eggs m^{-2}
3
2
1
0
-1
1
2
3

fig 3

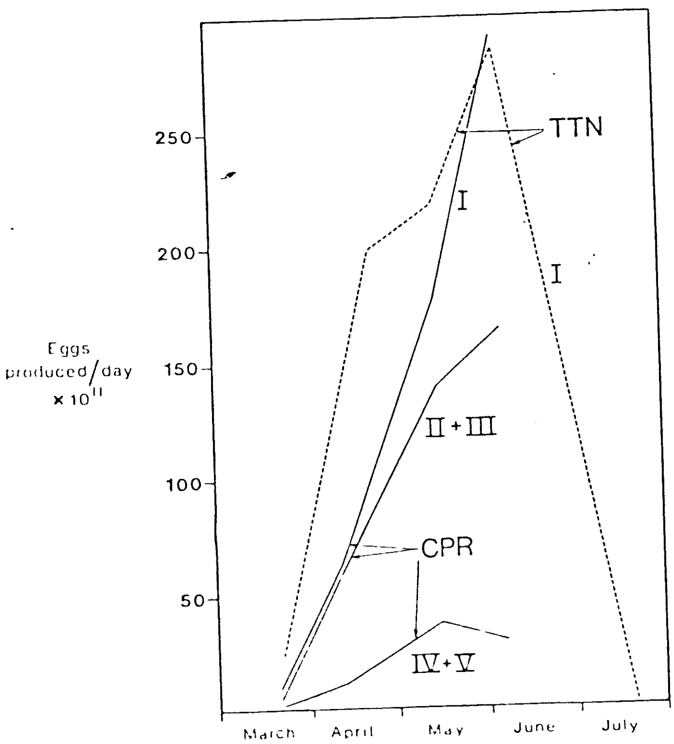

Eggs produced/day × 10^{11}
250
200
150
100
50
TTN
I
I
II + III
CPR
IV + V
March
April
May
June
July

fig 4

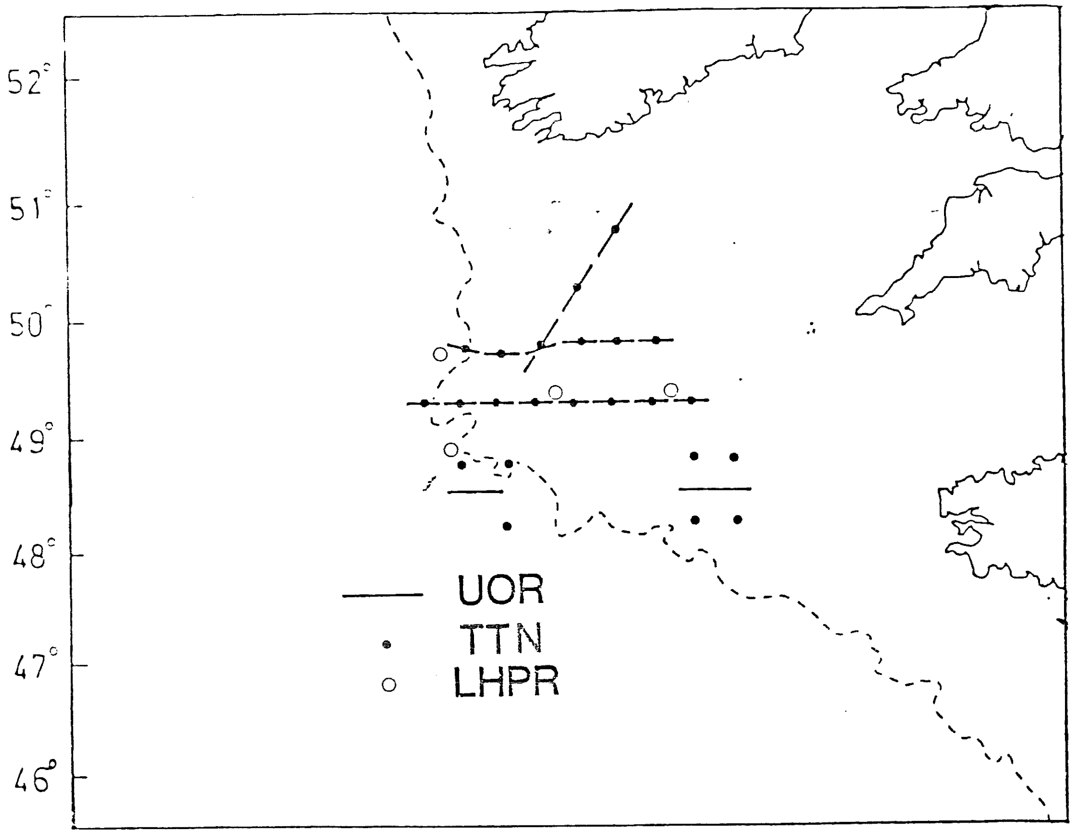

52°
51°
50°
49°
48°
47°
46°
UOR
TTN
LHPR

fig 5

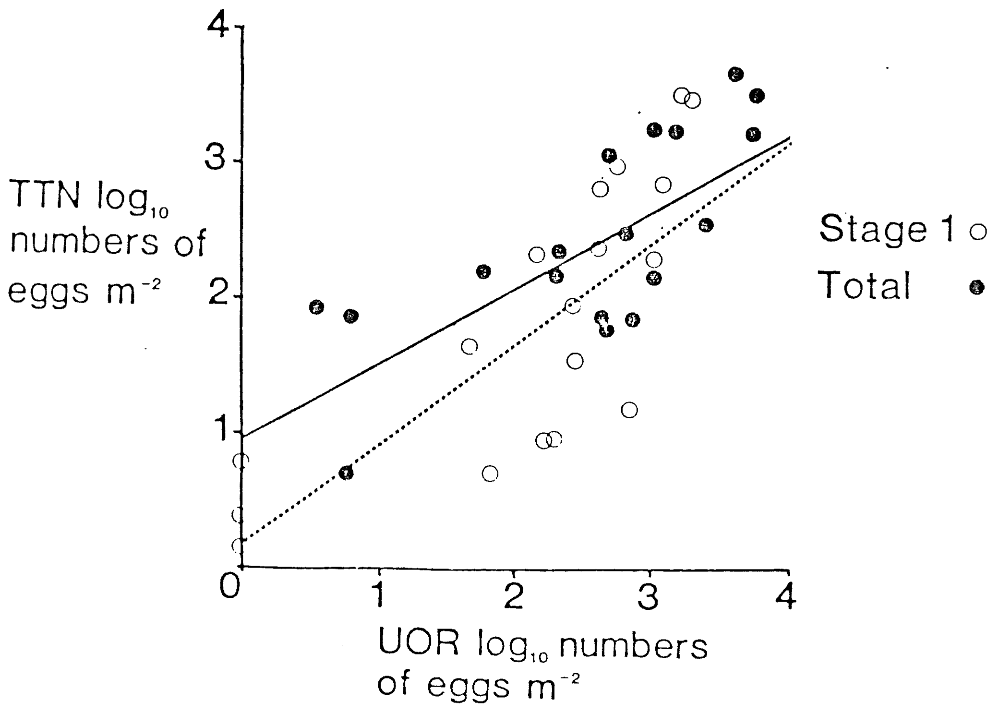

TTN $\log_{10}$ numbers of eggs m^{-2}
UOR $\log_{10}$ numbers of eggs m^{-2}
Stage 1
Total
0
1
2
3
4

fig 6

Table 1a

Cruise Species and stage	February $\bar{x}$	V	April $\bar{x}$	V	April $\bar{x}$	V	April/May $\bar{x}$	V	May $\bar{x}$	V	June $\bar{x}$	V	July $\bar{x}$	V
Pleuronectes platessa I	10.8	77.6	28.2	31.5			27.2	40.2						
II	5.9	126.8	15.4	37.6			28.3	25.1						
III	11.2	50.4	20.7	37.8			24.8	31.5						
IV	8.8	45.1	15.4	48.7			20.9	16.0						
V	2.5	73.6	26.5	23.6			61.5	20.2						
Mean		74.7		35.9				26.6						
Total	39.6	51.9	108.3	16.2	1.1	76.4	165.0	7.1	1.2	31.4				
Gadus morhua I	17.8	45.9	18.8	15.2	9.8	22.5	17.5	20.4						
II	6.3	71.7	5.8	43.5	1.8	59.4	8.3	26.2						
III	10.9	41.4	5.2	52.8	2.2	42.8	11.0	22.6						
IV	6.3	47.5	1.8	67.7	1.2	71.5	4.9	37.1						
V	1.7	86.4	1.0	68.1	0.5	74.2	2.5	39.8						
Mean		58.6		49.5		54.1		29.2						
Total	43.1	29.0	32.5	22.0	15.6	20.0	44.1	15.0						
Sprattus sprattus	47.2	49.1	223.9	39.5	8.6	98.1			27.6	39.6	15.2	35.3	5.0	65.8
Callionymus spp.							8.4	24.0			4.9	30.8	2.6	57.9
Trigla spp.							3.6	26.4						
Trachurus trachurus									5.3	44.4				
Scomber scombrus													1.8	121.1
Number of replicates	10		10		10		10		10		10		10	

$\bar{x}$ = Mean of 10 Samples
V = Coefficient of Variation

Table 1b

Species and stage / Cruise	February		April		April		April/May		May		June		July		August		October	
	$\bar{x}$	V	$\bar{x}$	V	$\bar{x}$	V	$\bar{x}$	V	$\bar{x}$	V	$\bar{x}$	V	$\bar{x}$	V	$\bar{x}$	V	$\bar{x}$	V
Pleuronectes platessa I	0.95	80.8	3.1	62.4	0.4	129.1	8.5	28.5	0.8	88.8								
II					1.6	61.0			2.7	64.1								
III					0.9	65.3			0.8	82.3								
IV											1.6	56.8						
Total	1.0	80.7	3.9	66.5	3.0	44.1	9.3	31.2	4.3	47.0	2.4	31.5						
Gadus morhua	0.5	98.2	0.5	79.5	8.4	25.4												
Merlangus merlangius					3.4	27.9					7.0	19.2			0.9	54.0		
Ammodytes spp.	2.6	55.7			62.3	53.5	3.1	47.5							5.2	34.0		
Limanda limanda			0.4	118.1	195.1	29.3					3.5	61.8			8.0	29.8		
Hippoglossoides platessoides											2.4	67.1						
Microstomus kitt															1.4	51.4	2.2	56.1
Sprattus sprattus			3.2	114.3	2.2	116.3							144.1	63.2				
Clupea harengus																	11.0	31.8
Scomber scombrus													6.1	49.8				
Trachurus trachurus															1.2	66.2		
Callionymus															4.8	51.6		
Onos spp.																	4.1	38.1
Arnoglossus laterna															3.9	32.2		
Nephrops norvegicus											8.9	44.5						
Number of replicates	10		10		10		10		10		10		10		10		10	

$\bar{x}$ = Mean of 10 samples; V = Coefficient of Variation

3.4 Ichthyoplankton Ecology and Recruitment
(J. Zijlstra, P. Munk, J. Magnusson, J. Riley, D. Harding)

The group accepted that the relative year-class size of marine fish was largely fixed on recruitment to the 0-group. Improved knowledge of the factors which affect mortality in the pelagic phase would be an advance towards the forecasting of year-class strengths and through this, to fish stock management. Recent progress was reviewed including submissions to the working group and areas were identified where additional data were needed. Some proposals for national programmes for 1982/3 using an inter-disciplinary approach are listed, some of these relate directly to the needs identified. The report is divided into three sections: progress, problems and proposals.

Progress

a. The "Critical phase"

Although mass mortality still occurs in research conditions, the most recent being in Moksness's capelin feeding experiment at Flødevigen, Norway, there seems to be limited evidence that such a phase characterised by higher mortality normally occurs in the sea; more information is needed on at-sea observations of mass mortality.

b. Starvation induced mortality

There is no firm evidence from the sea to indicate whether this is an important and usual occurrence; some RNA/DNA (herring) indicate poor condition. It is possible and may yet be demonstrated that poor feeding could lead to greater predatory deaths. This is another area that requires further study.

c. Planktonic drift - Patch studies

The 1978-80 UK studies proved that in certain circumstances ichthyoplankton patches can be tracked and sampled in the sea but indicated that these mesoscale exercises must be supported by microscale investigations within and outside the main patches, if the causes of mortality are to be evaluated.

d. Recruitment to nursery areas

Research in the Wadden Sea off Texel has demonstrated the significant predation by *Crangon vulgaris* on recruiting (late IV and V larvae and early 0 group), *Pleuronectes platessa*.

Problems

Aspects of planktonic mortality of fish larvae have been variously demonstrated but need to be quantified, if the mechanisms of year-class size determination are to be understood. These include:

a. Feeding -- There are indications from the laboratory work that poor feeding could increase proneness to predation but this has yet to be measured at sea. The importance of feeding in the tolerance of larvae to environmental conditions e.g., rapid temperature changes is a separate but related factor at present unquantified at sea.

b. Predators -- The relative importance of predators on larval mortality has not been measured. Some may be important in determining year-class strengths, e.g., when the Atlanto-Scandian herring were feeding on capelin larvae off the north coast of Iceland.

c. Spawning time -- The survival varies with spawning time within the species specific season. Little is published on the factors which control this variation, factors involved must include water temperature and currents and could be implicated in shock due to exposure to warm water on Georges Bank and to cold water off Iceland.

d. Hydrographic displacement of late larvae is implicated in mortalities of *Scophthalmus maximus* off the English N.E. coast and is probably of significance in other species characterised by extensive larval drift and specialised nursery areas, e.g., plaice, but this has not been measured. An estimation of this "hydrographic death" could form the subject of a cooperative research project after 1983.

e. A new "critical phase" -- recruitment -- Although some details of the mechanism and hazards are now defined for species in particular areas, e.g., plaice in the Wadden Sea, these are not yet demonstrated finely enough nor have they been shown to apply generally. An apparent density dependent depression of growth in 0 group plaice in the German Wadden Sea (Rauck and Zijlstra, 1978) and in the Texel area requires further studies.

f. Predatory deaths in the 0 group -- could be important in determining relative year-class strengths, e.g., redfish on redfish and be dependent on numbers of predators. Likely examples of this kind are presently not quantified.

g. Significance of discontinuity layers -- Fish larvae and older fish are apparently concentrated about such layers but little is known of their micro ecology covering primary and secondary production and the pelagic stages of fish.

h. General comment -- While the role of environmental variability dominates much of the present working hypotheses in fishery science, less well discussed is the effect of fishing pressure on stock-recruit relationships. Many of the world's fisheries have suffered severe declines and have been highlighted by the collapse of herring, sardine and anchovy fisheries. In Newfoundland, larval studies have come to a halt due to severe stock declines. While fishing pressure will drive a stock down, the contribution of fishing pressure, environmental changes or a combination of both as cause precipitating declines remains obscure. At reduced densities there are population compensating mechanisms, but the question of how these changes quantitatively affect stock size and condition and ultimately recruitment is not fully understood and needs to be addressed most vigorously in recruitment studies.

Proposals

a. Feeding--mortality studies -- At the new laboratories at Hirtshals in Denmark it is proposed that in 1982-83 fish larvae from differing feeding regimes will be exposed to at least two types of predators.

b. Mortality at recruitment -- The studies from Texel on the predation on plaice by shrimp have produced significant results and will continue. These studies of mortality should be encouraged.

c. 0 group mortality -- Iceland intends to continue the studies of the predation on 0 group redfish.

d. Fronts and thermoclines -- nterest was shown in this work. The success of future studies depends on a careful selection of the research location and the choice of physical and biological factors which should be measured. No decisions were made, pending the publication of a review on the significance of fronts in N.W. European seas to fish and fisheries by Harding.

3.5 Recommendations

Estimations of Spawning Biomass by Mesoscale Sampling

a. Essential requirements in cooperative ichthyoplankton survey programmes are the use of identical sampling devices, and the use of standard handling procedures. Though generally accepted, these basic requirements are apparently difficult to meet within present practice, and special attention has to be directed to this problem, particularly in the North Sea.

b. Sampling frequency in space and time has to be adjusted according to the specific distribution of the stock and the developmental stages considered. Initial results from a broad scale sampling programme along the northeast American coast are encouraging with respect to the multispecies approach. The fairly smooth production curves observed for three species indicated that bimonthly surveys are adequate for a reasonable estimate of total seasonal egg production, taking the entire area as a whole. Continuation of the present intensive surveys in this area as well as in the adjacent Scotian Shelf area are desirable to prove the consistency between years in the production curves and the spatial distribution patterns. In case smaller areas and even different spawning groups of single species have to be considered separately, as for instance in the North Sea larval herring surveys, more intensive sampling is required for restricted but different periods of time.

c. Multispecies ichthyoplankton surveys should be based on a standard sampling scheme, adapted to the average distribution pattern of those species and stages to be considered, and they should be arranged with the flexibility for an extension of the sampling effort as necessary according to yearly changes in the distribution. Within the frame of a complete coverage in space and time the sampling effort should be concentrated on areas and times where the main spawning or hatching is encountered, and a more densely spaced station grid is generally required near hydrographic fronts. In areas where tidal excursions are large in relation to the distances between sampling stations, sampling should, as far as possible, be conducted during neap tides.

d. Results from surveys should be summarised in standard format following, for example, the recommendations made by the Working Group on Larval Herring Surveys South of 62°N (ICES C.M. 1981/H:3). This facilitates data exchange and computer analysis.

In-situ Studies in Relation to Growth and Survival of Fish Larvae

a. There is a need to link laboratory and enclosure experiments more closely.

b. Emphasis should be put on both identification of predators and evaluating the importance of predation on young larvae as a significant factor in mortality.

c. Efforts should be made to study larval behaviour in enclosures/bags, in relation to predators and particularly in relation to microdistribution patterns of larval prey.

d. Laboratory studies of ageing larvae using the otoliths have met with some success. The otoliths of some species are still impossible to study due to their shape and thickness. Results should be treated with caution. Morphometric methods of ageing larvae have been studied, and although successful, only apply to the temperature and food conditions of the experimental rearing procedure. The effects of temperature on the development rate of a number of species of fish should be determined.

e. Studies should be continued to make larval otolith reading a rapid routine process so that it can be used to age larvae from preserved samples.

f. Otolith reading of larvae of known age reared in bags and enclosures should be correlated to morphometric characters so that these morphometric characters can be used to age larvae from field samples.

g. There should be a standardisation of the parameters used to describe the physiological condition of larvae, especially those from field samples. Published literature should contain a definition of the "index of condition" used by the research worker.

h. Further temperature and development studies should be carried out on eggs and larvae of important fish species.

i. Comment here is confined to larval surveys involved with understanding the ecology and population dynamics of larvae with respect to small scale distribution of larvae and their prey. We have not considered larval surveys made for stock assessment. Patch studies have been carried out to try to ascertain hatching success of eggs and subsequent larval condition and feeding success. There is a difficulty in obtaining larvae in good condition and the use of pumps is being studied. It is recommended that field studies should, if possible, have a built-in flexibility of timing and of ships used. There is a need for an inter-disciplinary approach, physical and biological parameters must be studied simultaneously before the biological observations can be fully interpreted. There is a need for a pre-knowledge of physical conditions before the surveys begin, e.g., temperature because this is the major influence on the hatching period of a patch of eggs.

j. Studies should be made of the way in which the physiological condition of eggs may affect the successful hatching of larvae and their subsequent survival.

k. Studies of predation on fish eggs should be continued, particularly with respect to temperature.

l. Studies of larval feeding should be continued, to find out whether food is a limiting factor on survival in the wild.

m. Where there is joint international development of projects between different groups of workers studying similar problems, e.g., cod feeding and food, special effort should be made to standardise methods among the participants.

Comparisons of Continuous and Discrete Sampling for Ichthyoplankton

The trials in 1981 were limited by operational difficulties with the UOR and the planned programme was not achieved. A more complete set of data are required before a thorough comparison, subjected to rigorous statistical analysis, can be made. The reliability and sampling performance of the Undulator, which offers the most promising approach, must be improved and subjected to further development. The potential benefits of such an improved sampling strategy justify a continuation of effort directed to assess its performance.

a. Additional comparative trials are recommended with underway continuous and conventional point samplers.

b. Studies should be undertaken that lead to the estimation of sampling error compared with conventional samplers.

c. Development should be continued to improve the reliability of control and data acquisition systems for the UOR including: flume testing of the UOR filtration system and fairing trials to improve depth capability of the UOR.

Ichthyoplankton Ecology and Recruitment

a. It is proposed that in 1982 fish larvae from differing feeding regimes be exposed to at least two types of predators during feeding and mortality studies at the new laboratories at Hirtshals in Denmark.

b. The studies at Texel dealing with mortality at recruitment through predation on plaice by shrimp have produced significant results and should be continued.

c. Iceland intends to continue the studies of the predation on 0 group redfish. Other studies of cannibalism on eggs and larvae in other regions are recommended.

d. Interest was shown in studies of larval growth and survival in oceanographic fronts and thermoclines. The success of future studies depends on a careful selection of the research location and the choice of physical and biological factors which should be measured. No decisions were made, pending the publication of a review on the significance of fronts in N.W. European seas to fish and fisheries by Derek Harding. Future recommendations will be contingent on the review. Special attention should be given in the review to the frequencies and extent of "hydrographic mortality."

4. APPENDICES

4.1 Canadian Report

4.2 Norwegian Report

4.3 Contributed Working Papers

4.3.1 The Detection of Larval Fish Food Particles by an *In-situ* Particle Counter, and Monitoring the Particle Density and Distribution in First Feeding Areas, by Snorr Telseth.

4.3.2 The Spawning Period of Arcto-Norwegian Cod during the years 1976-1981, by Per Solemdal.

4.3.3 Sampling Fish Larvae with Large Pumps, by Per Solemdal.

4.3.4 Post Larvae Investigations, by Herman Bjørke.

4.3.5 The Western Mackerel Spawning Stock Estimate for 1980, by S. J. Lockwood, I. G. Baxter, J. C. Gueguen, G. Joakimsson, R. Grainger, A. Eltink, and S. H. Coombs.

4.3.6 Larval Haddock and Cod Survival Studies on Georges Bank, by R. G. Lough and G. C. Laurence.

4.3.7 Comments on Efficiency of NEFC MARMAP Surveys, by Peter Berrien.

4.3.8 Measuring the Effect of the Variability of Egg Densities over Space and Time on Egg Abundance Estimates, by Michael Pennington and Peter Berrien.

4.1 Canadian Report

Report on the Research Activities on
Canada's East Coast

by

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Dartmouth, N. S.

Introduction

Administratively, federal government fisheries research laboratories on Canada's east-coast are grouped into three regions, each of which concentrates its effort in distinct geographical locations. These groupings are referred to as the Newfoundland, Scotia-Fundy and Gulf Regions. At present, most research carried out in the Gulf Region is conducted by biologists located in the other two areas. The regions will be completely distinct by 1983.

Considerable energy has been expended in each region on early life history related studies. This report outlines some of these studies and their progress to date. The activities will be classified as follows:

1. Surveys - these are carried out in support of assessment work.
2. Process studies - these are carried out to discover the underlying mechanisms involved in recruitment.
3. Laboratory studies - these are carried out in support of the process studies.
4. Gear development - this important component of the research plan is carried out to enhance our assaying capabilities of the systems that we are studying.

It is important to realize that this report only covers major projects being carried inside government laboratories. It does not attempt to describe current research programs in the Universities, many of which are quite extensive.

I. Surveys

At the moment, four mesoscale survey programs are being conducted on Canada's east coast. These are outlined in Table 1. The most extensive of these is the Scotian Shelf Ichthyoplankton Program (S.S.I.P.) which was initiated in 1977. It was patterned after the U.S. MARMAP surveys with the addition that post larval as well as egg and larval forms have been standardly sampled.

Phase I of the program is scheduled to be completed by the end of 1982. By that time, at least two coverages of the Shelf will have been made for each month of the year. The format of Phase II, which will be in-depth studies on either one stock or one bank will be decided upon completion of an internal review to be held in October 1981.

The three other surveys, two on herring and one on mackerel have been conducted in support of assessment work. The Bay of Fundy herring data set is the only one however which is long enough to have a major role in the assessment process.

II. Process Studies

A. Newfoundland Region

To date, the Flemish Cap Project has been the most ambitious process study to be carried out on Canada's East Coast.

The Project was ratified in May 1977 as a worthwhile area for an international study examining the causes of fluctuations in year-class strengh of groundfish, specifically cod and redfish. Further detailed planning was carried out during September 1977 and background sampling initiated during the fall and throughout 1978. The project activity got underway in 1979 with programs in oceanography, plankton and adult groundfish being carried out. In all, nine research cruises were made to Flemish Cap during 1979 by Canada and the USSR. In 1980 and 1981 this work has continued.

Several factors were thought to be important in singling out the Flemish Cap as a suitable area for such a fisheries study. These factors included:

1. Cod, and to a lesser extent redfish, were subject to large and irregular fluctuations in year-class strength since the onset of commercial records beginning in 1956;
2. Studies had shown the cod population to be relatively discrete from those of the adjacent Grand Banks;
3. Flemish Cap is a distinct oceanographic area bounded by strong currents (the Labrador and North Atlantic Currents);
4. There was a long series of oceanographic data upon which the study could be based and planning made;
5. It was a small enough area to facilitate sampling;

6. It was a relatively 'simple' ecosystem with only three commercial fish species (cod, redfish and plaice) and no major source of pelagic forage fish (e.g. capelin or sand lance).

In addition, studies of existing information indicated significant relationships between water temperature and year-class strengh of cod. This indicated environmental factors may play a vital role in determining recruitment of Flemish Cap cod.

Participation by Canadian and USSR research vessels was initially directed at cod spawning and larval survival on Flemish Cap, and assessment of the spawning stock. Examination of larval fish survival and retention on the bank related to the oceanographic environment, and associated currents, was outlined as a central area of study.

Coincident with the initiation of the Flemish Cap Project in 1977 was the declaration by Canada of a 200 mile fishing limit. This appears to have had a direct and significant effect on the Flemish Cap Project. Exclusion of foreign fishing vessels from the Canadian zone resulted in a heavy fishing effort to be concentrated on Flemish Cap. This has resulted in a rapidly declining cod stock that is now described as "extremely low" in abundance. In the April 1979 ichthyoplankton survey on Flemish Cap, immediately following cod spawning which is believed to peak in March, we caught a total of 21 cod larvae. Results from the 1980 April survey are similar.

Similarly, in 1979 an extensive oceanographic moored instrument program was initiated. Unfortunately, of 16 current meters and two temperature chains deployed at four separate locations, only two current meters were recovered. This high loss rate was unofficially attributed to the large number of fishing vessels operating in the area and has resulted in the termination of this aspect of the oceanographic program. This has to be viewed as a serious set-back given the believed importance of the current regime(s) affecting year-class strength of cod and redfish on Flemish Cap.

A series of six satellite-tracked drogued buoys were released between January 1979 and May 1980. This confirmed the presence of a weak anticyclonic gyre over Flemish Cap. Of considerable interest was that all six buoys exited from the Flemish Cap in the southeast corner, despite different drift patterns. Advection of larval fish from Flemish Cap in this quarter has previously been advanced as a possible significant source of larval mortality for the region. The satellite-tracked buoys have at least confirmed that the physical mechanism in the surface waters exists to effect larval transport out of the region. Whether or not it does so significantly has yet to be resolved.

The study on larval fish has largely defaulted to one of larval redfish, the only larval fish present in numbers. Peak extrusion of redfish occurs on Flemish Cap during the last part of April, beginning of May period. The surveys have indicated larval growth and 'persistence' occurred immediately to the north and west of shoal waters (i.e. 200 m) on Flemish Cap in 1979, coincident with a zone of high chlorophyll. Values of both larval redfish and chlorophyll over waters less than 200 m were consistently low, while preliminary studies of early *Calanus finmarchicus* indicated early copepodite abundance may follow a similar pattern.

From a stock-recruitment standpoint the most interesting aspect of the studies have shown a variable length-frequency pattern of larval redfish during July surveys. In both 1978 and 1980 the length-frequency pattern was bi-modal with peaks of 6-7 mm and 18-20 mm. Larval otolith studies have indicated the larger modal length originated from the late April-early May spawning peak of redfish. In July 1979 the larger redfish, 18-20 mm in length, were absent on Flemish Cap.

This pattern has been mirrored in cod feeding studies conducted in January of each following year. Juvenile redfish have been shown to be the preferred food of cod on Flemish Cap, when available. Studies in January of 1979 and 1981 indicated cod were feeding on an abundance of small redfish, 5-6 cm standard length, presumed to be one-year-olds (0 group) spawned the previous spring. In January 1980, these small redfish were completely absent from cod stomachs. These data indicate that larval redfish spawned in April-May 1979 experienced an unusually high mortality resulting in low numbers of juvenile prey in the 5-6 cm range normally available to cod. Possible causes of this high mortality have not been examined at this point.

Unfortunately, studies on larval redfish relating to recruitment mechanisms are plagued by specific problems. Studies have indicated the probable existence of three species of redfish on Flemish Cap, *Sebastes marinus*, *S. mentalla*, and *S. fasciatus*, although this has yet to be completely resolved. This is complicated by different spawning times and depth distributions. No criteria presently exist to satisfactorily identify these different species of larval redfish. Preliminary attempts to raise larval redfish have proven unsuccessful and communication with workers at the Southwest Fisheries Centre, La Jolla, California have indicated larval redfish to be unusually difficult to raise.

In addition, there is the question of the oceanic distribution of redfish. Larval redfish have been reported to occur extensively throughout the western North Atlantic, presumably spawned from an oceanic redfish population. Hence, the 'discreteness' of Flemish Cap redfish remains unknown. Questions involving migration in and out of the area remain unanswered and therefore relationships of larval abundance to recruitment are not clear. A further complication is the slow growth of redfish, one estimate being that they will not recruit to the fishery for 10 years. As a result, samples first collected in 1979 cannot be related to an estimate of recruited abundance until 1989. Finally, redfish are live spawners and there are the resultant questions as to differences between these fish and egg spawners.

Not surprisingly the Flemish Cap Project, as originally planned, is coming under some question. The participants will be meeting during the NAFO annual meeting in September 1981 to review our progress to date and the project as a whole. A central theme remaining to the study is the large 1973 year-class of cod spawned on Flemish Cap apparently originated from a low spawning stock biomass. Examination of the possible repeat occurrence of this phenomenon is still viewed as an important matter.

B. Scotia-Fundy Region

One study has been carried out on small scale variation of the larval silver hake concentrations located on Emerald-Western Bank during August-September, 1980. Of particular interest was how these concentrations relate to the physical and biological oceanography of the area.

Secondary objectives were:

1. Determination of larval silver hake catchability coefficients for the bongo and Isaacs-Kidd nets.

2. Variability of larval silver hake catch by bongo gear both within one tow (between sides of a bongo frame) and within one station.

3. Effect of preservation time and type on larval and otolith condition.

4. Vertical distribution of silver hake in relation to red and white hake.

The data is presently being processed and hopefully be ready for presentation in October.

Another study is presently being conducted on the relationship among larval and adult herring and tidally-induced fronts in S. W. Nova Scotia.

Finally a large process study is scheduled to commence sometime in 1982 on the Scotian Shelf. The format of this study would be similar to that carried out on Flemish Cap. Program plans will be outlined this fall after the review of S.S.I.P.

C. Gulf Region

A number of small process studies have been conducted in the Southern Gulf of St. Lawrence, virtually all of which have been directed on herring or mackerel. These are:

1. Herring spawning bed survey to determine size of egg beds and their relation to bottom type.

2. Mackerel patch study in 1978 to study spatial distributions of egg concentrations.

3. Egg and larval herring distributions in estuary in relation to currents and tides.

4. Particle distribution in the water column in relation to Langmuir cells.

5. Larval mackerel feeding behaviour.

6. Juvenile herring feeding behaviour and movement.

As the Gulf region develops, these projects will no doubt be augmented.

III Laboratory Studies

A. Newfoundland Region

At present the ageing of larval cod and redfish has been initiated. These studies are in support of the Flemish Cap Project.

B. Scotia-Fundy Region

Larval cod and silver hake has been initiated with details of the techniques still to be ironed out. Experiments have been conducted on the best methods for preservation of the larvae and their otoliths.

Studies are planned to study larval morphology and biochemistry and how these relate to adult stock structures.

C. Gulf Region

Larval herring are presently being aged routinely in support of survey work in the Gulf.

An experiment is to be conducted on the effect of plankton tows on the condition of mackerel eggs.

Iv Gear Developments

A. Newfoundland Region

A number of projects are underway, some of which are:

1. Production of satellite-derived surface temperature profiles on-board a vessel in real-time.

2. Interfacing of Guildline CTD and Impulsephysik fluorometer to General Oceanics Rossette sampler.

3. Development of surface pump system for temperature and fluorescence.

B. Scotia-Fundy Region

At the Bedford Institute, a number of projects are underway:

1. Interface of BATFISH towed vehicle with particle counter.

2. Development of deep pump system.

3. Development of 0.5 m version of Sameoto BIONESS.

4. Modification of LHPR system.

5. Development of on-board data hi-way which combines information from Lowestoft surface pump system, Loran C and BIONESS/Rossette sensors and feeds all data into HP1000 mini-computer

6. Development of S.S.I.P. Data base.

7. Development of on-board incubation chamber.

C. Gulf Region

Here, studies are being carried out on optimum bridle arrangements for meter nets and juvenile trawl gear.

SUMMARY

This document contains an overview on research activities related to the early life history of fish on Canada's East Coast. It is by no means comprehensive. However, it does show the extent of research effort undertaken by Canada in the pursuit of knowledge into the mechanisms that control recruitment to our commercial fisheries.

4.2 Norwegian Report

FISH LARVAE INVESTIGATIONS IN NORWAY

by
Per Solemdal
Institute of Marine Research
Bergen, Norway

A. Single species investigations.

The different projects are grouped according to species. Types of investigations (field, enclosure, laboratory etc.) are specified for each project.

Cod.

Project: Feeding and transport of fish larvae (mainly cod) in the coastal current.

1. Objective: To relate the food intake of cod larvae to density and availability of food organisms and physical conditions, such as wind, currents, light etc.

2. Participants: Bjørnar Ellertsen (zooplankton), Per Solemdal (fish-eggs and larvae), Svein Sundby (physical oceanography) and Snorre Tilseth (fish-eggs and larvae), all working at the Institute of Marine Research, Bergen, Norway.

3. Area and frequency: Mainly Lofoten, up to Sørøya, Finnmark, March - May. Started 1975, planned to 1984.

4. Activities in 1981:

a) Sampling cod eggs on the main spawning grounds, mainly Lofoten, 3 times per week, 10 March - 5 May, to establish spawning curves.

b) Cruises with research vessels "Johan Ruud", "Johan Hjort" and "Michael Sars" during the period 10 March - 10 May, in

Lofoten - Vesterålen and up to the banks of Svensgrunn and Malangsgrunn.

5. Special methods:

a) Vertical distributions of fish larvae sampled by large pumps.

b) Vertical distribution of prey organisms (mainly copepod nauplii) sampled by plankton pump and *in situ* particle counter "Micro-count" (description and results are given in separate paper to this meeting by Snorre Tilseth).

c) Drift experiments with "Argos" sattelite positioned drifters.

6. Reporting:

a) Internal cruise reports to the Institute of Marine Research, Bergen (in Norwegian).

b) Bi-annual reports to the Norwegian Council of Fishery Research (in Norwegian).

c) Reports to the ICES statutory meeting in Woods Hole, 1981: "Vertical distribution of pelagic fish-eggs in relation to species, spawning, behaviour and wind conditions" by P. Solemdal.
"The detection of larval fish food particles by an *in situ* particle counter, and monitoring of the particle density and distribution in first-feeding areas" by S. Tilseth and B. Ellertsen.

Project: Identification of fish-eggs by electrophoretic method.

1. Objective: The spawning of cod and haddock overlap to some degree in Norwegian waters, both in space and time. Their eggs are almost impossible to separate visually in early development stages.

2. Participants: Jarle Mork, Biological Station, University of Trondheim.

3. Area: Trondheimsfjord, Lofoten and Vesterålen.

4. Activities in 1981: Cruises in Lofoten (Vesterålen, March and May.

5. Special Methods: Sensitive Electrophoresis (isoelectric focusing).

6. Reporting: Internal cruisereports from Institute of Marine Research, Bergen (in Norwegian).

Project: Effects of oil on cod eggs and larvae.

1. Objective: Studies of sublethal effects of the water-soluble fraction of Ekofisk crude oil on the early larval stages of cod.

2. Participants: Snorre Tilseth, Tor Solberg and Kjell Westrheim, Institute of Marine Research, Bergen.

3. Area: Laboratory.

4. Activities in 1981: Incubation and rearing of larvae in 50-250 ppb of the water-soluble fraction of oil hydrocarbons, and the study of the effects on larval swimming and feeding behaviour.

5. Reporting: ICES-paper, Woods Hole, 1981, E:52: "Sublethal effects of the water-soluble fraction of Ekofisk crude oil on the early larval stages of cod (Gadus morhua L.)" by S. Tilseth, T.S. Solberg and K. Westrheim.

Project: Incubation and first-feeding of cod larvae.

1. Objective: First-feeding of cod larvae is the main problem in developing methods of massproduction of 0-group cod. Both wild plankton and artificial food will be tested.

2. Participants: Stig Skreslet, Nordland Distriktshøgskole, Bodø.

3. Area: Lofoten.

6. Reporting: Bi-annual reports to the Norwegian Council of Fishery Research (in Norwegian).

Project: Artificial food for fish larvae.

1. Objective: Develope artificial food with correct particle size, specific gravity and texture, highly nutrient and easily digested. Salmonids are in focus, but artificial food for cod is planned.

2. Participants: Jan Raa, Institutt for fiskerifag, University of Tromsø, 9000 Tromsø.

6. Reporting: Bi-annual reports to the Norwegian Council of Fishery Research (in Norwegian).

Project: Large-scale rearing of cod fry in an inlet.

1. Objective: Elaborate a method for mass-rearing of cod fry on the natural production in ponds with minor environmental manipulations.

2. Participants: Victor Øiestad, Institute of Marine Research, Bergen, and Per Gunnar Kvenseth, Inst. Fish. Biology, Univ. of Bergen.

3. Area: In a natural pond (60 000 m^3), closed by dams at the Mariculture Station (a part of Institute of Marine Research) about 10 miles south of Bergen.

4. Effort and duration: Larval release March/April; weekly monitoring of hydrography, phytoplankton and zooplankton; daily sampling of fish larvae for three weeks, then weekly to termination in the autumn.

5. Methods: Ruttner (hydrogr. and phytopl.) net-hauls (fish and macro-zoopl.), pumping (micro-zoopl.).

6. Reports: International Symposium on Coastal Lagoons, Sept. 81. Bordeuax (Poster); World Conference on Aquaculture, Sept. 81. Venezia (Poster); ICES, Oct. 1981. Woods Hole, CM 1981/F:11; Norwegian Council for Fishery Research (in Norwegian).

Herring.

Project: Larval herring survey program - North Sea.

This is part of the ICES-joint survey to provide quantitative estimates of the North-Sea herring stocks.

Norwegian co-ordinator: Herman Bjørke.

Project: Ring formation in otoliths

1. Objective: Otoliths from fast-growing herring fry from enclosure experiments lasting for 100-135 days have been examined for ring formation frequency and ring width have been compared to specific growth rate and feeding conditions.

2. Participants: Harald Gjøsæter, Jakob Gjøsæter, Victor Øiestad and Snorre Tilseth.

6. Reporting: ICES, Woods Hole (H:31 and G:54)

Project: Predators on herring eggs and larvae.

1. Preliminary experiments have been carried out with the euphausiid *Meganyctiphanes norwegicus* as predator on herring larvae to identify their predation potensial and find method for identification of herring as gut content in euphausiids.

   Reporting: Internal, in Norwegian.

2. Identification of schools of euphausiids has been initiated at the spawning grounds for herring at the West-coast of Norway, Møre. Report in prep.

3. Predation on eggs of spring spawning herring.

1. Objective: Find the main predators and estimate how much they eat.

2. Participants: Toresen, R.

3. Area: Buagrunnen, at the Møre coast, western Norway.

4. Effort-duration: Sampling during the spawning period. Finished in April 1981.

5. Activity 1981: Working on the sampled materials during summer and autumn.

6. Methods: Stomach samples of cod, haddock and saithe. Experiment showing the elimination of eggs from the stomach of haddock.

7. Reporting: Thesis in preparation (In Norwegian).

Project: Fishery biological investigations on herring in Lindåspollene.

Subtitle: Recruitment investigations.

1. Objective: Estimate abundance of herring spawn and larvae during their first two months of life, aimed primarily for:

i. Spawning stock size,
ii. Mortality of eggs and larvae,
iii. Distribution, growth and feeding of larvae.

2. Participants: Department of Fisheries Biology, University of Bergen. (Mr. Arne Johannessen and Mr. Helge Ullebust)

3. Area: Lindåspollene, western Norway.

4. Duration: 1977 - 1981.

Sampling frequency: At the beginning, middle and end of the egg incubation period, scuba diving observations were performed on the spawning ground.

Larval sampling were carried out every 2-3 days during the hatching period, thereafter once every fortnight.

Activity in 1981: No field activities. Final preparations for publishing.

6. Methods: Scuba diving observations and underwater photographing on the spawning ground. Larval sampling with BONGO 20 cm (275 µm) during the hatching period, thereafter BONGO 60 (500 µm) without closing device.

7. Reporting: Annual reports for the Norwegian Council for Fishery Research (1977-1980) by Arne Johannessen. ICES - reports for the Council Meetings. Final results of the investigations will be published in scientific journals during 1981/82.

Capelin.

Project: Maturation of female capelin.

1. Objective: Histological studies of gonads to describe immature and maturing specimens, in order to improve estimates of the spawning stock.

2. Participants: Knut Forberg, Institutt for fiskerifag, University of Tromsø.

3. Area: Barents Sea, Balsfjord.

6. Reporting: Reports to the Norwegian Council of Fishery Research (in Norwegian) "A histological study of the development of capelin oocytes (in prep.). "A maturity scale for female capelin" (in prep.).

Project: Capelin egg and larvae investigations.

1. Objective: Mapping of spawning area and quantitative sampling of capelin larvae.

2. Participants: Soviet and Norwegian research vessels from PINRO and Institute of Marine Research, Bergen. Norwegian co-ordinator: Johannes Hamre.

3. Area: Troms to Kola.

Project: Food uptake, growth and survival of capelin larvae. (*Mallotus villosus* Müller) in an outdoor constructed basin.

1. Objective: To compare biological data from a population of known number and age with field data.

2. Participants: Erlend Moksness, Statens Biologiske Stasjon, Flødevigen.

3. Area: Constructed basin of 2000 m^3.

6. Reporting: Fisk.Dir.Ser. Havunders. 17(in press).

Mackerel

Project: Eggs and larvae of the North-Sea mackerel.

1. Objective: Estimates of the spawning stock on the basis of number of spawned eggs and fecundity. Identification of stocks on the basis of spawning area.

2. Participants: Svein Iversen, Institute of Marine Research, Bergen.

3. Area: North Sea, covered 3 times during June-July 1981.

6. Reporting: The results were reported to ICES in 1977 and 1981, and a third report will be presented to the ICES Statutory Meeting in 1982. Results are also found in internal cruise reports from the Institute of Marine Research, Bergen (in Norwegian).

Haddock

Project: Reproduction in haddock.

1. Objective: Egg and larval development of haddock is poorly known. Through laboratory enclosure and plastic bag experiments information of the early stages will be accumulated.

2. Participants: Erlend Moksness and Per Hognestad, Statens Biologiske Stasjon, Flødevigen.

6. Reporting: Bi-annual reports to the Norwegian Council of Fishery Research (in Norwegian).

Plaice

Project: Behaviour and genetic studies.

1. Objective: To document the effect of releasing large numbers of metamorphosed plaice larvae, both acoustic and genetic tagging are applied.

2. Participants: Gunnar Sundnes, Biological Station, University of Trondheim and Bård Holand, The Foundation of Scientific and industrial Research at the Norwegian Institute of Technology, Trondheim, Jarle Mork, Biological Station, Univ. of Trondheim.

3. Area: Borgenfjorden, near Trondheim.

6. Reporting: Bi-annual reports to the Norwegian Council of fishery Research (in Norwegian).

Halibut

In 1980 the first few halibut larvae were reared beyond metamorphosis as reported to ICES (CM 1980/F:9). This year osmoregulation of eggs and larvae were studied by J. Riis Vestergård from Zoo.fys.lab. C, August Krogh Inst., Univ. of Copenhagen, during a research period in Bergen at Institute of Marine Research/Zoo.fys.lab. Univ. of Bergen; and by scientists at Dunstaffnage Marine Research Laboratory, Oban, Scotland.

Population genetics of halibut are studied by Tore Haug, University of Tromsø.

B. Multi species investigations

Project: Population genetics-natural stocks.

1. Objective Discription of the genetic characteristics of different populations of commercial species, mainly herring and cod, in order to find a genetic marker for separating the populations routinoubly.

2. Participants: Knut Jørstad, Institute of Marine Research, Bergen.

3. Area: Møre-Finnmark.

5. Special methods: Combined biopsy for enzyme electrophoresis and tagging experiments.

6. Reporting: Internal cruise reports (in Norwegian). "Genetic analysis of tagged cod". (*Gadus morhua* L). Fisken Hav. 1981(2): 1-16 (In Norwegian, English abstract). "Crossing experiments between Arctic and coastal cod". Fisken Hav., 1981(2): 17-30 (In Norwegian, English abstract).

Project: Basin experiment with fish larvae.

1. Objective: Study the impact of food density on growth and survival of large homogenous fish larvae populations from first feeding to the 0-group stage. In combination with plastic bags, examine the effect of marginal feeding conditions which were set up in the bags.

2. Participants: Victor Øiestad (1975-1980), Erlend Moksness (1976-1980), Arne S. Haugen (1979-1980) and Bjørnar Ellertsen (1975).

3. Area: The experiments were carried out in out-door basin at Statens Biologiske Stasjon Flødevigen, Southern Norway ($58^{o}24$'N and $8^{o}43$'E).

4. Effort and duration: The experiments have included cod (1975-1977), herring (1975-1979), capelin (1977-1979), plaice (1975 and 1976), flounder (1975 and 1976) and turbot (1978-1980). Larvae were released in March-April and the experiments terminated in the autumn when the basins were drained. Hydrography, nutrient salts, phytoplankton and zooplankton was

monitored weekly. Fish larvae were sampled mostly daily to metamorphosis. The experiments were terminated in 1980.

5. Activity in 1981: These experiments have been continued within a new framework, see the Haddock-project.

6. Methods: Siphonation (hydrogr., nutr. salt and phytopl.) pumping (micro-zoopl)/net-hauls (fish larvae and macrozoopl.)/ release of a large larvae population in the basin combined with a release of cohorts in a number of preconditioned plastic bags.

6. Reporting:

Ellertsen, B., E. Moksness, P. Solemdal, S. Tilseth, T. Westgård and V. Øiestad. 1981. Growth and survival of three larval populations of cod (Gadus morhua L.) in an enclosure. Experiments and methematical model. In K. Sherman, Ed., Int.Coun.Explor.Sea Rapp.P.-V.Réun., Vol. 178.

Moksness, E. and V. Øiestad. 1979. Growth and survival experiment with capelin larvae (Mallotus villosus) in a basin and in plastic bags. Int.Coun.Explor.Sea CM 1979/F:53 (Mimeo).

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Projects: Quantitative investigations of fish-eggs, larvae, postlarvae and 0-group fish.

1. Objective: To monitor spawning and larval stages of the most important species to record irregularities and to obtain information of yearclass strength.

All species are recorded, but the cruises are designed to cover the most important: cod, haddock, herring, sprat, capelin.

The investigations are carried out during April-December, and cover the coast from Ryfylke to Finnmark.

According to period the investigations can be grouped as follows:

1. Fish-eggs and larvae investigations in the coastal area from Karmøy-Lofoten, in April. The main spawning areas are mapped, and numbers of larvae recorded. Sampling gear: Gulf III, Juday net. Co-ordinator: Herman Bjørke, Institute of Marine Research, Bergen.

2. Postlarvae investigations, Lofoten to Finnmark, July. Sampling gear: Pelagic trawl, finemeshed codend. Co-ordinator: Herman Bjørke.

3. 0-group investigations.

   a) Joint survey with the Soviet Union in the Barents Sea, August-September.

   b) Fjord and coastal area from Ryfylke-Finnmark, mainly for herring and sprat.

4.3 Contributed Working Papers

4.3.1 The Detection of Larval Fish Food Particles by an In-situ Particle Counter, and Monitoring the Particle Density and Distribution in First Feeding Areas, by Snorre Telseth.

4.3.2 The Spawning Period of Arcto-Norwegian Cod during the years 1976-1981, by Per Solemdal.

4.3.3 Sampling Fish Larvae with Large Pumps, by Per Solemdal.

4.3.4 Post Larvae Investigations, by Herman Bjørke.

4.3.5 The Western Mackerel Spawning Stock Estimate for 1980, by S. J. Lockwood, I. G. Baxter, J. C. Gueguen, G. Joakimsson, R. Grainger, A. Eltink, and S. H. Coombs.

4.3.6 Larval Haddock and Cod Survival Studies on Georges Bank, by R. G. Lough and G. C. Laurence.

4.3.7 Comments on Efficiency of NEFC MARMAP Surveys, by Peter Berrien.

4.3.8 Measuring the Effect of the Variability of Egg Densities over Space and Time on Egg Abundance Estimates, by Michael Pennington and Peter Berrien.

LARVAL FISH ECOLOGY WORKING GROUP
Lowestoft, Suffolk, U.K.
July 1-3, 1981

Contribution No. 1

THE DETECTION OF LARVAL FISH FOOD PARTICLES BY AN IN-SITU PARTICLE COUNTER, AND MONITORING THE PARTICLE DENSITY AND DISTRIBUTION IN FIRST FEEDING AREAS

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4.3.1 The Detection of Larval Fish Food Particles by an In-situ Particle Counter, and Monitoring the Particle Density and Distribution in First Feeding Areas, by Snorre Tilseth

Johan Hjorts' hypothesis for fish larval mortality is based on variable feeding condition at a critical stage which can cause extreme variations in the year class strength. It has been difficult to test this simple attractive hypothesis in field surveys. The main reason for this has been the inadequacy of the sampling gear currently in use (pumps and nets) to establish whether any body of water can or cannot support fish larval survival.

During the last few years fishery scientists have done a great deal of work on the behaviour of fish larvae and their energy requirement for growth and survival. The results of this research have, without almost any exceptions, showed the great difference between the required density of nutrient particles for first feeding larvae to survive, compared to the densities found in the sea. However, pelagic fish have success in their environment and it has been recognized that there have to be patches of suitable concentrations of food organisms for first feeding larvae.

There has, consequently, been a need in fisheries research today to detect and describe these patches, and to study the biological and physical mechanisms affecting the formation of patches.

To do this one has to design and make new sampling systems adapted to particle sizes important to first feeding fish larvae. The solution to this problem seems to be *in situ* particle analysis.

The present note describes and presents some of the results achieved by an *in situ* instrument system designed to sample, count and size-analyse particles within the size range 100-600 μm, the size range of food particles most frequently captured by cod larvae.

The Particle Analyser

The *in-situ* particle analyser system is schematically presented in Fig. 3. The system is based on a Hiac-PC 320 Particle Analyser (works on the principle of light blockage).

The sensor (E-2500, dynamic range 80-2500 μm) is installed in a pressure-proof box together with a depth detector. A pump is connected to the sensor. The sensors and the pump are lowered into the sea by a special winch. Sea water is sampled by the pump through a 60 cm 30 mm in diameter hose and pumped through the sensor at a flow rate of 6.15 liter per minute.

Particles are counted by the Hiac PC-320 Particle Analyser, depth sensed by the separate depth detector unit. The Micro-count datalogger unit contains an input-output interface to take care of the incoming data, a large internal data storage area to hold the accumulated data, operator communication via a small CRT display, a keypad, and a microprocessor with program to control the system. Finally, a Silen 733 terminal is connected to the micro-computer. This terminal contains a full text keyboard and a page printer, used for initial operator communication, and later for printout of data tables. Two cassette tape stations are included in the terminal.

The system operates from 0-50 m of depth and the registration of particles are presented on the TV monitor as particles per liter. The vertical distribution of particles can be presented on the monitor per meter, per 2 meters or per 5 meters, depending on the selected depth intervals one wants to monitor.

The Hiac Particle Analyser measures the size of irregular particles, such as nauplii, as ratio of its areas. *Artemia* nauplii were measured by the microscope in the same way and their size distribution divided in four 50 µm size groups from 200-400 µm. Four of the Hiac Particle Analyser channels were set according to the sensor calibration diagram in the same size groups. The result of this comparison is presented in Fig. 2.

A test at sea was also made. The *in-situ* particle analyser was submerged to 5 meters depth. The concentration of particles, 300-500 µm size range was calculated in ten samples (total volume 25 l) and the particle density at 5 m was estimated. At the same time sea water from the same depth was pumped on deck through a hose (5 cm diam.) by an electric submersible pump (Flygt, 2051, 350 l/min). Two 23.7 liter samples (calibrated tanks) were filtered on 90 µm plankton net and the particles within the size range 300-500 µm were counted. The results from the two methods are presented in Table 1.

Table 1. The particle density (300-500 µm) at 5 m of depth at position 5 in the Austnesfjorden (Fig. 3). The result from the *in-situ* particle analyser is compared to that from the plankton pump.

	In-situ P.A.	Plankton pump
Particle cons.	16/liter (SD±2.1)	19/liter
Samples	10 x 2.5 liter	2 x 23.5 liter
Total No. of Particles	381	1692

Both the size calibration on *Artemia* nauplii and the counting experiments at sea turned out satisfactorily.

Field Investigations

In Fig. 3 (see also Fig. 11 for general view) is presented a map with sections of the Austnesfjord where most of the *in situ* particle analyser tests took place. The figure also shows the increase in the number of cod larvae in the fjord during the survey.

In Fig. 4 is presented the vertical particle (150-600 µm) distribution in a 24 h station at position 5 on the 22-23.4.81 in the Austnesfjord. The maximum observed particle concentration was a small patch of 50 particles per liter at about 15 m. The particle isolines in the upper 20 m tend to ascend to the surface at midnight, indicating diurnal vertical migration.

Another 24 h station was made 6 days later at the same position (Fig. 5 A and B). The particle concentration had increased markedly during that period. More than 50 particles per liter were found at 25-35 m on every profile during the 24 hours station. A very dense surface patch was found at midnight with more than 500 particles per liter. In Fig. 5B is presented the distribution of nauplii only, during the very same 24 h station. This Figure is the result of samples taken by the submersible plankton pump. The samples were taken at the same time as the *in situ* particle profiles, at the following depths: 0, 2.5, 5, 7.5, 10, 15, 20, 25, 30, 35, and 40 meters. Figs. 5A and B show about the same particle/nauplii isopleth diagram and particle/nauplii distributions. However, Fig. 5B shows more clearly the diurnal vertical migration of the nauplii. This was investigated more closely to see what sizes of nauplii which made vertical diurnal migration. In Fig. 6 is presented the size frequency distribution of nauplii at 30 m at 13 h, 23 h and 09 h, and 0 m at 23 h during the 24 h station on the 28-29.4.81. It appears from the figure that it is only the bigger nauplii (200-350 µm carapax-length) which make vertical diurnal migration. The hydrographic situation during that 24 h station was perfect for this type of observation. There was no wind in the fjord and consequently no vertical turbulence. The temperature distribution in the upper 60 m during the experiment is presented in Fig. 7. Cooling of the surface water took place during the 24 hours station and one can see cores of cold water (2.4-2.6^{o}C) in the upper few meters. Between 5 to 15 m a layer of warmer water (2.7-2.8^{o}C) was observed. An intermediate layer of colder water (2.6^{o}C) was found between 15-50 m, above the transition layer (Coastal water-Atlantic water) with rapidly increasing temperature with depth.

The highest concentration of particles was found in the cold intermediate watermasses. Both Figs. 5A and B show decreasing particle/nauplii concentrations down towards the transition layer. In the unstable cold watermasses the nauplii/particles migrates through the upper stratified layers to the surface when there was no or very little vertical turbulence. The effect of wind stress or turbulence on vertically migrating particles in presented in Figs. 8A, B, C, and D. The figures present continuous measurements of wind velocity and direction (8A) from 9/5-15/5-80, temperature distribution (0-90 m, 8B) particle (300-500 µm) distribution (0-40 m, 8C) and "the integrated particle density" (0-40 m, 8D). The observations were made from an experiment in 1980 at position 5 in the Austnesfjord (see Fig. 3). From the 9/5 to 12/5 the wind was blowing down-fjord with varying velocity. On 12 May the wind changed direction 180° and was blowing up-fjord with a velocity of 5-10 m/sec (Fig. 8A). Unfortunately observation of temperature and particle distribution were not made from 10 to 12 May. However one 24 h station was made on 9 May during the period when the wind was blowing down-fjord. During that period the upper 10 m of the water column showed tendencies of mixing and colder intermediate watermasses were observed between 15 to 55 m above the transition layer with rapidly increasing temperatures with depth (Fig. 8B).

Within the cold intermediate watermasses a particle maximum layer was found (Fig. 8C), and the particle density was increasing during the period (Fig. 8D). The wind was blowing the surface water down-fjord and this was compensated by the intermediate watermasses moving in the opposite direction. What we observed during the 24 h station on 9 May was a patch of particle rich intermediate water moving in from the outer part of the fjord. The particle isolines in the upper 10 m followed the isoterms (Fig. 8B and C). When the wind direction reversed and increased in velocity 12 May, the current system also reversed. The surface water moved up-fjord and became completely mixed within 24 h. The intermediate watermasses moved in the opposite direction and the transition layer (bottom water of the fjord) moved in the same direction as the surface layers. This is shown in Fig. 8B where the isoterms of the transition layer ascends from 60-70 m to 30-40 m from 12 to 15 May.

No particle diurnal vertical migration was observed during that period (Fig. 8C). The particle density decreased (Fig. 8D) and became almost homogeneous from the surface down to 40 m and no particle patches were observed.

These results clearly show that one has to take into account both the weather conditions and the time of the day when considering vertical profiles on a section. This is demonstrated in the following three figures (Figs. 9, 10A and B). The particle (150-600 μm) distribution in 0-40 m through a section of the Austnesfjord is presented in Fig. 9. The section was made by night on the 27/4-28/4-81 from 21^{30} h to 04^{20} h. There was very little to no wind in the fjord when the section was made. Patches of more than 100 particles per liter were found in the surface water of the outer parts of the fjord. A minimum layer was observed at 10 m of depth in the middle of the fjord where the particle density was less than 10 particles per liter. In the bottom of the fjord three patches of more than 50 particles per liter were found at different depths.

The same section through the fjord was made 24 h later by day time (Fig. 10A). Within that short period of time the particle distribution in the fjord had changed completely. A particle minimum layer (> 10 particles/liter) was found from the surface down to about 20 m through almost the entire fjord and the surface patches in the outer parts of the fjord had disappeared. Only one big patch with more than 50 particles per liter was observed between 20-40 m at the bottom of the fjord. The difference in particle distribution of the Austnesfjord by day and night, can most probably be explained by the vertical diurnal migration of the nauplii. However, in the outer part of the fjord a change in watermasses has probably also occurred. The big "day patch" observed at the bottom of the fjord was split up in parts with different depth positions by night. This probably represents different size groups of nauplii with different vertical diurnal migration patterns (see Fig. 6).

The in situ particle analyser gives a fairly good picture of the nauplii distribution (the main cod larval food organisms) in the Austnesfjord. This is shown by comparison of the results found by the in situ instrument with the results from the plankton pump samples examined microscopically (Figs. 5A and B., Figs. 10A and B). The same particle/nauplii distribution patterns were found by both methods. The difference between the isopleth diagrams is caused by the difference in sampling, and also in the different treatments of the samples. Only the nauplii were counted in the pump samples. However, all particles within the size range 150-600 μm, that block light are counted by the in situ instrument. This is the food particle size range most frequently found in the alimentary channel of cod larvae.

In Fig. 11 a map of the Lofoten area is presented. The main spawning area of the Arcto-Norwegian cod stock is located at Henningsvaer, Hølla and the Austnesfjord. Some of the cod eggs are being trapped in the Austnesfjord. However, the main amount is transported by the Coastal current along the Lofoten islands. Most of the eggs will hatch in the waters outside the islands, and the main first feeding area is thought to be in the open ocean bay of the Vesteralsfjord.

The particle distribution in the waters around the Lofoten islands and in the Vesteralsfjord was monitored at the time when the cod eggs were hatching. Simultaneously plankton pump samples, CTD-sonde profiles, Juday net (80 cm in diam.) samples and Tucker trawl samples were taken at the stations on the sections presented in Fig. 11. In the present note only a few of the particle vertical sections will be presented.

Fig. 12A and B shows the particle distribution on the northeast section in the Vesteralsfjord. Fig. A presents the in situ particle analyser results and Fig. B the plankton pump results. Plankton pump samples were only taken at every second station on the section. The two figures show the same particle distribution picture. However, due to the more frequent samples taken by the particle analyser, a more accurate distribution of the particles on the section was achieved. This is clearly seen by comparing the extent of the surface patch in the two figures, observed at about 3 nautical miles off land. This is an example of how important it is to make frequent samples when looking for particle/nauplii patches.

The following sections were made in the open ocean water off the Lofoten islands: Eggum (Fig. 13), Myrland (Fig. 14), Fuglehuk (Fig. 15) and Skiva (Fig. 16) (see Fig. 11). The Skiva section was surveyed at three different periods during the cruise.

The Eggum and Myrland sections were surveyed by day and only on the Myrland section a surface patch (> 50 particles/liter) was observed at about 8 nautical miles off land. On the Eggum section a patch of more than 50 particles per liter was found at 10 meters depth at the same distance off land as on the Myrland section. Common for both of the two sections was the low particle densities (10-30 particles/liter) in the surrounding watermasses. The particle distribution was a little different on the next section where we found a high density patch (50-100 particles/liter) close to the shore extending to about 2 nautical miles off land from the surface down to 15 m. On the same section at about 8 nautical miles off land a surface patch (> 50 particles/liter) was observed. The section was surveyed by night. There are good reasons to believe that the observed patch on all three sections (Eggum, Myrland and Fuglehuk) constitute a coherent watermass with higher particle density than the surrounding watermasses; this can be seen on the isolines at this position on these three sections. On the southernmost section there was observed a more complicated particle distribution picture. The section was surveyed on the 24/4-81 by day and two patches were observed at about 4 nautical miles off land, one at about 5-10 m depth (> 100 particles/liter) and another at about 20-25 m (> 50 particles/liter). Further off land along the section the particle density decreased. Three days later (27/4-28/4) the same section was surveyed by night (Fig. 16B). Two surface patches were found. One smaller at about 8 nautical miles off land and the other at about 14 nautical miles off land extending from the surface down to 20 m. The last survey of the Skiva section was made by night on the 6/5-7/5-81 (Fig. 16C). The particle density on the section had increased substantially in 8 days. On the outer half of the section in the upper 10 m of water the particle concentration was between 100 and more than 200 particle per liter.

It was obvious that within this period the particle density in the area was increasing. One can expect good survival of cod larvae at food particle concentrations between 100-200 particles/liter. The same area was surveyed (plankton pump samples) at about the same period of time in 1980 and the maximum particle concentrations observed was 10-20 nauplii/liter. The results from the cod 0-group survey in the autumn showed a very small index indicating a poor 1980-year class. The food particle situation for first feeding cod larvae in 1981 looks much more promising for the 1981 recruitment to the Arcto-Norwegian cod stock.

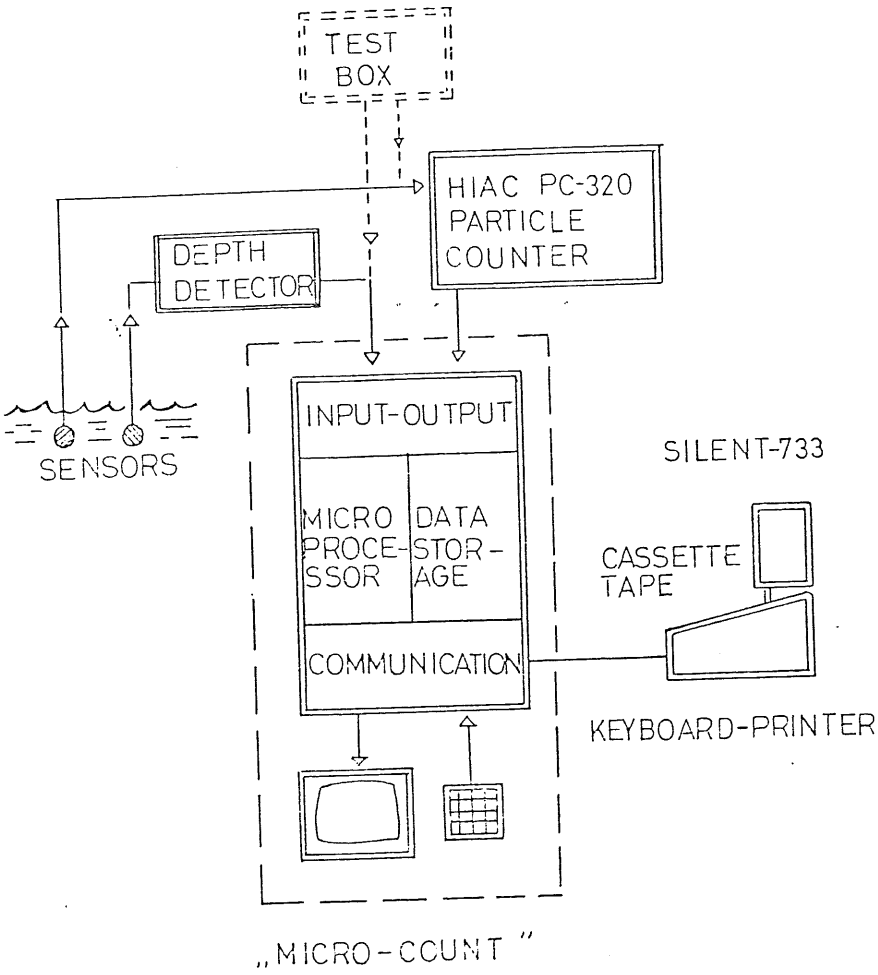


Fig. 1. The particle analyser system.

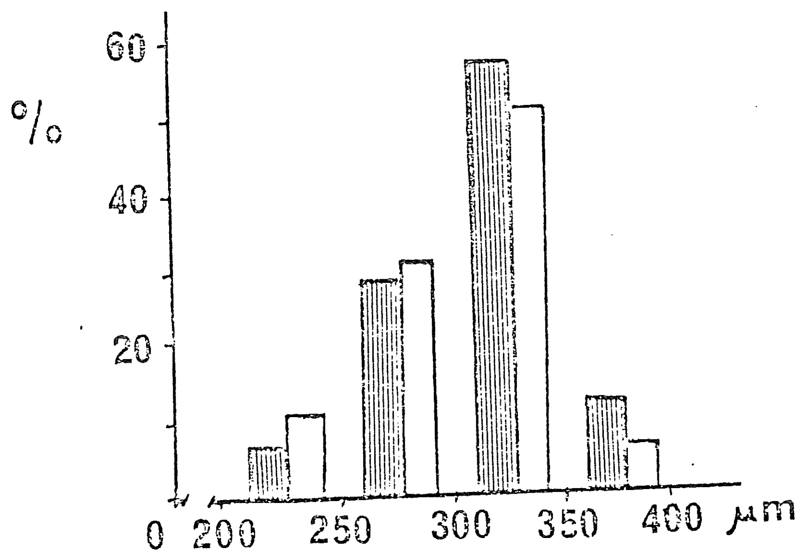


Fig. 2. Length distribution of Artemia nauplii analysed by the Hiac Particle Analyser (n=1542) compared to measurements made by the microscope (n=45).

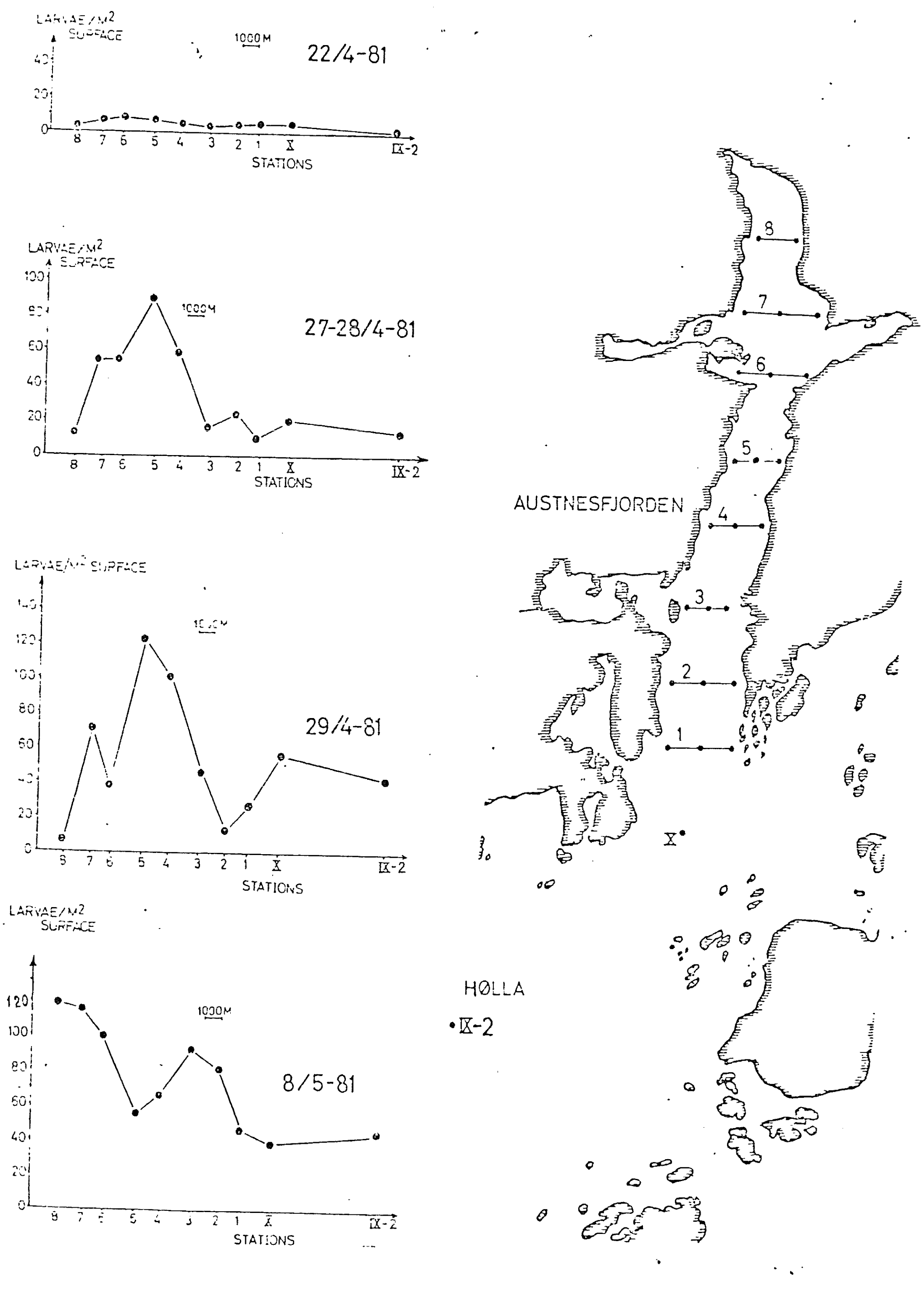


Fig. 3. Map of the Ausnesfjord with stations, sections and figures of the cod larval distribution per m^2 surface 22/4-8/5-81.

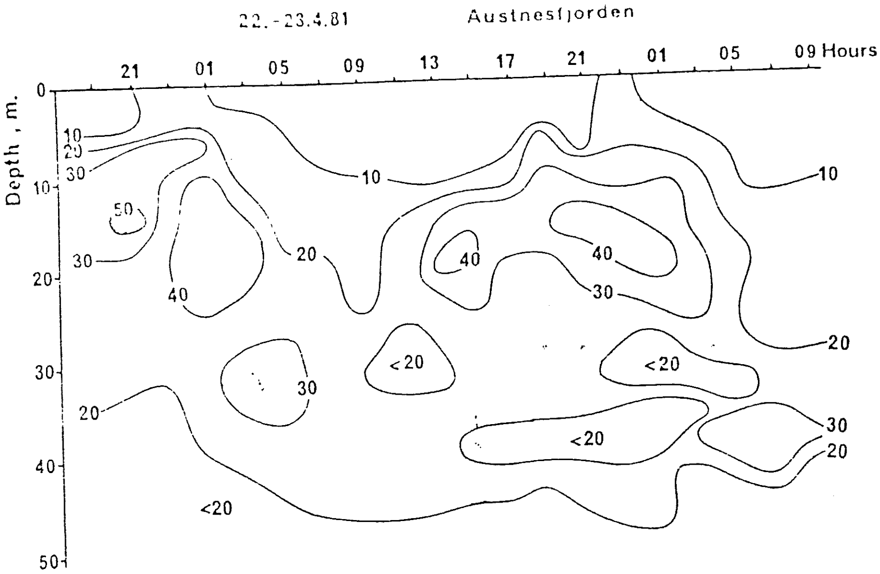


Fig. 4. Isopleth diagram of the particle concentration (per liter) center station, section 5 in the Austnesfjord 22-23/4-81. Particle size range 150-600 µm.

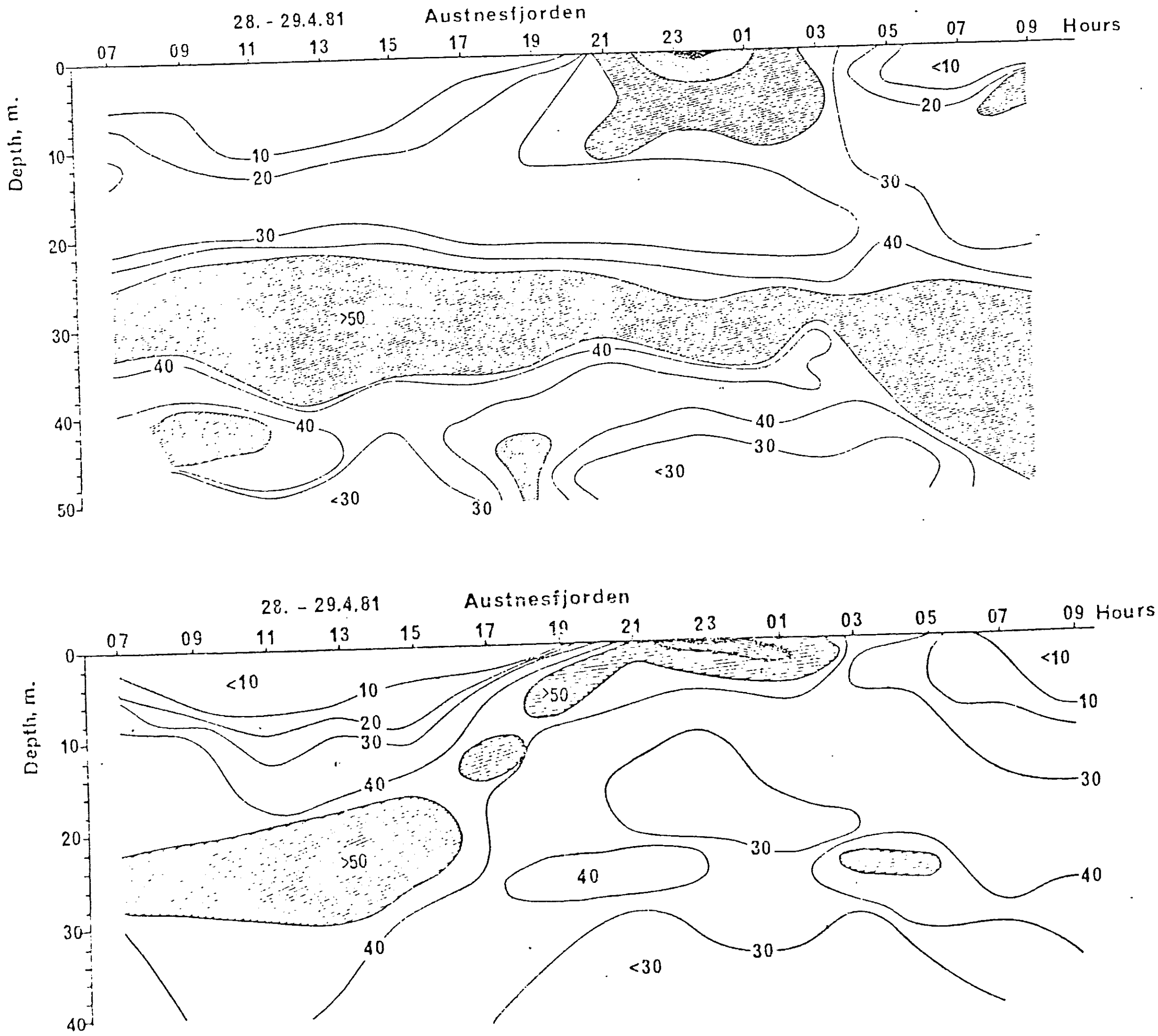


Fig. 5. Isopleth diagrams of the particle concentrations (per liter) A, and nauplii density (per liter), center station, section 5 in the Austnesfjord 28-29/4-81. Particle size range 150-600µm.

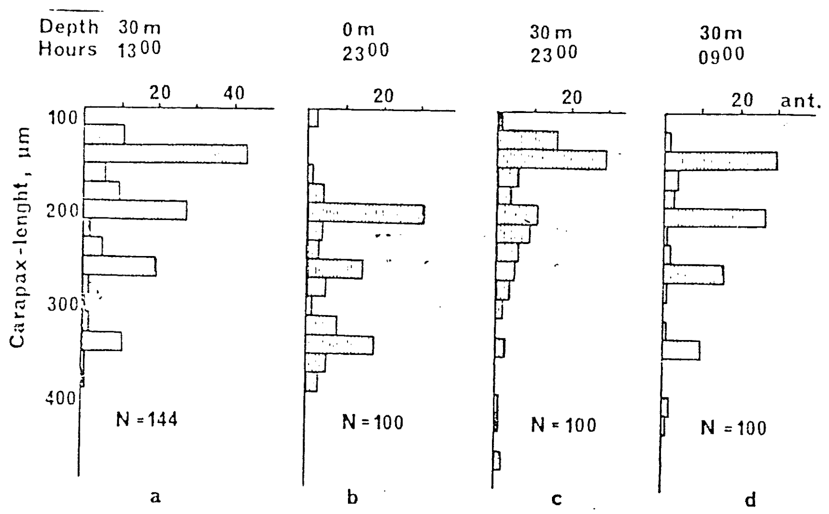


Fig. 6. Nauplii carapax-length (µm) distribution at 30 m at 13, 23 and 9 hour and at 0 m at 23 m, center station, section 5 in the Austnesfjord 28-29/4-81.

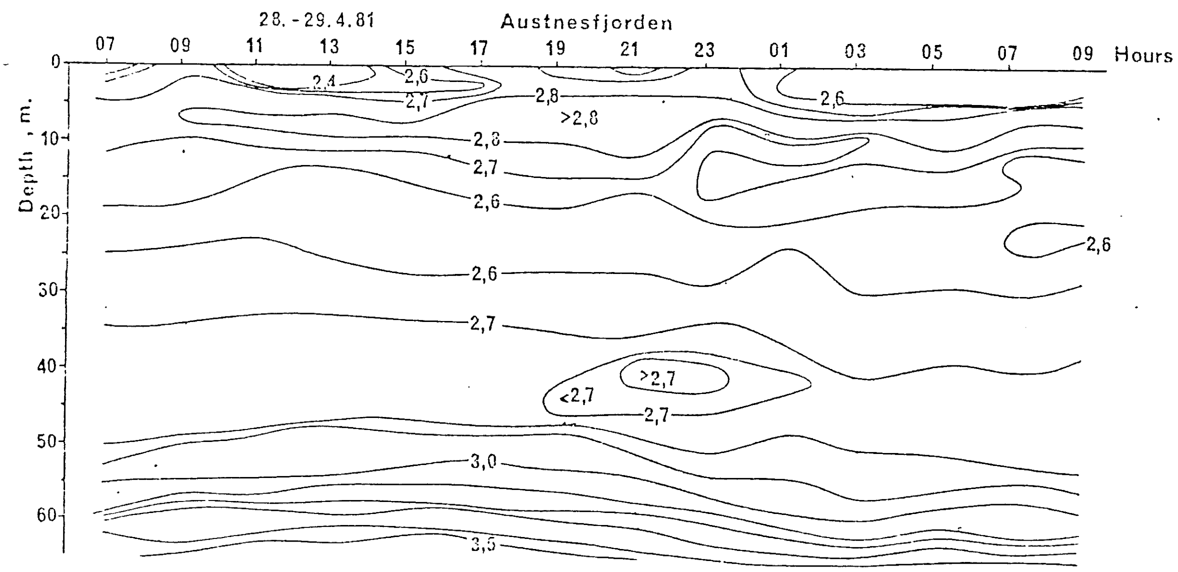


Fig. 7. Isopleth diagram of the temperature distribution, center station, section 5 in the Austnesfjord 28-29/4-81.

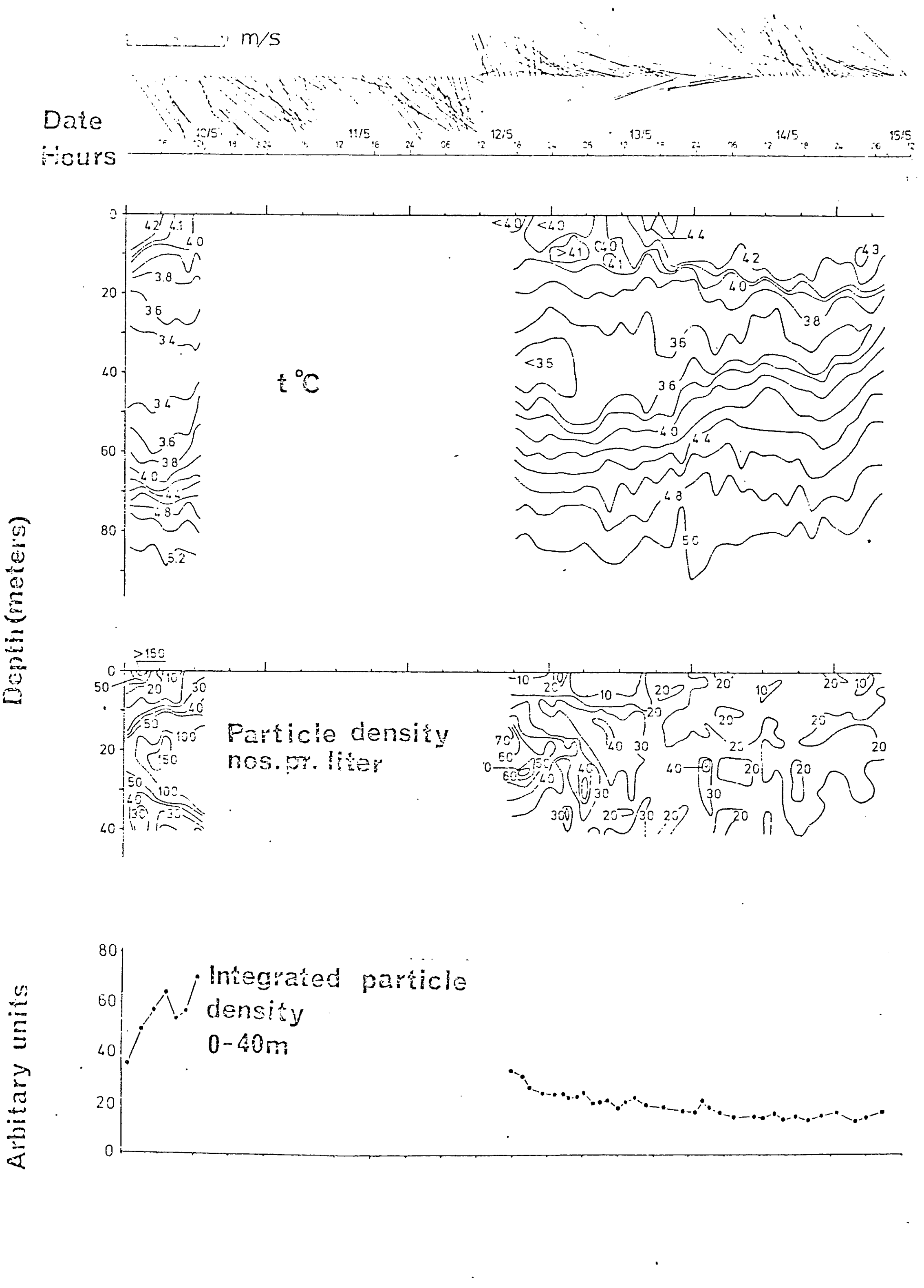


Fig. 8A, B. C and D. Presenting A; wind velocity and direction, B; isopleth diagrams of the temperature and C; particle concentration (300-500 µm) distribution and D; integrated particle density, at the center station on section 5 in the Austnesfjord 9/5-15/5-81.

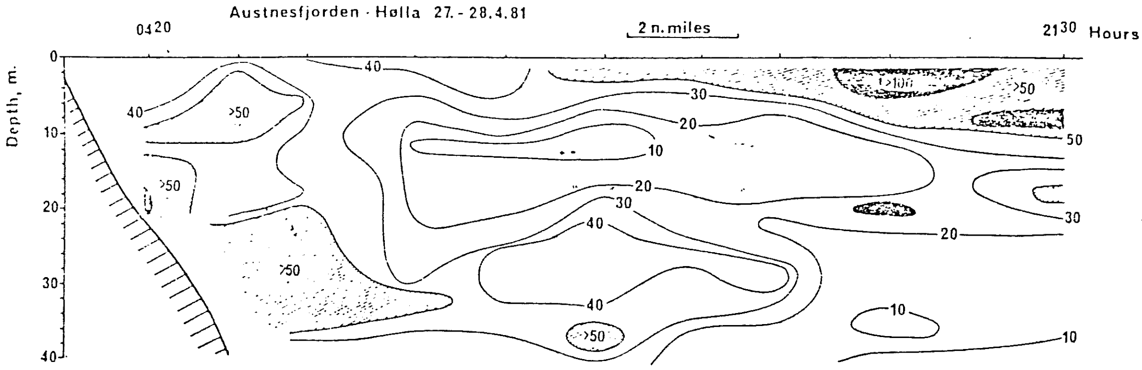
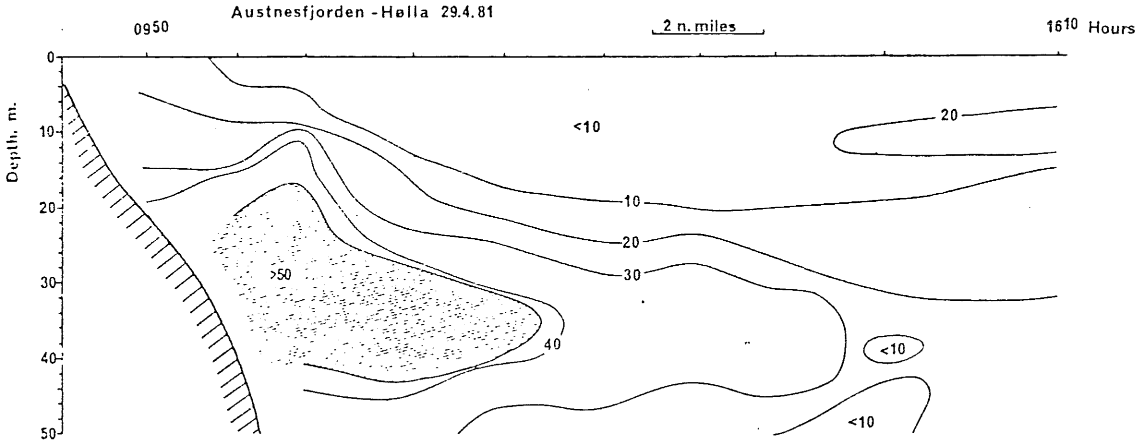


Fig. 9. The particle distribution (per liter) in the Austnesfjord 27-28/4-81 at 21^{30} hours to 04^{20} hour. Particle size range 150-600 µm.



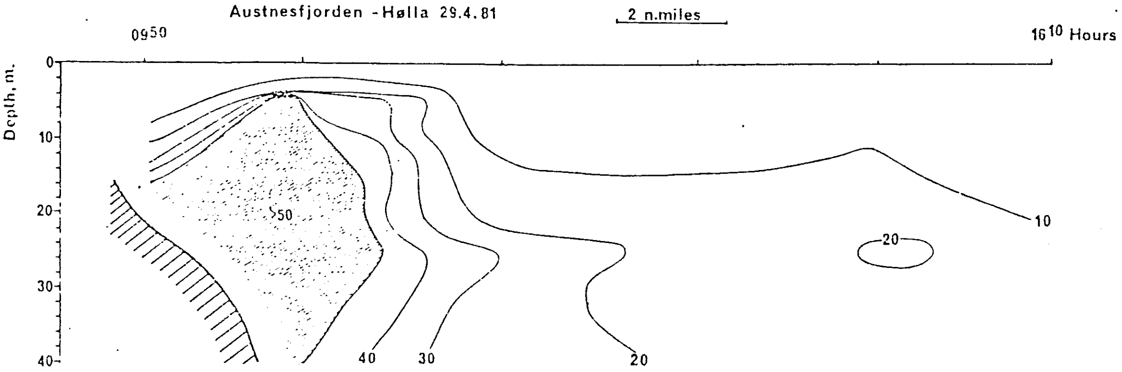


Fig. 10A and B. The distribution of particles (A) and nauplii (B) (per liter) in the Austnesfjord 29/4-81.

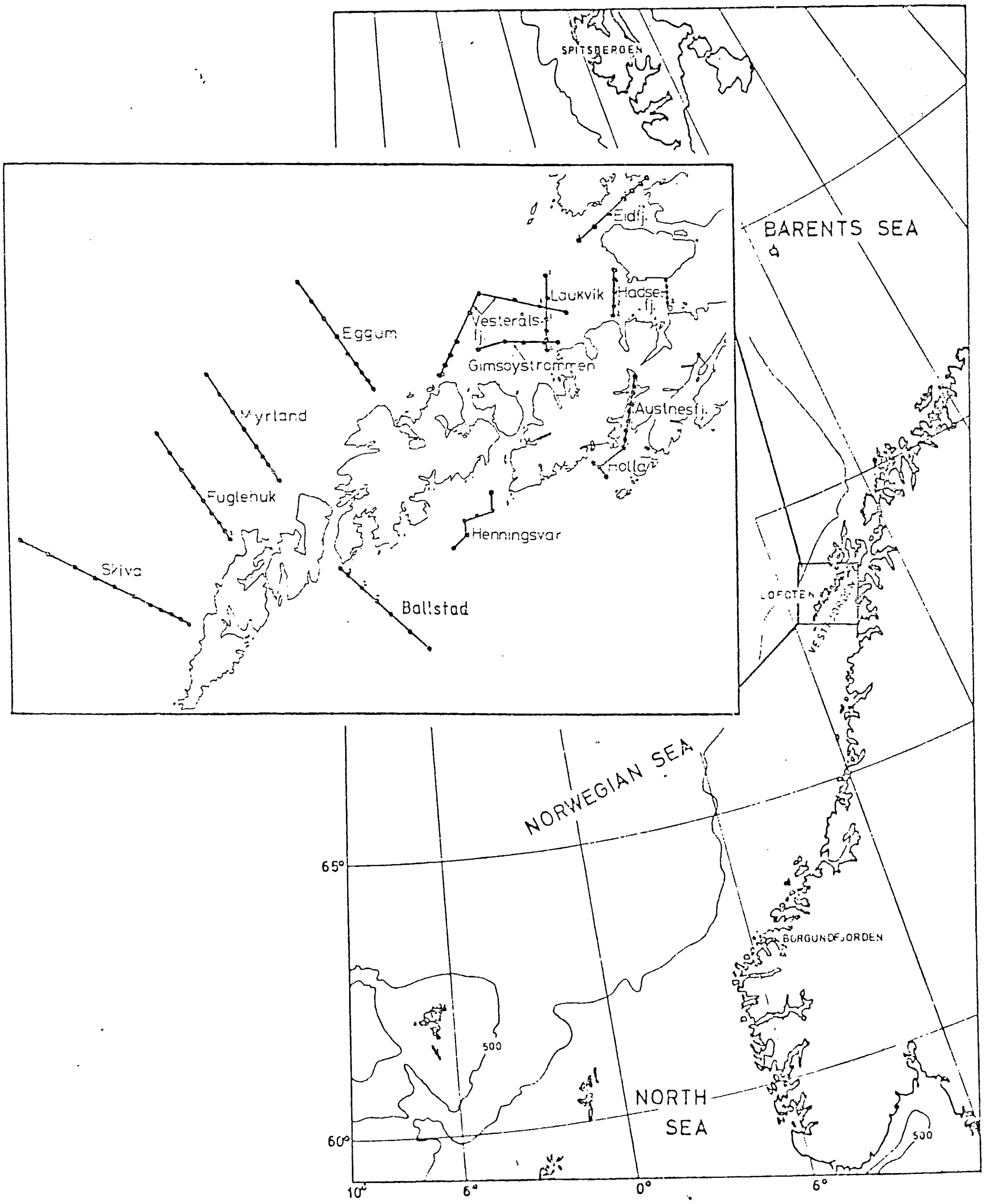
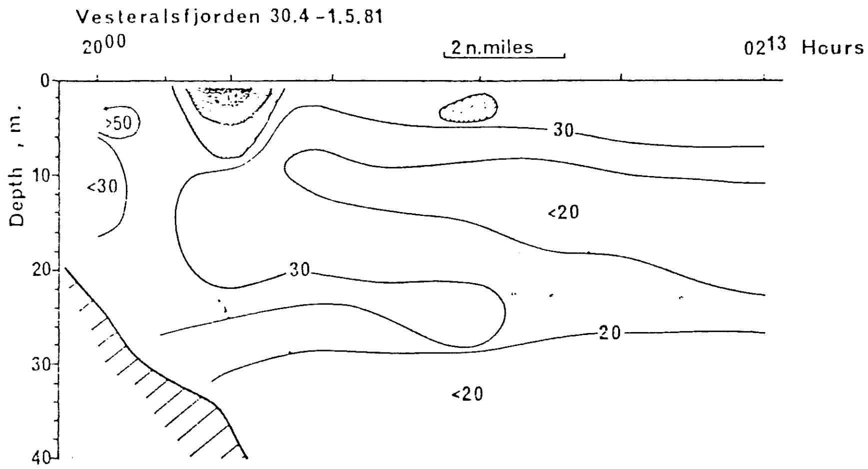


Fig. 11. Map of the Lofoten area with station and sections 21/4-8/5-81.



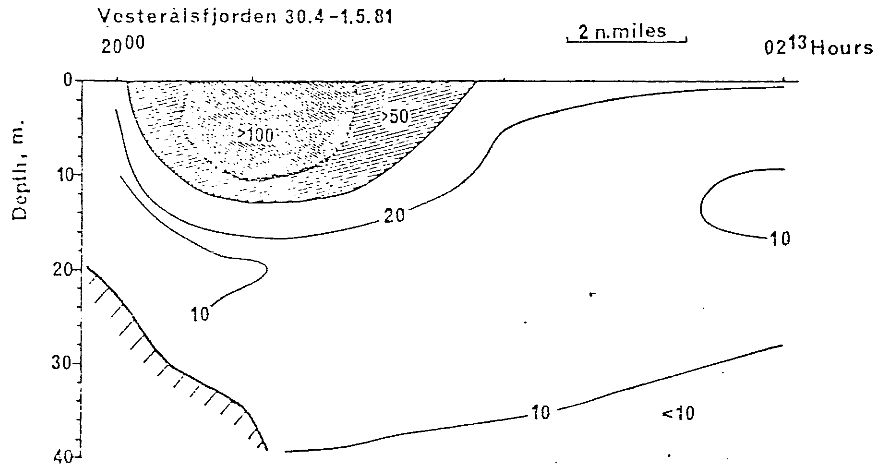


Fig. 12A and B. The particle (per liter, Fig. A) and nauplii (per liter, Fig. B) vertical sections in the Vesterålsfjord, 30/4-1/5-81.

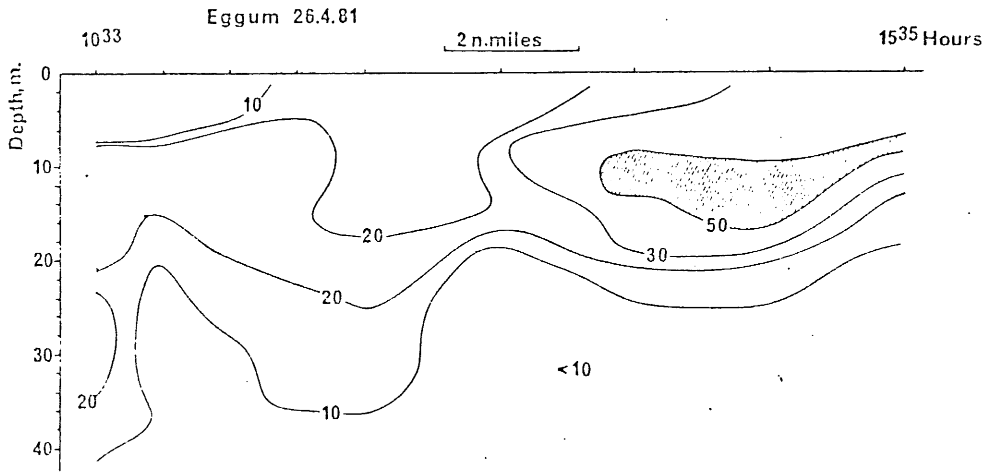


Fig. 13. The particle (per liter) vertical section on the Eggum section 26/4-81.

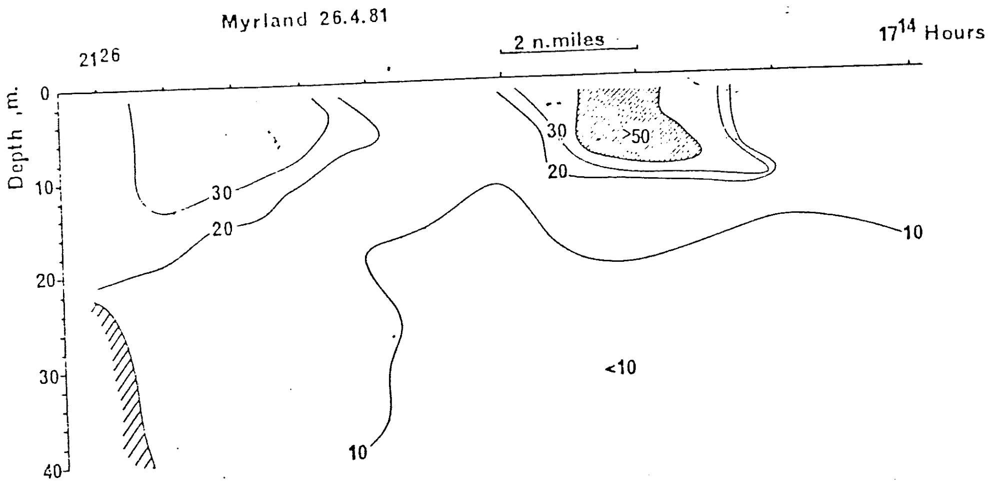


Fig. 14. The particle (per liter) vertical section on the Myrland section, 26/4-81.

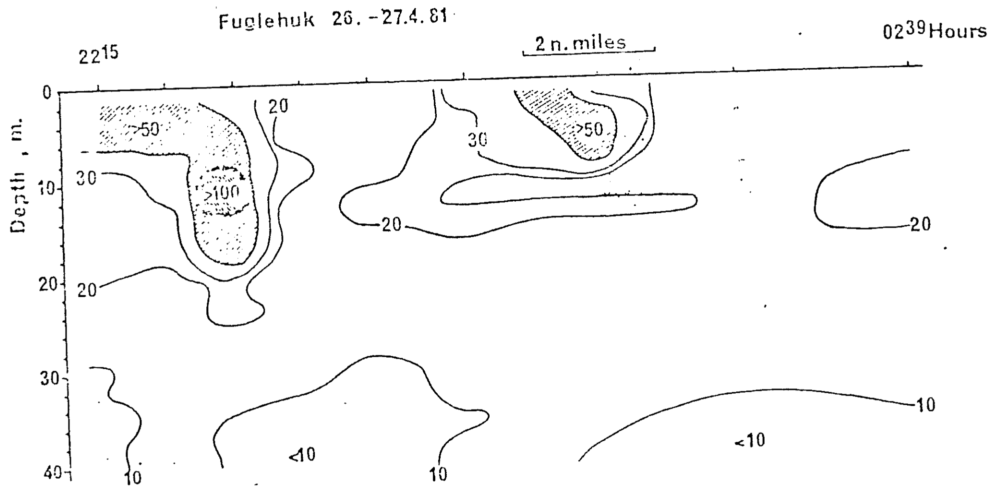


Fig. 15. The particle (per liter) vertical section on the Fuglehuk section, 26/4-27/4-81.

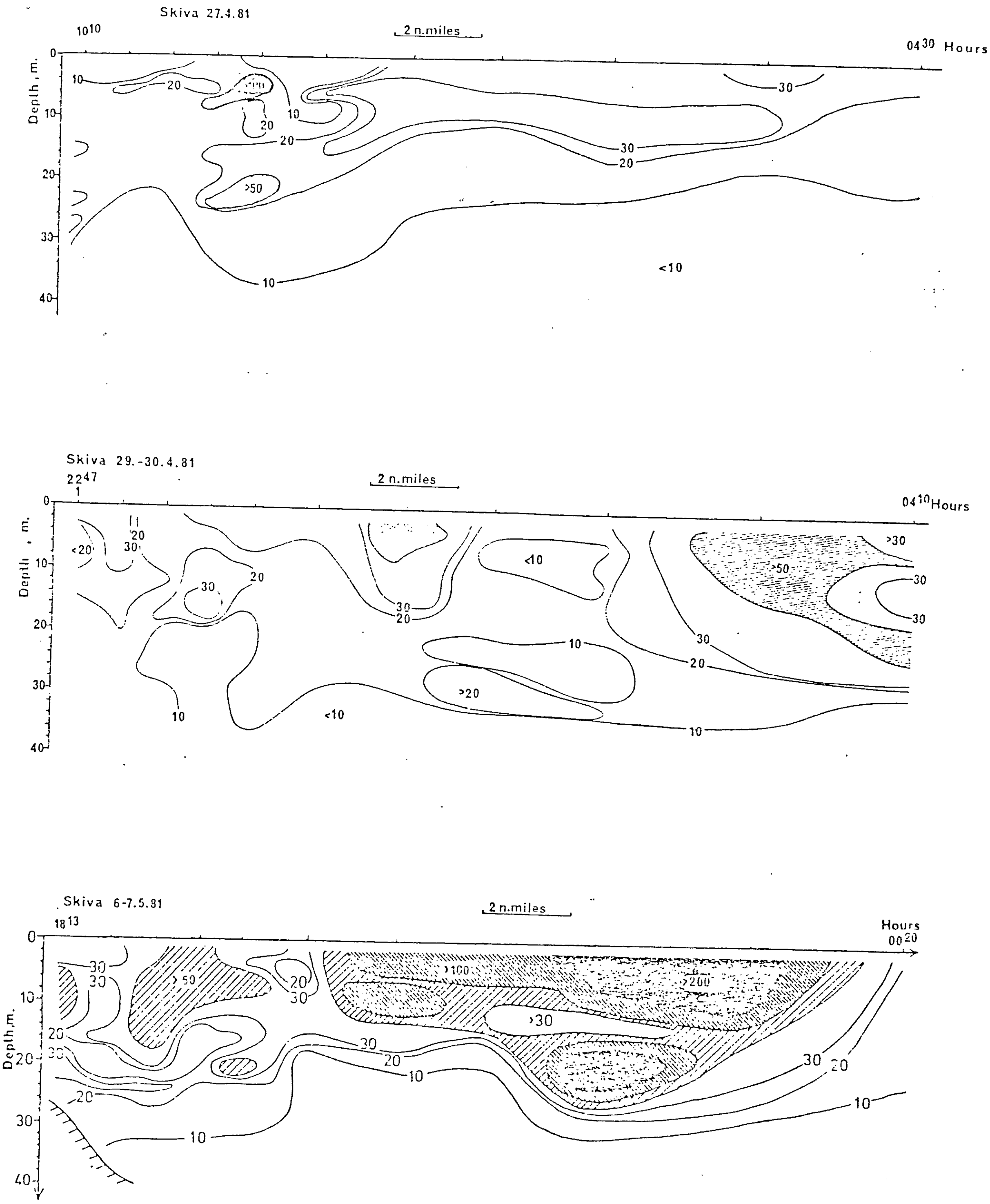


Fig. 16A, B and C. The particle (per liter) vertical section on the Skiva section on the 27/4, 29/4-30/4 and the 6/6-7/5-81.

LARVAL FISH ECOLOGY WORKING GROUP
Lowestoft, Suffolk, U.K.
July 1-3, 1981

Contribution No. 2

THE SPAWNING PERIOD OF ARCTO-NORWEGIAN COD DURING THE YEARS 1976-1981

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4.3.2 The Spawning Period of Arcto-Norwegian Cod During the Years 1975-1981, by Per Solemdal

1. Introduction

The spawning period is a rather fixed species characteristic, with small annual variations. Of possible biological factors involved, the age composition of the spawning population is supposed to influence the period of maximum spawning, older fish spawning earlier than first-time spawners.

According to Hjort (1914) mass mortality of fish larvae would occur as a result of starvation. Low food densities may occur as a mismatch between the production cycle of nauplii and the occurrence of first-feeding fish larvae.

The spawning of cod and Calanus takes place in different parts of the water column, and in different periods and areas. It can be easily understood that the chances for a perfect match are very low.

The degree of change in maximum spawning due to change in age composition of the spawning population is poorly known.

The main objective of the present investigations is to obtain spawning curves for a series of years to compare with the corresponding age compositions.

Spawning curves, in combination with one or a few egg surveys, can be used to calculate the total egg production from a restricted spawning area.

The practical objective of the spawning investigations in Lofoten has been to match our first-feeding larvae investigations to the right period and area. This seems to be a general problem of investigations aiming at prognosis on year-class strength on the basis of the larval stages.

2. Materials and Methods

The stations are shown in Fig. 1. Throughout all the years 3 stations from each of the subareas--Austnesfjorden, Hølla and Haenningsvaerstraumen--were used to calculate the spawning curves. Number of stations have been increased during the last years, but the new stations are not included in the present material.

A small Juday net, 0.1 m^2 surface, with meshsize 180 or 375 μm, was used. Two hauls were taken at each station from the depths 100-30 and 30-0 m. The sampling frequence was 2 or 3 times per week, usually from about 10 March to the beginning of May. The eggs were aged according to Westernhagen (1970) (see Ellertsen et al. 1981). The development period from fertilization and including Stage 1 aβ takes about 3 days. The majority of these eggs are spawned since last sampling and reflects the true intensity of the spawning. Due to the long incubation period, about 3 weeks, and the varying speed of transport of the eggs out of the spawning area, the older egg stages are treated separately.

3. Results

Fig. 2 shows the spawning curves for the years 1976-81. The material from the three subareas, Fig. 1, are pooled for each date. The 3 curves are densities of newly spawned eggs, older stages and total egg density. In general the spawning curves (eggs less than 3 days of age) show maximum in the first week of April. In 1980 no spawning maximum occurred, and in 1981 two maxima occurred, one in the middle of March and one during the first week of April.

The varying speed of egg transport between years are specially shown in the years 1976 and 1977. In 1976 the 0-3 days old eggs are in minority almost throughout the spawning season. In 1977 the opposite occurred.

According to the density of 0-3 days old eggs, it usually reaches a maximum level of 1000-2000 eggs per m^2 surface.

In Figs. 3-5, the spawning curves for the 3 subareas--Hølla, Austnesfjorden and Haenningsvaerstraumen--are given for all the investigated spawning seasons. Fig. 3 also includes the spawning curve of 1975, Hølla being the only subarea investigated this first year. As seen from Fig. 3a the spawning maximum in 1975 is the most delayed of all the investigated years. The 2 spawning maxima shown in 1981, Fig. 2, are demonstrated on Hølla, Fig. 3a, but not for the 2 other subareas, Fig. 4a and 5a. Similarly, the 2 spawning maxima found in Austnesfjorden in 1977, Fig. 4a, are not found in the 2 other subareas, Figs. 3a and 5a.

It must be noted that the egg densities given in the figures do not reflect the total amount of eggs produced the different years.

4. Discussion

The general impression from the spawning curves in Fig. 1 is the stability of the spawning maximum from year to year in the first week of April. According to Wiborg (1957) the spawning maximum for the Arcto-Norwegian cod in Lofoten during 1950-60 was the middle of March. For the late 60's Smedstad and Øiestad (1974) report spawning maximum in Lofoten at the end of March.

The general trend towards a higher proportion of first-time spawners during this period is reflected in the delay of the spawning maximum.

Year to year variation in spawning maximum, for instance the 2 spawning maxima in 1981, may be related to the polarized age composition of the spawning population this year, the large 1975 year class contributing substantially as first-time spawners in 1981. The variation of spawning maximum and intensity between subareas within the same year is mainly caused by the depth of the thermocline, where the cod is spawning (Ellertsen et al. 1981). This is clearly shown in Austnesfjorden in 1977, when 2 groups of spawning cod entered the fjord.

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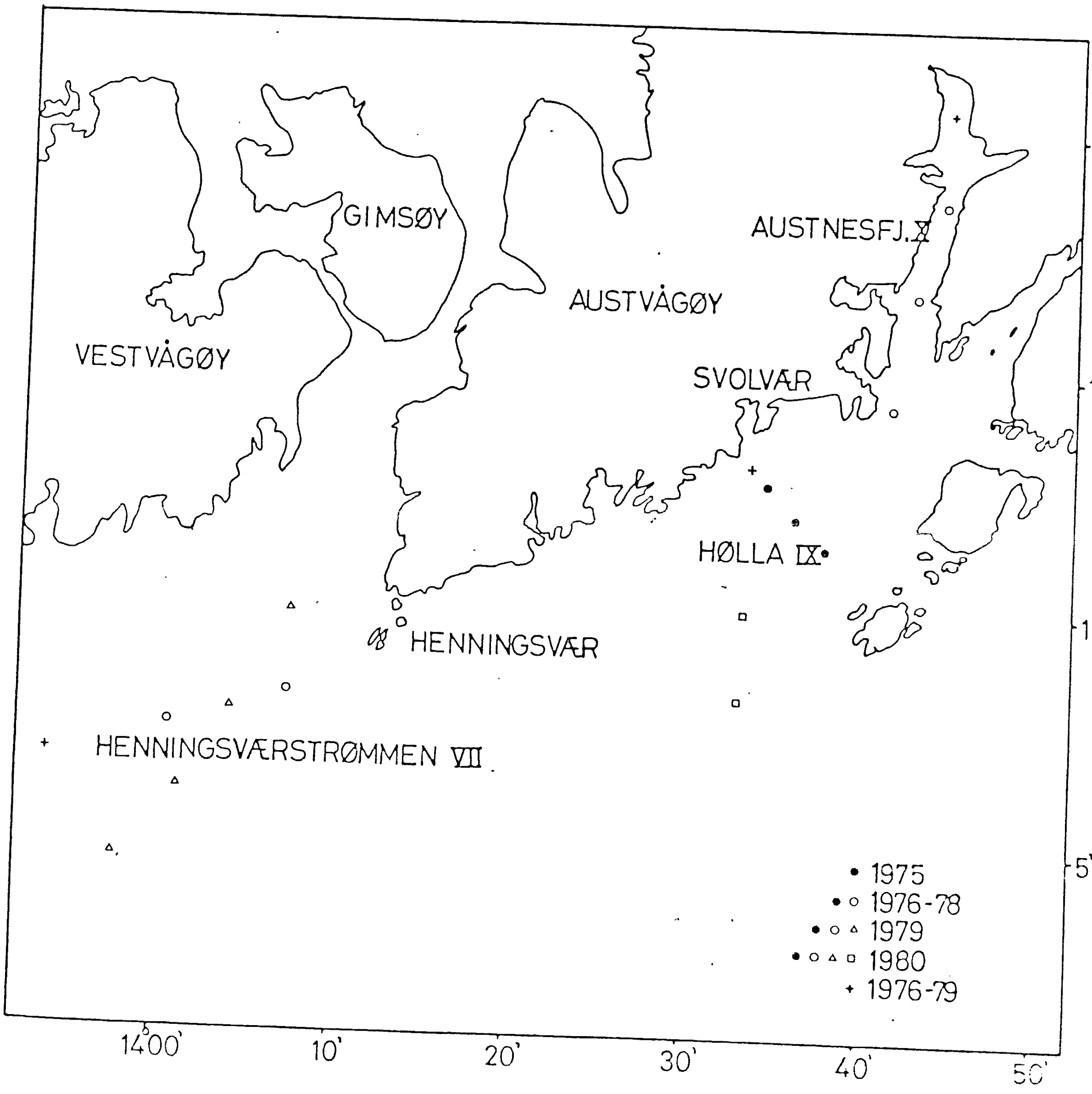

Fig. 1. Area of spawning investigations in Lofoten, 1975-81. Subareas Austnesfjorden, Hølla and Haenningsvaerstraumen with stations are indicated.

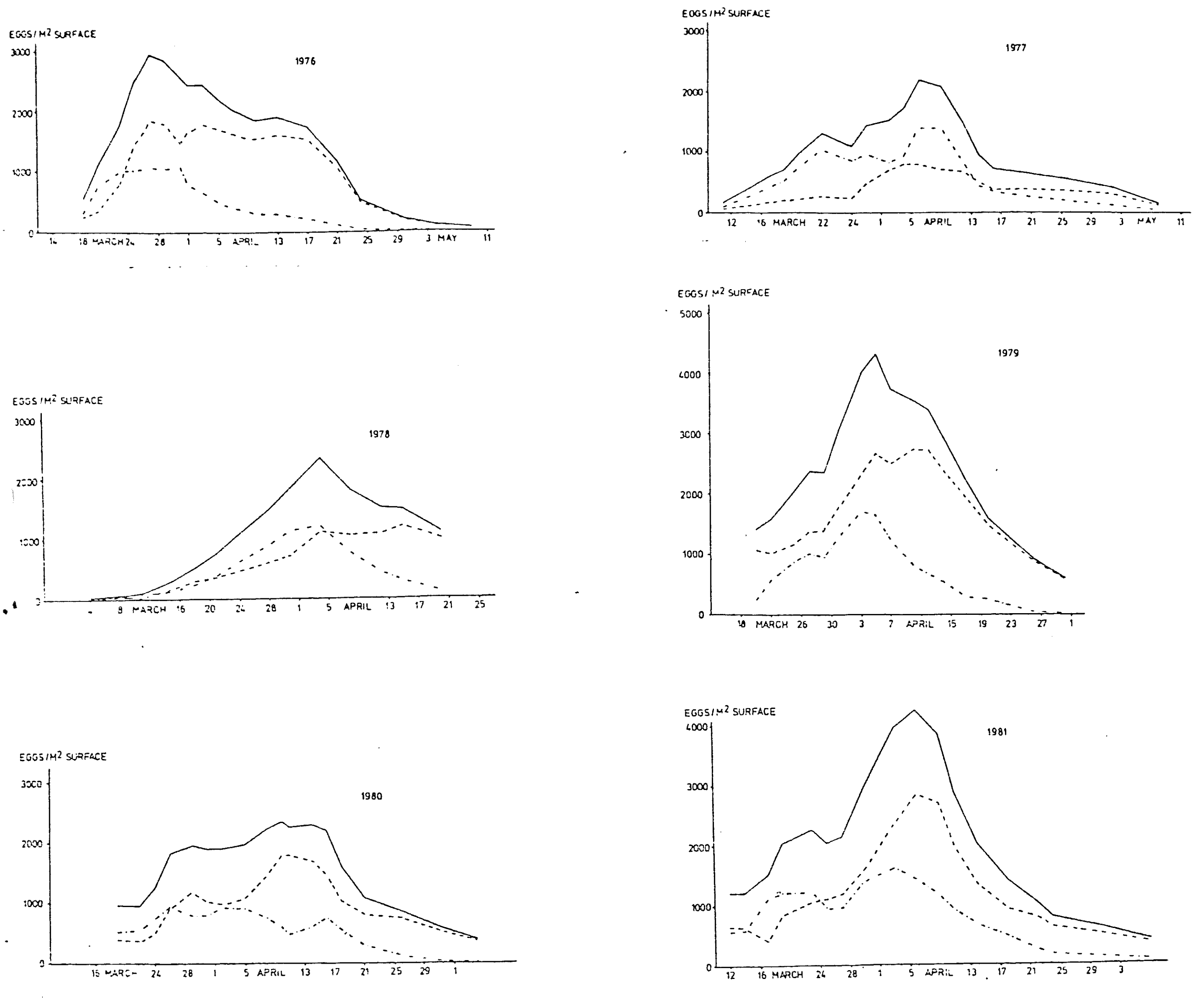

Fig. 2 . Spawning curves, Lofoten 1976-81. Calculated as cod eggs per m^2 surface. (-· --) cod eggs up to 3 days old. (----) older cod eggs. (———) total egg density.

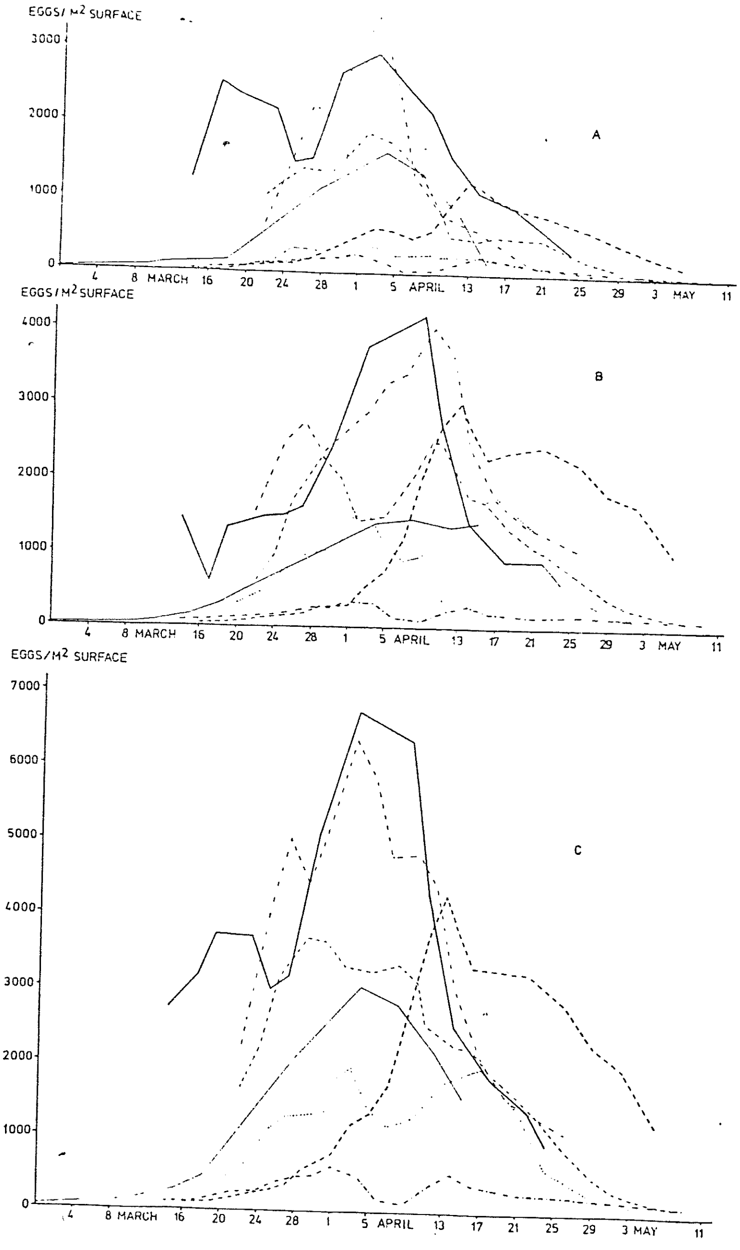

Fig. 3 Spawning curves, Hølla (Lofoten), 1975-81.
Calculated as cod eggs per m^2 surface.
A: Cod eggs up to 3 days old
B: Older cod eggs
C: Total egg density
(---) 1975, (......) 1976, (-..-) 1977, (—) 1978, (-...-) 1979,
(---) 1980, (—) 1981.

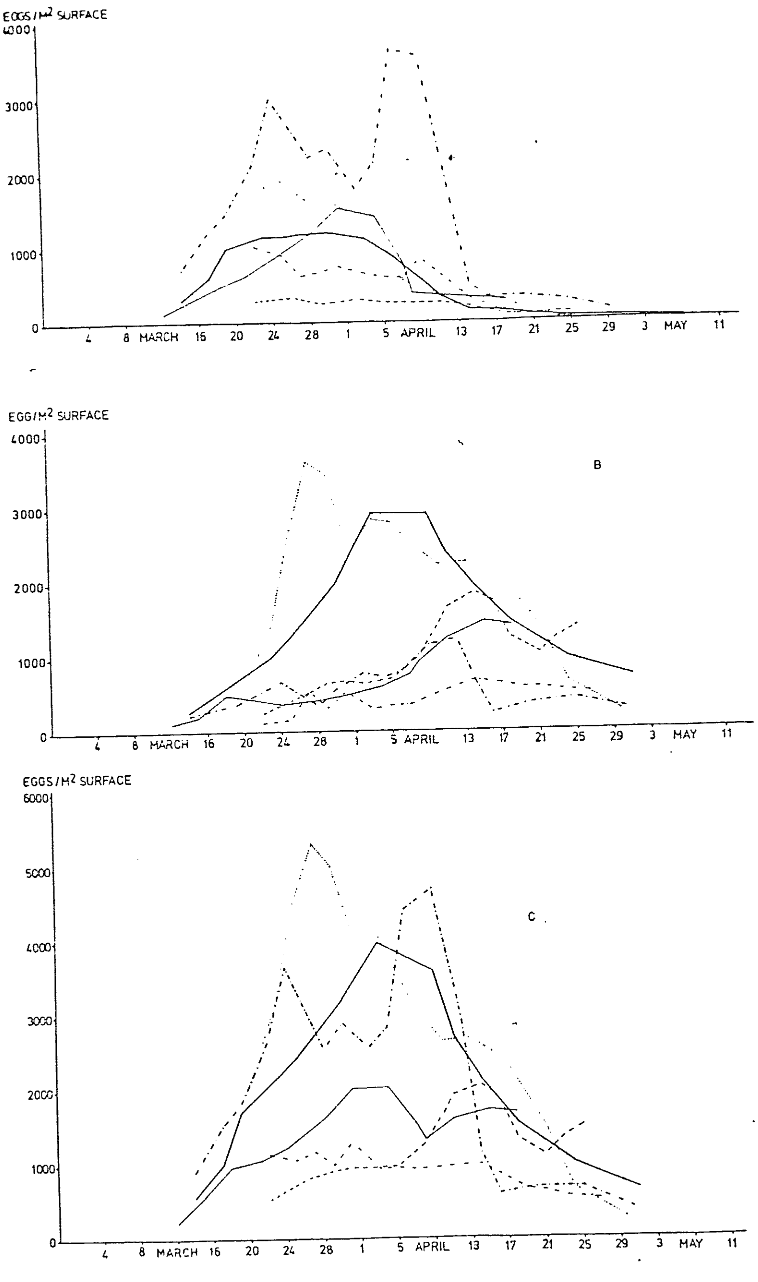

Fig. 4 Spawning curves, Austnesfjorden (Lofoten), 1976-81
Calculated as cod eggs per m^2 surface.
A: Cod eggs up to 3 days old
B: Older cod eggs
C: Total egg density
(.......) 1976, (-·-·) 1977, (—) 1978, (-··-) 1979,
(---) 1980, (—) 1981.

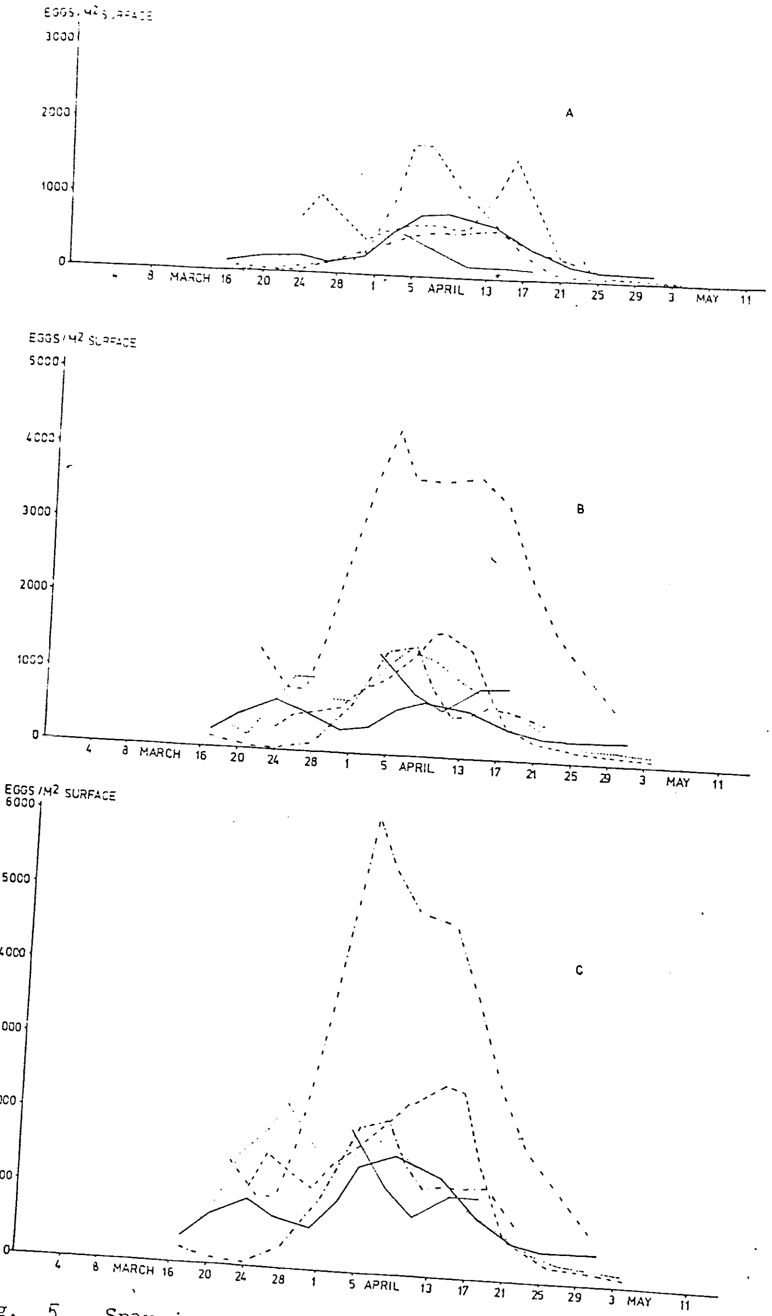

Fig. 5 Spawning curves, Henningsværstrømmen (Lofoten). 1976-81.
Calculated as cod eggs per m^2 surface.
A: Cod eggs up to 3 days old
B: Older cod eggs
C: Total egg density
(......) 1976, (-...) 1977, (—) 1978, (-.-.) 1979,
(---) 1980, (—) 1981.

LARVAL FISH ECOLOGY WORKING GROUP
Lowestoft, Suffolk, U.K.
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Contribution No. 3

SAMPLING FISH LARVAE WITH LARGE PUMPS

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4.3.3 Sampling fish Larvae with Large Pumps, by Per Solemdal

Introduction

Methods involved in field studies of fish larvae and their prey organisms have improved considerably during recent years. Traditional nets are equipped with opening/closing devices, while new systems have also been introduced, such as large pumps.

Since 1975 a project has been carried out at the Institute of Marine Research, Bergen, on the survival and growth of cod larvae of the Arcto-Norwegian tribe drifting from Lofoten to the Barents Sea.

The idea of Hjort (1914) that the variations of year class strength is caused by varying densities of prey organisms available for fish larvae starting exogeneous food uptake, is still relevant. Mortality due to starvation can occur from several reasons:

1) Match/mismatch between the occurrence of first-feeding larvae and the production of suitable food organisms, mainly nauplii of *Calanus finmarchicus*. This is Johan Hjort's theory.

2) Generally low production of food organisms throughout the season.

3) Mixing of the surface layers containing high densities of prey organisms and fish larvae with deeper layers with low densities. This dilution is mainly caused by wind.

Testing these hypotheses needs sampling equipment for both prey organisms and fish larvae in discrete depths. Hence the development of adequate sampling gears has been a main part of the project up to now. Having solved the sampling problem one main problem exists: What period and area is relevant for investigation of prey densities to obtain information of the future year class strength of Arcto-Norwegian cod?

Results

In 1977 a hydraulic submersible fish pump "Rapp", U-60, with 10" hose was used. The water was filtered through Juday nets, either alongside the ship or on deck. The mesh size was 375 µm, and 180 µm, respectively. The quality of the larvae was poor during the first tests, both due to long time of sampling, high filtration rate, 6 m^3/min, and too large mesh sizes. Reducing the volume to 2 m^3/min and using 180 µm mesh size improved the quality of larvae considerably. See Ellertsen et al. (1977).

1979

A similar system with larger capacity, 15 m^3/min, was tested in 1979. The filtration was performed on deck with a small Juday net, 180 µm mesh size, in a container of 2 m^3/min. The quality of larvae was bad. Mechanical stress, especially when passing through the U-shaped pipe, was assumed to be the main reason for this. When reducing the flow rate from 10-15 m^3/min to 2-3 m^3/min, the improvement was considerable. See Ellertsen et al. (1979).

1980

This year an electric submersible pump, Flygt, was tried with capacity of about 5 m^3/min. The larval quality was not very good. See Tilseth and Ellertsen (1981).

The experiments in 1977 and 79 provided vertical profiles of cod larvae from sheltered areas. In order to make the gear more routine and robust for sampling planktonic organisms down to densities of 0.1 per m^3, the following problems have to be solved:

1) The operation of the system must be easier.

2) The organisms, both for quantitative and qualitative analysis must "stand" filtration volumes of 15-20 m^3/min.

1981

An oil filled electric submersible propeller pump from Pleuger, capacity 2950 l/min, was tested. Instead of filtrating on deck, a small Juday net was attached directly to the head of the pump. The net closed immediately when the pump stopped. A schematic drawing is shown in Fig.1.

In practice the pump was wrapped in tyres to prevent damage. The pump was lowered to right depth, and then started. According to the density of organisms the time varied between 5 and 20 minutes for each sample. The pump was then stopped and brought on deck. The net was washed, the bucket emptied and the pump put down to the next depth. The quality of the larvae was fairly good. This pump was also used to obtain egg samples from larger depths in Lofoten (Solemdal and Sundby, 1981).

During the years 1977, 1979 and 1980, systematic investigations on the factors causing bad quality of the larvae were not carried out. In 1981 some experiments were carried out in a concrete tank at the Institute of Marine Research, Bergen, to test the effect of water velocity on the quality of the larvae.

Homogeneous groups of cod larvae, 4-5 days old, were released into the tank. The following week the larvae were sampled daily in different ways:

1. Control. Larvae kept in a bucket at same temperature as the "tank" larvae were sampled with a pipette directly into 4% formaldehyde.

2. Larvae sampled by a small Juday net 180 µm mesh size, at a speed of 0.5 m/sec in the tank. Time of sampling was about 5 minutes.

3. Same sampling as 2, but speed increased to 1.0 m/sec.

4. Pleuger pump (same filtration system as shown in Fig. 1), capacity $3m^3/min$, sampling 5 minutes in the tank.

The results are shown in Fig. 2. The 3 quality categories of the sampled fixed larvae are defined as follows:

1. Larvae straight, easy to measure, and all organs intact.

2. Larvae curved, organs intact.

3. Larvae curved, yolk sac, intestine or other organs lacking

The figure shows an increasing amount of stage 3 larvae with increasing water velocity.

Conclusion

Water velocity is the main factor in damaging fish larvae during pump sampling.

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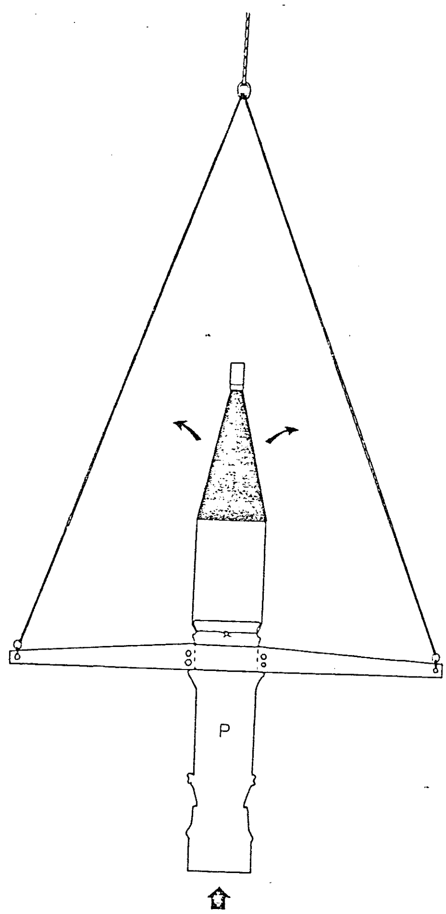

Fig. 1. The submersible Pleuger pump and the arrangement of filtrating water through a small Juday net in situ.

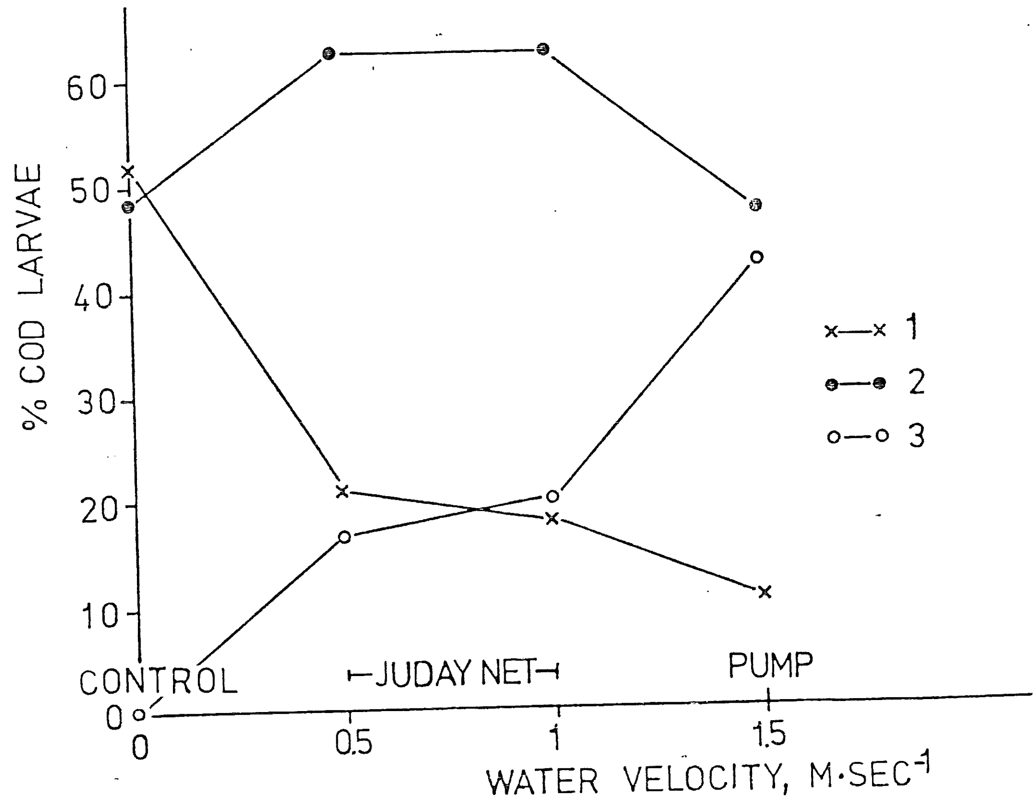

Fig. 2. Cod larvae sampled by different gears and velocities divided into three categories according to quality. (See text): Qualitative category 1: x—x
2: ●—●
3: o—o

LARVAL FISH ECOLOGY WORKING GROUP
Lowestoft, Suffolk, U.K.
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Contribution No. 4

POST LARVAE INVESTIGATIONS

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4.3.4 Post Larvae Investigations, by Herman Bjørke, Institute of Marine Research, Bergen

It is stated that the amount of 0-group fish of economic important species in the Barents Sea in August-September reflects the year class strength. In 1977 an investigation was started to see if the same reflections of year class strength could be seen in June-July at the northwest coast of Norway. In addition one could get updated knowledge about the distribution of fish larvae in case of an oilspill along the Norwegian coast. At each station two hauls were made using a commercial small-meshed pelagic trawl, one with the headrope at 40 m and 20 m, and one with the headrope at the surface. These investigations are still carried out. Around 20 species are found, and most abundant are redfish, herring, cod, haddock, sand-eel and saithe. Only in 1980 were capelin abundant.

From 78 to 94% of these species are found in the upper twenty meters, redfish most and haddock least.

An index for abundance of important species have been made each year, and this is in correspondence with the 0-group index for cod, saithe and haddock for the period 1978-1980 when comparisons could be made. They all indicate small year classes. For herring the correspondence is more questionable since the 0-group investigations does not give any index because of low abundance of herring. However, the highest post larvae index of herring was found in 1980, whereas the 0-group investigations reported very low abundance of this species. Redfish and capelin indexes could not be made due to inadequate coverage of the distribution area during the post larvae surveys. This year the survey area will be extended southwards.

LARVAL FISH ECOLOGY WORKING GROUP
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Contribution No. 5

THE WESTERN MACKEREL SPAWNING STOCK ESTIMATE FOR 1980

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4.3.5 The Western Mackerel Spawning Stock Estimate for 1980, by S. J. Lockwood, I. G. Baxter, J. C. Gueguen, G. Joakimsson, R. Grainger, A. Eltink, and S. H. Coombs

Abstract

In the absence of suitable alternative data the Western mackerel stock VPA has been linked to a spawning stock size estimate made by plankton survey in 1977. With the passage of time each successive year's assessment became increasingly dependent upon the reported catch statistics. To diminish this dependence and to provide a new reference point the spawning stock was estimated again by plankton survey during 1980. This paper describes this survey and presents the stock size estimate made. This stock estimate was used as the basis for the stock assessment made by the Mackerel Working Group in 1981.

Resumé

En l'absence de données appropriées provenant d'autres sources, VPA du stock des maquereaux de l'Ouest a été effectuée en prenant pour base une estimation de l'importance du stock de frai réalisée à partir d'un relevé du plancton en 1977. Avec l'écoulement du temps, l'évaluation de chaque année successive dépendait de plus en plus des statistiques rapportées des prises. Dans le but de diminuer cette dépendance et de fournir un nouveau point de référence, le stock de frai avait été estimé encore une fois à partir d'un relevé du plancton au cours de 1980. Le présent travail comprend une description de ce relevé et présente l'estimation de l'importance du stock. Cette estimation du stock a été utilisée comme base de l'évaluation du stock réalisee par le Group de Travail sur le Maquereau en 1981.

Introduction

The Western mackerel stock size was first estimated by plankton survey in 1977 (Lockwood et al., in press). The estimate made has subsequently been used as the reference point to which cohort analyses have been linked in the absence of more conventional data, e.g. estimates of F (Anon., 1980, 1981). At an informal meeting in February 1979 representatives from seven laboratories with an interest in the Western mackerel stock agreed to participate in a co-operative programme of plankton surveys to re-estimate the spawning stock size in 1980. The programme involved four research vessels, ANTON DOHRN, CIROLANA, SCOTIA and THALASSA, surveying the main spawning grounds; Irish charter vessels surveying an area off southern Ireland; and sampling of Dutch commercial catches made on the spawning grounds in the spawning season. It was decided to omit the Celtic Sea area east of a line from Ile d'Ouessant (48°30'N 6° 05'W) to Mizzen Head (51°30'N 9°45'W) as this large area contributed relatively little (<2%) of the total egg production from the Celtic Sea in 1977. From the analysis of vertical distribution samples collected by Coombs et al., (in press) in 1977, it was established that during the first half of the spawning season mackerel eggs may be found at depths considerably greater than the 100 m maximum depth sampled in

1977 (Lockwood et al., in press). As a consequence it was agreed that the maximum sampling depth in 1980 should be increased to 200 m. Apart from these changes the survey area and general sampling procedures during 1980 were those followed in 1977.

Material and Methods

The mackerel spawning grounds along the edge of the continental shelf from the southern Bay of Biscay to the area west of Ireland were sampled six times; once each in March (ANTON DOHRN + SCOTIA); April, May and July (CIROLANA) and twice during June (SCOTIA and THALASSA). Paired bongo nets were used on the ANTON DOHRN (Dornheim & Joakimsson, 1980), variants of an unencased 50 cm tin tow net (Lockwood, 1974) were used on CIROLANA, THALASSA and SCOTIA, and the Irish coastal survey was made with a Dutch Gulf III sampler (Zijlstra, 1970). The bongo nets were towed to a maximum depth of 150 m, the other nets to a maximum of 200 m. Temperature profiles were recorded at each station.

Plankton samples were taken at the centre of standard ½° x ½° rectangles (Figure 1) by CIROLANA, SCOTIA and THALASSA, but the ANTON DOHRN survey west of Ireland was more intensive (Dornheim & Joakimsson, 1980), as was the Irish survey (Figure 1). Mackerel eggs were picked out of the plankton samples and the number of Stage I eggs (Lockwood et al., 1977) were raised to the number per m^2 per day. These data were plotted on charts and contours drawn to illustrate the centres of spawning. Initially the total production estimate was made by calculating a geometric mean production value for each cruise and raising it by the total area (Lockwood et al., in press), but it was found, for reasons which are not immediately apparent, that there is a serious discrepancy between the arithmetic and geometric means on some cruises (Figure 2). These differences render the method inappropriate so an alternative method has been used.

The total daily production in each standard rectangle was estimated as the product of the daily production per m^2 and the area of the rectangle (Figure 1). Values of daily production rates for unsampled rectangles were interpolated by calculating the geometric mean of all the sampled rectangles surrounding the unsampled rectangle, providing that a minimum of two sampled rectangles were immediately adjacent to the unsampled rectangle (Figure 3). The total production estimate for the spawning grounds for each cruise was estimated as the sum of the production in each rectangle, both sampled rectangles and interpolated rectangles. The total production estimate for each cruise was plotted against the median date of the cruise and a production curve drawn. The area under the curve was measured by trapezoidal integration to estimate the total production for the main spawning area.

Vertical Distribution of Mackerel Eggs in the Celtic Sea in 1980

As part of the Mackerel egg survey the vertical distribution of the eggs was investigated using a modified Longhurst-Hardy Plankton Recorder (LHPR) (Longhurst et al., 1966). Hauls were made at selected stations in March, April, May and June to a maximum depth of 316 m.

Sex Ratio and Maturity

Biological samples taken from commercial and research vessel catches in the western spawning area were examined to establish the sex ratio in the spawning population and to construct a maturity ogive. The sexual maturity of individual fish was recorded on a scale of one to eight (Macer, 1974, 1976). Fish which were at maturity Stage III (early, developing) were assumed to be maturing prior to spawning in the current spawning season and fish at Stage VII (spent) were assumed to have spawned in the current spawning season. English data over the five year period (1973-78) and Dutch data for 1979-80 were combined to construct age-maturity and length-maturity ogives.

Fecundity

The spawning population length- frequency data were derived from a limited amount of German and English research vessel data, but most data originated from Dutch and French commercial catches. Monthly length-frequency distributions were converted to fecundity-frequency distributions from the expression:

Fecundity = 8.80 (total length)$^{3.02}$ (Lockwood et al., in press). From these mean fecundities were estimated for each month, March-July.

Results

The distributions of Stage I mackerel eggs along the edge of the continental shelf, throughout the spawning season, are shown in Figure 4, A-F. These distributions show clearly that the spawning is well established along the edge of the shelf from Spain to at least 54°N in March. This distribution is maintained throughout April, May and June with centres of spawning in the vicinity of the Great Sole Bank (49°30'N 10°00'W) and La Chapelle Bank (47°45'N 7°00'W). By mid July the spawning was virtually finished on the main spawning grounds but was still taking place off south east Ireland (Table 1B and Figure 4F). The vertical distribution profiles (Figure 5) were constructed using Stage I eggs only. Due to operational problems only two hauls were taken in March, neither of which contained sufficient mackerel eggs to determine their vertical distribution.

As in 1977 (Coombs et al., in press) Stage I mackerel eggs were found progressively nearer to the surface as the season advanced (Figure 5); few eggs were taken below 150 m depth, indicating that in the months of April, May and June they were sampled adequately, for the purpose of the stock estimate, by the plankton hauls taken to 200 m depth. The absence of a depth distribution for March is not a serious limitation on the data since egg production in that month was low (Figure 6). Although there was a coherent relationship between the mean vertical distribution of eggs and the degree of thermal stratification (Figure 5) this relationship was not clear on the basis of individual hauls, due to variability of the vertical distributions between hauls. Similarly there was no clear relationship between vertical distribution of the eggs and either geographical position of the haul or the depth of water over which it was taken.

The production estimates for each cruise are given in Table 1. These estimates are used to draw a spawning production curve (Figure 6) and to estimate the total egg production within the main spawning area: 1.48×10^{15} eggs. The 1977 production curve is also shown for direct comparison.

Some maturity data were available from the sampling of Dutch commercial catches on the spawning grounds during 1979 and 1980, but most data were available from the English sampling programme 1973-80. Maturity ogives constructed from these data (Figure 7) show that 50% of mackerel reach maturity at 28 cm or as 3 group fish. For computational convenience it was assumed that knife-edge maturity occurs at 28 cm and fecundity-frequency distributions were prepared from length-frequency distributions of all fish over 27 cm in the available samples. Monthly mean fecundity values were calculated from these distributions and used to convert the egg production curve (Table 1 and Figure 6) to a spawning stock curve (Table 2 and Figure 8).

While deviations from a sex ratio of 1 male per female do occur in certain areas at certain times of year, the overall picture is one where the sexes are numerically equal (Table 3). The estimated number of mature female fish is doubled to estimate the spawning stock size.

During the spawning season there were an estimated 6223×10^{6} mature mackerel on the main western spawning grounds.

Discussion

When surveys such as this are carried out in relatively quick succession, 1977 and 1980, it is inevitable that comparisons will be made and differences found. These differences, e.g. the apparent drop in production during May 1980, should not be allowed to overshadow the similarities however, particularly as it is these which probably give greater support to the conclusions drawn than any doubts which may arise due to differences.

The generally coarse nature of the standard survey grid inhibits the detailed examination of centres of spawning or 'patches' but the geographic distribution of eggs along the edge of the continental shelf is the same as the distribution found in 1977, including the localised areas of high production in the vicinity of La Chapelle Bank and Great Sole Bank. The pattern of vertical distribution was also consistent. In the absence of a thermocline mackerel eggs were found in abundance to depths in excess of 150 m, but once a thermocline was formed the majority of eggs were found above the thermocline (about 40 m depth). This observation suggests that mackerel spawning behaviour may change during the spawning season. Early in the spawning season, prior to May, some mackerel, if not all, spawn close to the sea bed. Once a thermocline is established they are probably all spawning in mid-water, mainly in the upper 40 m. This distribution of eggs would justify a timesaving change in tactics during future surveys. Wherever a clearly defined thermocline is found sampling can be limited to a maximum depth of 50 m, thereby allowing time to sample more stations.

The differences in the statistical distributions which were found (Figure 2)have not yet been investigated fully but they show that a log transformation was not the appropriate method for treating the 1980 data. This transformation was used in 1977 as it permitted the estimation of confidence limits with relative ease, but these limits are not directly applicable to the final stock estimate (Lockwood et al., in press), and may be confusing. For this reason total production in each rectangle was estimated as an independent event and total production estimated from the sum of the individual events. This approach assumes no specific statistical distribution, and no confidence limits on the final production estimate were calculated.

The general shape of production curve is the same as in 1977 (Figure 6). Spawning commences around February-March time and runs through to July with peak spawning in June. The Irish survey results show that, as in 1977, spawning continues later in the eastern Celtic Sea but with an intensity almost two orders of magnitude less than on the main spawning grounds.

Direct comparisons of spawning stock estimates for 1977 and 1980 have not yet been made as the secondary parameters for raising egg production to numbers of fish, sex ratio, maturity, fecundity are different. These differences reflect the increased amount of data available for this 1980 assessment compared with that for 1977.

The final stock estimate made by this survey, 6200×10^6 mature fish, does not differ greatly from the VPA estimate for 1980, 6100×10^6 mature fish (Anon., 1980). This suggests that the assumptions made by the Mackerel Working Group about unreported catches and discarded catches have been reasonable and recent assessment not seriously amiss. Certainly the results from this survey do not suggest that a major revision of the VPA is necessary. (The Western stock assessment made by the Mackerel Working Group in April 1981 used this survey's stock estimate to estimate level of F in 1980 with which to start the VPA run. This analysis produced a pattern of F's similar to those estimated previously and, as a consequence, the VPA continued to estimate a spawning stock size compatible with that estimated by egg survey in 1977.)

The Western mackerel stock has now been assessed annually since 1975 but it is only since 1978, with the results of the 1977 plankton survey, that the assessments have shown any stability. If the assessment's dependence on egg survey data is to continue,another survey must be planned for 1983. The authors of this paper have agreed in principal to this objective but a commitment to participate from all nations with an interest in this stock will help to spread the undoubted cost in ship's time and manpower that these surveys demand.

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Table 1 The Western mackerel egg production estimate 1980, summary of results
(A) - Main survey area (within the limits of the grid, Figure 1)

RV Cruise	ANTON DOHRN + SCOTIA 2/80	CIROLANA 4/80	CIROLANA 5/80	SCOTIA 5/80	THALASSA	CIROLANA 7/80
Median sampling date	24 March	9 April	6 May	6 June	25 June	25 July
Rectangles sampled	113	85	96	107	127	70
Rectangles containing Stage I eggs	75	58	63	78	66	13
Rectangles interpolated	22	48	59	25	20	25
Daily production eggs x 10^{10}	237.28	1006.09	558.11	2447.82	1967.48	24.56

Total production estimate on the main spawning ground: 1.48×10^{15} eggs

(B) - Irish inshore survey

	February	March	April	May	June	July
Daily production eggs x 10^{10}	<1.0		3.89		28.1	24.4

Total production estimate on the inshore ground (Figure 1): 0.02×10^{15} eggs

Table 2 The Western mackerel spawning stock estimate 1980, the number of mature male mackerel per female

Country	ICES areas	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
			Main spawning season										
England	VIIB VIIE-J VIII	1.04	1.13	0.79		0.67			0.90		1.30	1.02	1.05
France	VIIJ VIII						0.85	0.65					
Germany													
Holland	VIIB & J				1.07								
Scotland	VIA	0.76	1.29	0.90	1.16	0.82	0.99	0.93	0.90	0.96	1.19	1.15	1.32

NOTE: English data are predominantly from the inshore fishery around Cornwall (VIIE-F)

Table 3 The Western mackerel spawning stock estimate 1980, summary of results

RV Cruise	ANTON DOHRN + SCOTIA 2/80	CIROLANA 4/80	CIROLANA 5/80	SCOTIA 5/80	THALASSA	CIROLANA 7/80
Daily egg production x 10^{10}	237.28	1006.09	558.11	2447.82	1967.48	24.56
Mean fecundity	503863	522313	530711	456950	456950	363930
Mature female fish	4710000	19260000	10520000	53570000	43100000	670000
Spawning stock x 10^6	9.42	38.52	21.03	107.14	86.11	1.35

Total spawning stock estimate = 6223 x 10^6 mature mackerel

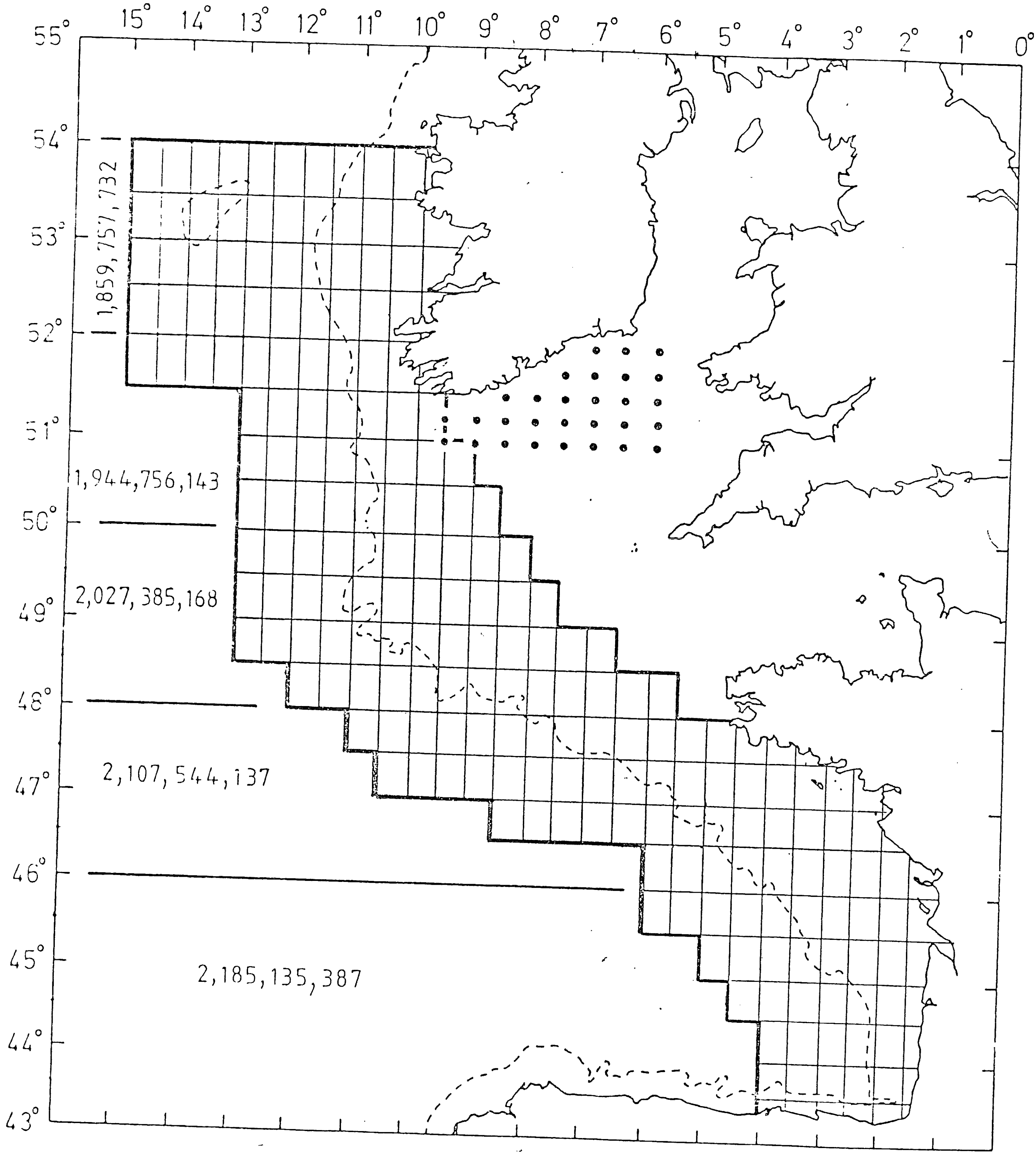


Figure 1 The mean area (m^2) per $\frac{1}{2}° \times \frac{1}{2}°$ rectangle by 2° latitude bands. The rectangles are drawn over the main spawning area surveyed in 1980. The area of the Irish inshore survey is shown by the matrix of closed circles which mark station positions.

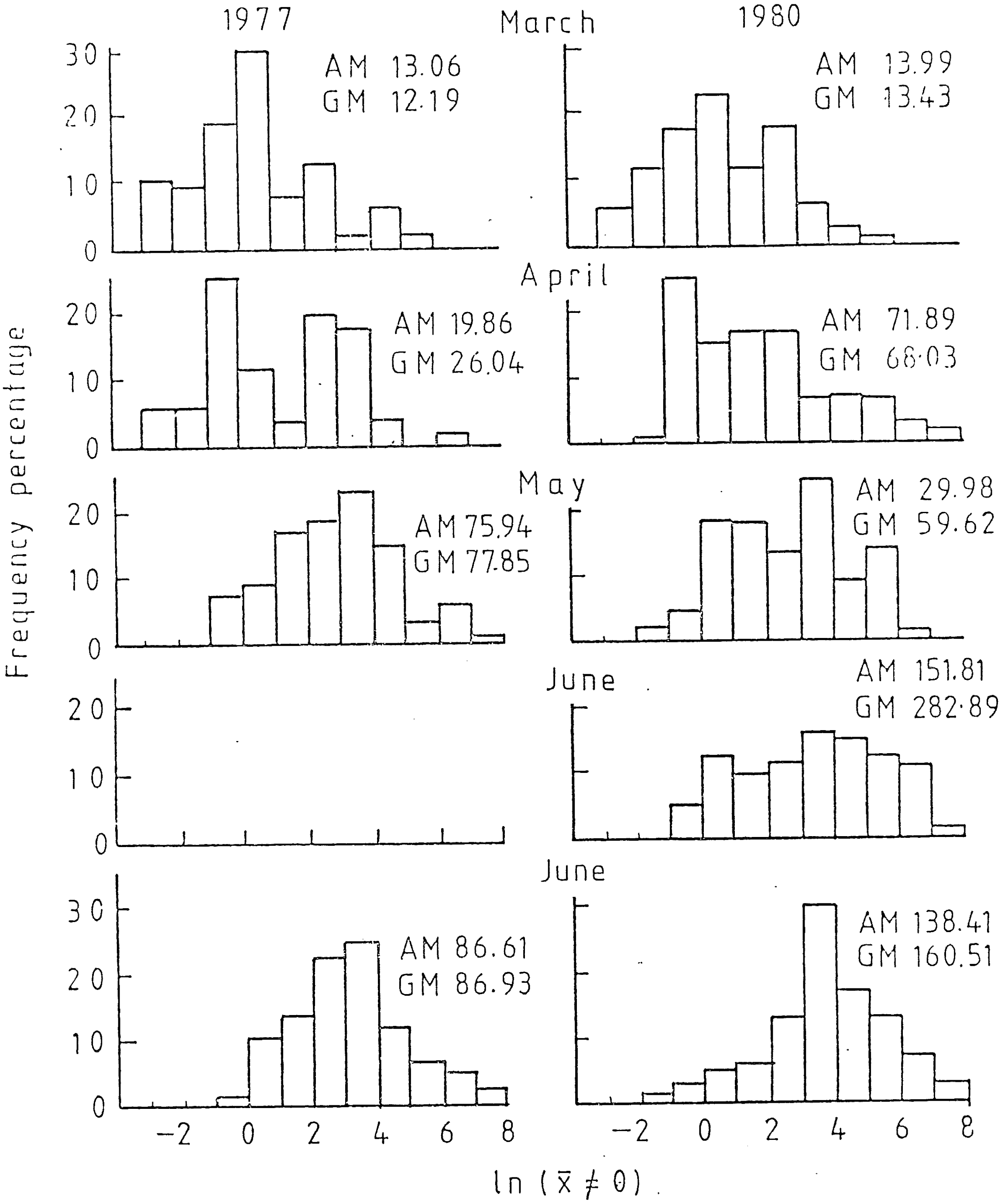


Figure 2 Frequency percentage distributions of the daily production estimates for each month in 1977 and 1980. AM = arithmetic mean; GM = geometric mean.

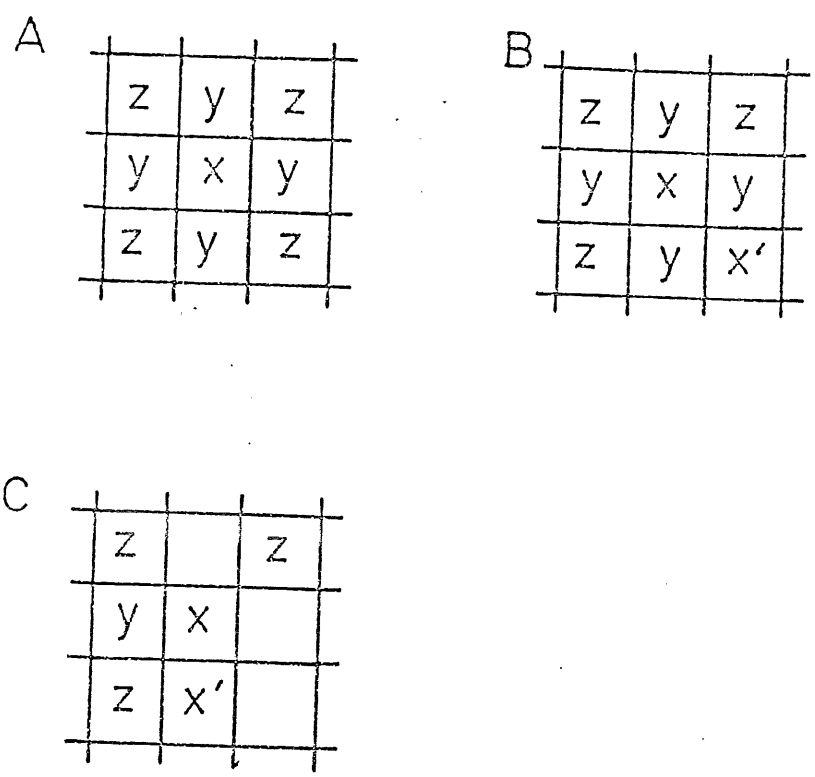


Figure 3 The convention followed for interpolating production estimates for unsampled rectangles (x).

A - As two adjacent rectangles are sampled (Y), x is the geometric mean of eight surrounding stations, Y and Z.

B - Two adjacent rectangles are sampled (Y), x is the geometric mean of seven surrounding stations. The interpolated value (x') is omitted from the calculation.

C - A value is not interpolated for x as only one adjacent rectangle has been sampled (Y). The value (x') is omitted when calculating x.

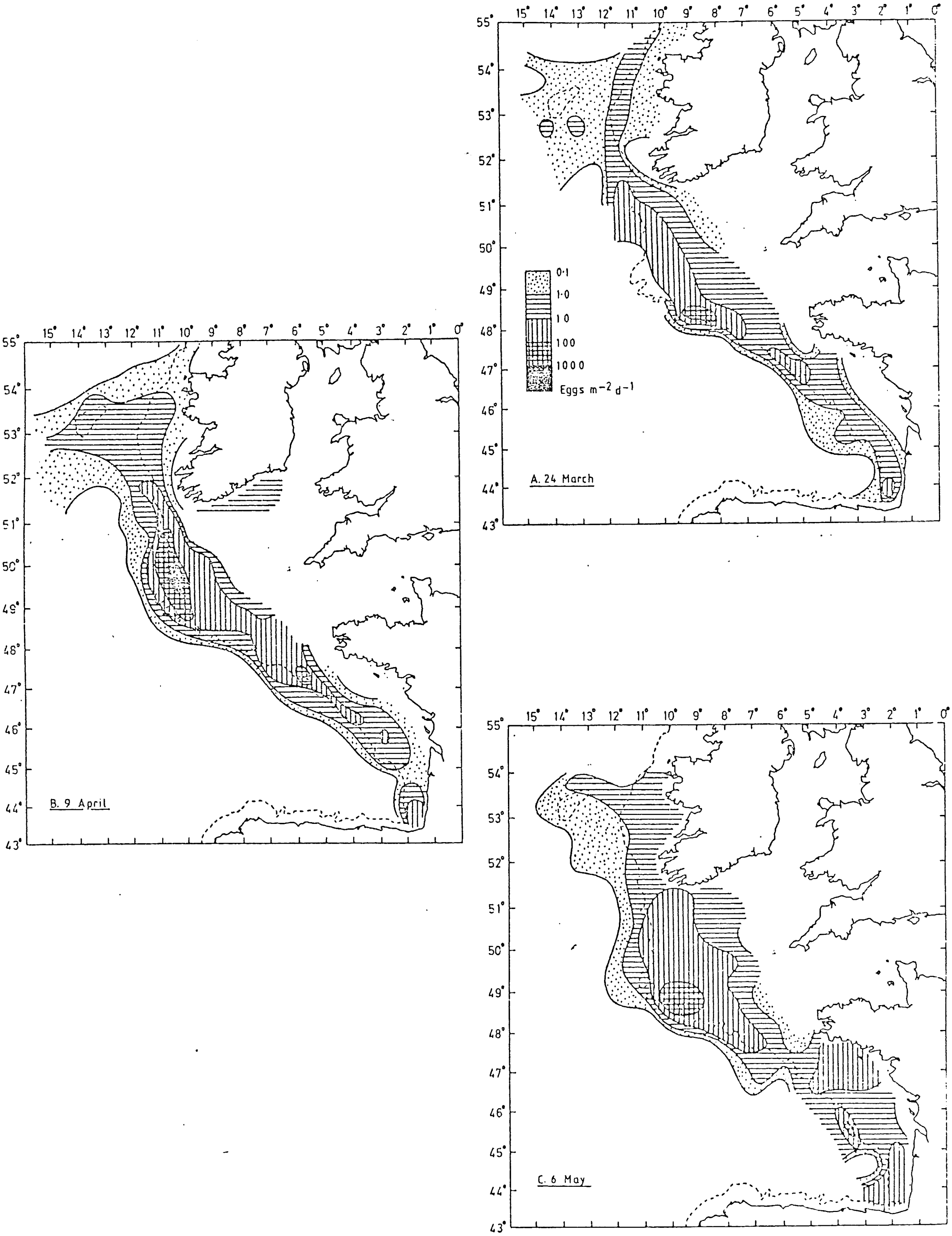
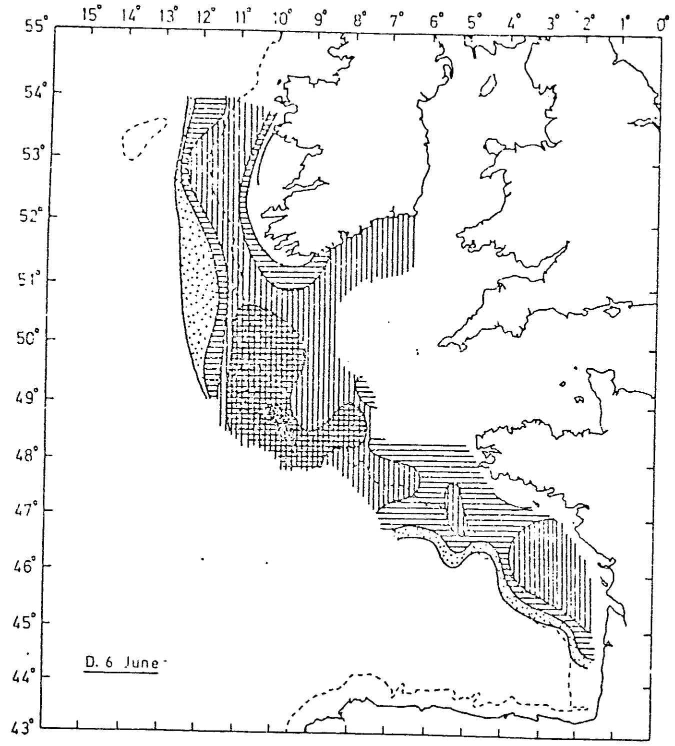
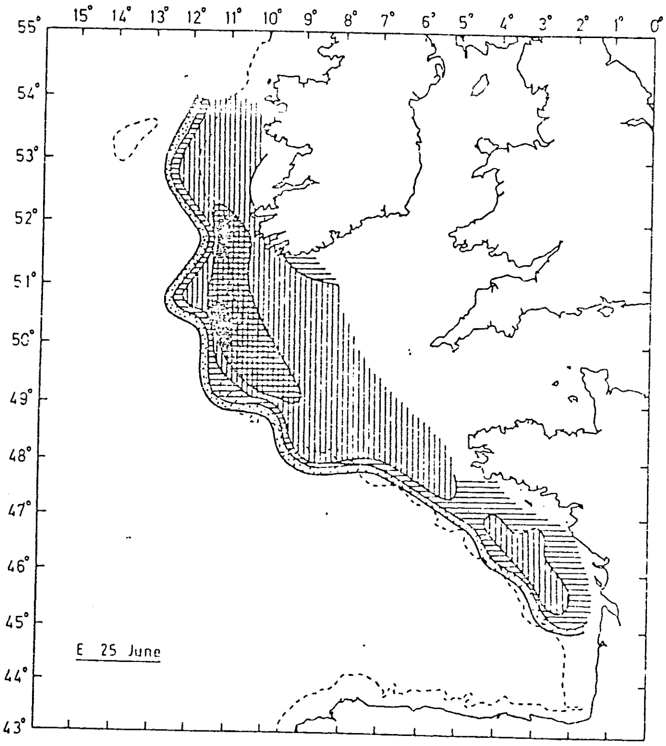


Figure 4 (A-F) The distribution of Stage 1 mackerel eggs March-July 1980.


15° 14° 13° 12° 11° 10° 9° 8° 7° 6° 5° 4° 3° 2° 1° 0°
55° 54° 53° 52° 51° 50° 49° 48° 47° 46° 45° 44° 43°
D. 6 June


15° 14° 13° 12° 11° 10° 9° 8° 7° 6° 5° 4° 3° 2° 1° 0°
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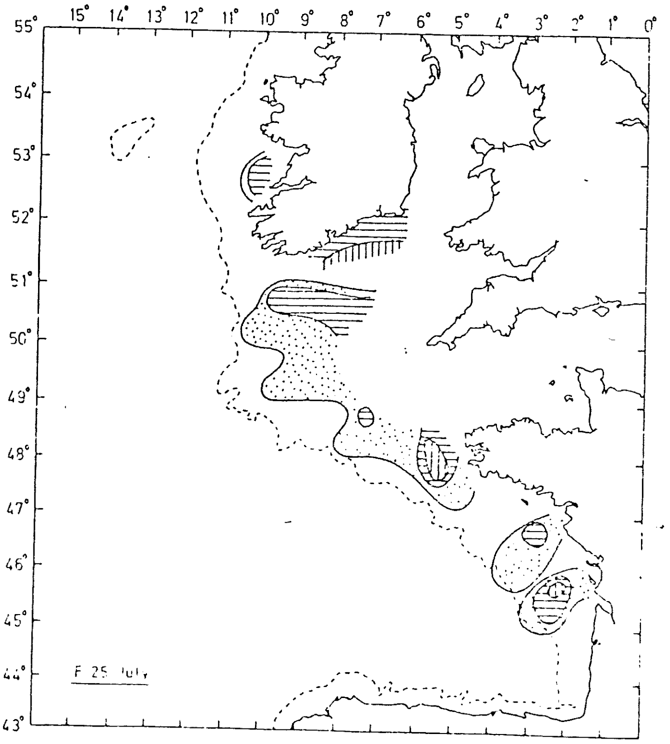
E 25 June


15° 14° 13° 12° 11° 10° 9° 8° 7° 6° 5° 4° 3° 2° 1° 0°
55° 54° 53° 52° 51° 50° 49° 48° 47° 46° 45° 44° 43°

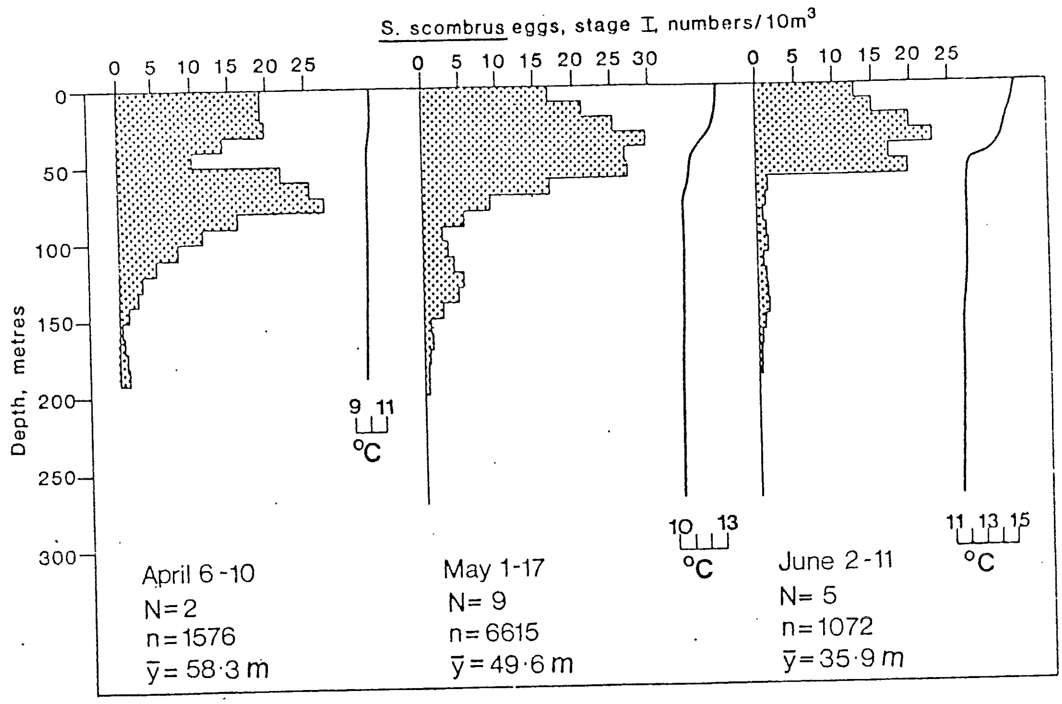


Figure 5 The mean distribution of Stage 1 mackerel eggs taken in a Longhurst-Hardy plankton sampler. N = The number of hauls; n = the number of Stage 1 mackerel eggs; y = the mean depth of the distribution.

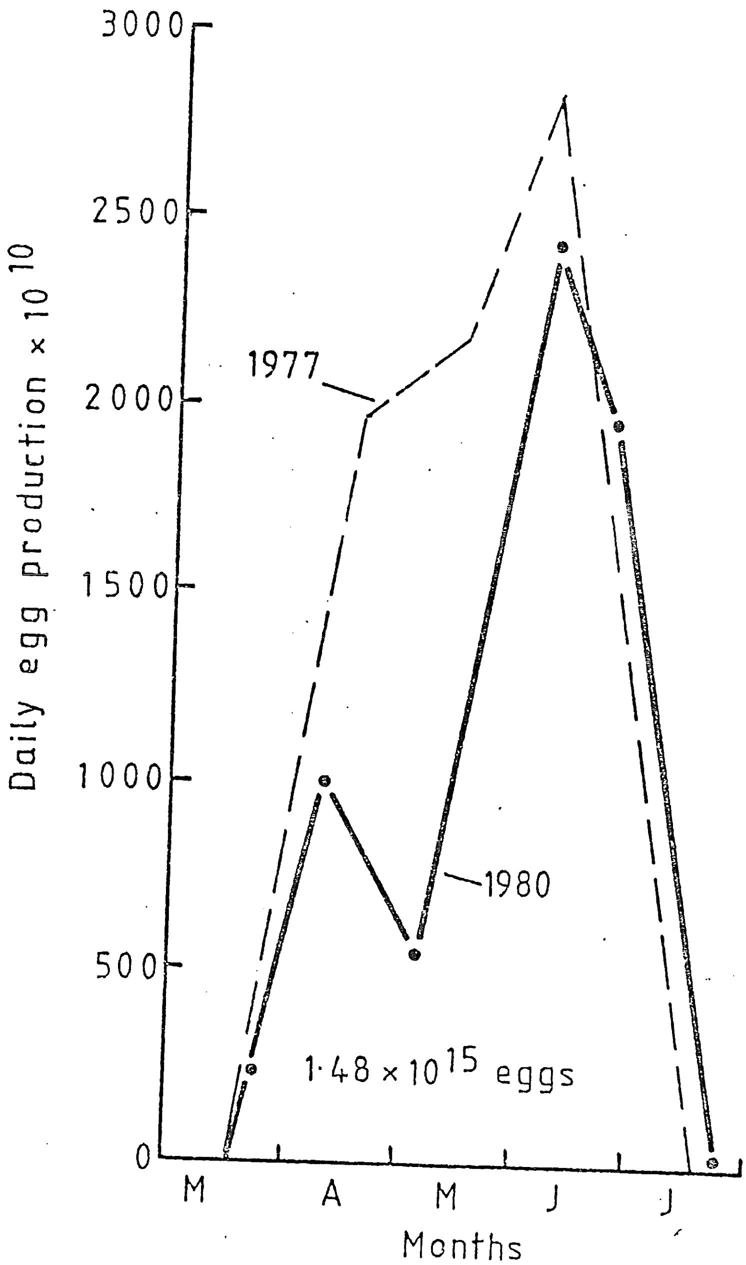


Figure 6 Total egg production curve, March-July 1980. The production curve for 1977 is shown for comparison.

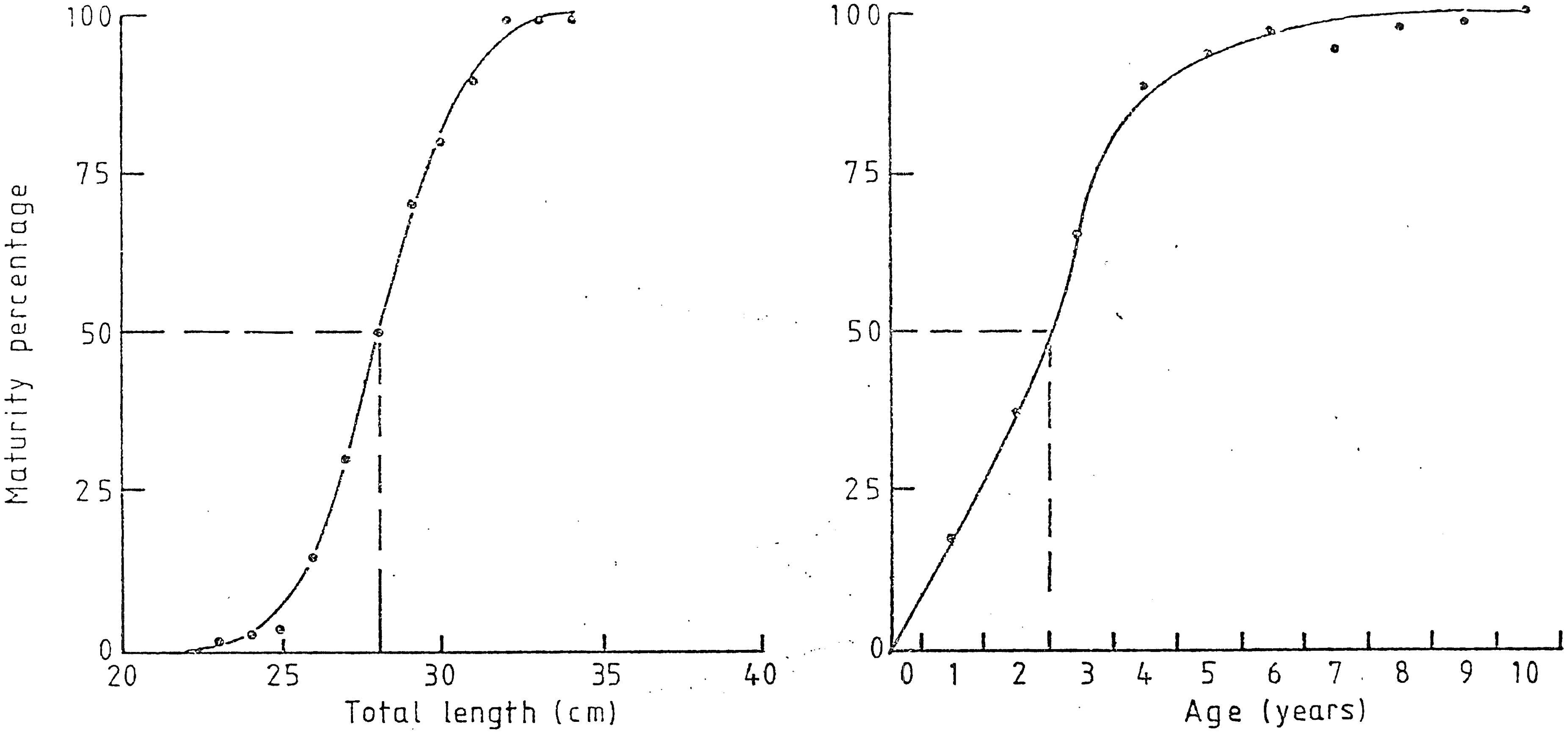


Figure 7   Maturity-length and maturity-age ogives (fitted by eye).

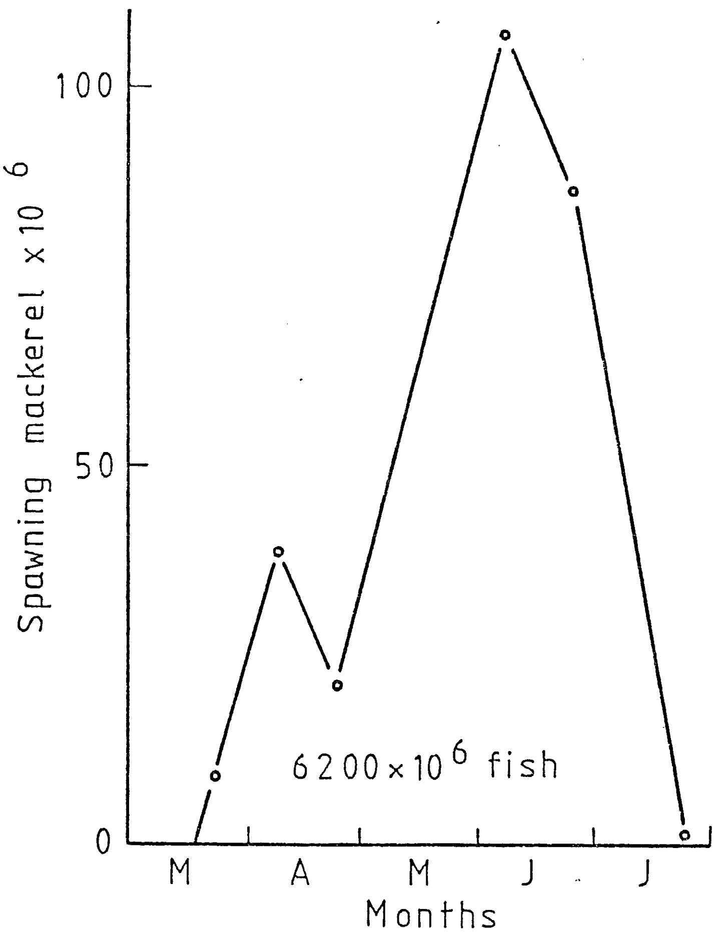


Figure 8 The number of mature mackerel on the spawning ground during the spawning season.

LARVAL FISH ECOLOGY WORKING GROUP
Lowestoft, Suffolk, U.K.
July 1-3, 1981

Contribution No. 6

LARVAL HADDOCK AND COD SURVIVAL STUDIES ON GEORGES BANK

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4.3.6 Larval Haddock and Cod Survival Studies on Georges Bank, by R. G. Lough and G. C. Laurence

INTRODUCTION

Our ability to predict early life stage survival and relate it to recruitment requires three main components: (1) seasonal population abundance estimates or indices of egg and larval stages, (2) quantitative estimates of larval growth and feeding parameters, and (3) predictive models. Two of these three requirements are currently available as well as portions of the third. Ichthyoplankton surveys are conducted routinely by NEFC, at least bimonthly in the MARMAP mode over a broad area of the northwest Atlantic continental shelf (Smith et al. 1979, Sherman 1980), and provide timely abundance estimates of all larval fish. A variety of larval fish growth and survival models exist (Laurence 1977, Beyer and Laurence 1980, 1981; Beyer 1980), some of which have population predictive capabilities. Larval trophodynamics, physiology, and behavior have been studied extensively in the laboratory and field and many factors have been identified and quantified (Laurence 1981). An important missing component is a physical mathematical description of the spatial-temporal bounds of larval prey organisms. Once this is known, prey encounter rate functions in the existing models can be used to predict larval growth and survival on the individual and population level based on the abundance estimates of the eggs or early larvae from ichthyoplankton surveys as an initial starting point. In the case of the target species, the haddock, predicted estimates of larval survival can then be correlated with data from subsequent autumn juvenile survey estimates as a validation test.

In this study, we will be focusing on the haddock, *Melanogrammus aeglefinus*, because of the commercial and ecological importance of this species, and because we have the best overall base of life history data, including: good laboratory experimental data base, measures of year-class strength at the "0-group" stage, and fecundity and spawning population biomass data. In addition, there is a considerable amount of background field data as to the location of the spawning grounds on Georges Bank and the general movements of the eggs, larvae and post-larval stages (to "0-group" age) on Georges Bank (Figure 1).

The general plan is to conduct a series of process-oriented cruises beginning in the spring of 1981 on Georges Bank, concentrating on the feeding dynamics of larval haddock. Special emphasis is being given to a three-dimensional description of the spatial-temporal variability of the distribution of larvae and their prey (copepods) food and factors affecting their production. A field program of this nature attempting to cover at least three trophic levels simultaneously requires sampling on spatial scales ranging from centimeters to kilometers and temporal scales from minutes to weeks.

Our basic field strategy is to compare and contrast their fine-scale distribution in the well-mixed waters on the crest of Georges Bank with the stratified waters on the southern flank (see Figure 2) using electronically-controlled opening/closing plankton nets (MOCNESS[1]), plankton pumps, electronic particle counter, STD-continuous fluorometry, and a host of other conventional biological and hydrological sampling gear, instruments, and techniques in a multidisciplinary mode. Observations also will be made on the potential predator field of larval fish by sampling the macroplankton and micronekton components on the same cruises. Broad-scale MARMAP ichthyo-zooplankton-primary productivity surveys of the Georges Bank area and contiguous waters will be monitored during the haddock season to provide us with the big picture to relate our more intensive fine-scale studies.

OPERATIONS

During spring of 1981, a two-part study was conducted aboard ALBATROSS IV: Cruise AL 81-03, 15-April-1 May; and Cruise AL 81-05, 18-30 May. Ten days prior to ALBATROSS IV's departure on 15 April 1981, cod larvae and gadid eggs were first located on the Southeast Part of Georges Bank during a mesoscale survey of the shelf conducted on a MARMAP cruise of the GEORGE B. KELEZ. Upon arriving in the study area, a sampling grid of stations was completed on ALBATROSS IV within a 2-day period, deploying a standard MARMAP bongo-net array (Posgay and Marak 1980) on station every 5 miles to characterize the larval fish-zooplankton field in which subsequent fine-scale studies would be conducted. A suitable station site(s) was located within the bongo grid and the following sequence of fine-scale sampling operations was repeated every 6 hours for 1-2 days on the station site or following a drogue:

1. Light-meter cast
2. STD-fluorometer cast with Niskin bottle rosette
3. Special bottom-trip Niskin bottle cast
4. MOCNESS-1 m haul (9 nets, 0.333- or 0.202-mm mesh)

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[1]Multiple Opening/Closing Net and Environmental Sensing System--after Wiebe et al. (1976).

5. Plankton pump cast (4-5 depth levels)

6. Light-meter cast

7. STD-fluorometer cast with Niskin bottle rosette

8. Special bottom-trip Niskin bottle cast

9. MOCNESS-1/4 m haul (9 nets, 0.064-mm mesh)

When sampling for the micronektonic predators of larval fish using the MOCNESS-10 m, the sequence of station activities only included the following operations:

1. Light-meter cast

2. STD-fluorometer cast with Niskin bottle rosette

3. Special bottom-trip Niskin bottle cast

4. MOCNESS-1 m haul (9 nets, 0.333-mm mesh)

5. MOCNESS-10 m haul (5 nets, 3.0-mm mesh)

MODNESS-10 m stations were made during the second part of the study only on Cruise AL 81-05.

Temperature-salinity profiles were made routinely at each station to identify water mass types and physical structuring of the water column that may also produce stratification of the plankton populations. Drifting drogues were deployed in some of the station experiments to follow the same parcel of water during sampling operations and to measure short-term residual current drift in the study area. One drogue with 4 vector-averaging current meters spaced at 7.6 m intervals was deployed on Cruise AL 81-03 and followed for 67 hours in an attempt to measure vertical shear in the water column.

Real-time identification and enumeration of fish eggs, larvae, and zooplankton were made on all 61-cm and 20-cm bongo-net samples (0.333- and 0.165-mm mesh nets) and MOCNESS vertical samples employing special shipboard subsampling and silhouette photography techniques (Ortner et al. 1979) and an electronic digitizer (ZEISS MOP in-hand unit) for length-frequency subsamples of fish larvae.

Water samples for chlorophyll a analysis were taken from the STD-Niskin bottles collected at selected depths and processed aboard the vessel for comparison with continuous in-situ profiles. Particle size distribution also was determined on water samples from the same Niskin bottle samples using a HIAC Criterion PC 320 12-channel particle counting and sizing system (Pugh 1978, Tungate and Reynolds 1980).

Special collections of larvae were preserved throughout the cruise to be analyzed back in the laboratory for otolith ring deposition (Methot and

Kramer 1979, Lough et al. 1982) and biochemical analyses, RNA-DNA ratios (Buckley 1980), as well as the conventional morphometric studies of larval condition indices. These new techniques will allow us to accurately age larvae to the nearest day and assess subtle changes in the growth of individual larvae and nutritional state in relation to feeding conditions. Selected larvae also will be processed for gut content-prey selectivity studies.

CRUISE RESULTS

Part I. Cruise AL 81-03, 15 April-1 May 1981

Cod larvae were broadly distributed over the 35 x 25 mile grid sampling area on the Southeast Part of Georges Bank, mostly between the 60- and 100-m bottom contours. However, a well-defined patch of cod larvae (20 x 10 miles with densities > 256/10 m^2) was centered within the sampled grid at 41°81'N, 66°58'W, with the longer axis of the patch aligned in a northeast-southwest direction (bottom depth 65-75 m). The modal standard length of the cod larvae was 7 mm, ranging in size from 3 mm to 15 mm. Based on laboratory growth rates (Laurence 1978) most of these cod larvae were estimated to have hatched in February and March. Gadid eggs, believed to be predominantly haddock, also were abundant over the grid area. High densities of eggs (4,000-6,000/10 m^2) were located on the northeast corner of the grid and decreased logarithmically to < 64/10 m^2 toward the southwest corner. Also, more earlier stage eggs were observed at the high egg density station to the northeast, whereas later stage eggs predominated to the southwest. The majority of eggs were late stage V and VI (Colton and Marak 1962) and were estimated to have been spawned 8-10 days previous. Total development time of the eggs at 5.8°C (ambient water temperature), from spawning to hatching was estimated to take 12.6 days based on laboratory rearing studies by Laurence and Rogers (1976).

The dominant zooplankton species from the 61-cm bongo, 0.333-mm mesh samples were Calanus finmarchicus copepodites (100-1000/m^3) and Pseudocalanus sp. adults (100-1000/m^3). The contoured distribution of both of these copepod species on the sampling grid gave the impression of a southwest transport from the northeast part of Georges Bank. Also, it was noted very clearly that only reproductively mature adult chaetognaths, Sagitta elegans, were located on the northeast grid station while recently-hatched and younger individuals were found to the southwest. Furthermore, a hydroid bloom was occurring along this same gradient. Re-sampling a transect of bongo stations through the grid center 7 days later produced larval fish and gadid egg concentrations nearly identical to the previous stations values indicating a remarkable cohesiveness of the plankton distributions during this period.

Temperature-salinity profiles indicated that the water column was well-mixed from surface to bottom throughout the study area (ca. 5.8°C, 33‰), however the chlorophyll a concentration increased from about 3 mg/m^3 near surface to >10/m^3 at the bottom. The greater part of the total chlorophyll a concentration could be attributed to the dominant net (> 20 μm) phytoplankton species (Thalassiothrix sp., Coscinodiscus sp., and Ceratium spp.) as opposed to the smaller nannoplankton (< 20 μm) component.

Discrete vertical sampling of the water column by 10-m level MOCNESS hauls indicated that gadid eggs were distributed throughout the water column; however, they consistently showed an increase in egg density with depth. Cod (and sand lance) larvae also were collected throughout the water column, but in general, they too, appeared to be more concentrated in the lower half of the water column, below 30 m depth. Vertical sampling of the dominant copepods indicated that Calanus finmarchicus copepodites and adults were distributed uniformly throughout the water column, whereas Pseudocalanus sp. adults and copepodites tended to reside in the lower half of the water column coincident with the older cod larvae who select them as preferred prey items at this size. Preliminary processing of the calanoid copepod nauplii, preferred food prey of small fish larvae, showed them to be distributed throughout the water column at densities in the range of 1-10 nauplii/liter.

Residual current drift in the study area based on a number of drogue deployments was 1-4 miles/day southeast or south for some periods and little net movement at other times. Preliminary results of the drogued current-meter array indicated that the upper part of the water column was moving horizontally somewhat greater than the lower part in a clockwise semidiurnal tidal regime. A small vertical shear of 1-2 cm/sec is estimated. In the final days of this cruise a slight warming of the surface waters was observed indicating the onset of spring thermal stratification on the southern flank of the bank when most of the gadid eggs were about to hatch.

Part II. Cruise AL 81-05, 18-30 May 1981

A broad patch of predominately haddock larvae with fewer numbers of cod larvae (< 2%) was located by a 40 station bongo-grid survey on the Southeast Part of Georges Bank (centered on 41°00'N, 67°20'W). The patch resided for the most part between the 60- and 100-m bottom contours, the shoal well-mixed region and the shelf/slope front, and extended about 30 miles in a northeast-southwest direction, paralleling the bottom contours in this region. Larval gadid densities ranged 100-1500/10 m^2 within the patch. Gadid eggs were rarely observed in these samples. The modal standard length of the haddock larvae was 7 mm (range: 3-10 mm) indicating that these larvae most likely were from the same population of gadid eggs observed on the previous cruise, 81-03, originally located approximately 30-40 miles to the northeast. Assuming a mean hatching length of 3.4 mm at 6°C (Laurence and Rogers 1976), a field estimated growth rate of 0.18 mm/day was estimated for those larvae to reach 7 mm over the 20 days elapsed since the previous cruise which is similar to laboratory growth rates for larvae reared between 7° and 9°C (Laurence 1978). The highest densities of larvae on the grid appeared to be located on the central part at mid-depth stations (70-80 m) and on the northwest corner (< 60 m) indicating that larvae were being transported in a general southwesterly direction as well as into the shoaler regions just east of Little Georges. Also, the estimated larval transport rate of 1-2 miles/day between cruises for the larvae to arrive in this area is consistent with the long-term mean residual current based on previous oceanographic studies (Butman et al. 1981).

The dominant zooplankters in the study area were Calanus finmarchicus copepodites, Pseudocalanus sp. copepodites and adults, and Oithona sp.

copepodites and adults. A dense hydroid bloom was observed in waters less than 60 m depth. The water column was well stratified at the beginning of the cruise in waters greater than 60 m depth with surface temperatures at 10°C and bottom temperatures at 6°C. At the first fine-scale study station (40°55.5'N, 67°13.5'W), 80-m bottom depth, a strong thermocline was observed at 10-20 m (Figure 3). Fish larvae and Calanus finmarchicus were observed to reside predominantly in the upper 20 m of the water column, associated with the thermocline, while Pseudocalanus sp. only increased slightly at the thermocline depth. Also, the chlorophyll a vertical profiles showed an increased concentration above 20 m (2-3 mg/m^3) compared to deeper depths (0.7 mg/m^3).

A storm swept the area with high northeasterly winds (35-40 knots) and upon resuming operations at the same site 2 days later, it was evident that the entire water column was well-mixed (ca. 7°C) (Figure 4). Chlorophyll a values were uniformly low (< 1 mg/m^3) from surface to bottom. The fish larvae and zooplankton now were distributed throughout the water column without any marked stratification as observed prior to the storm. The highest densities of fish larvae were located between 20- and 50-m depth. Preliminary processing of the gut contents indicated that both haddock and cod larvae had a high incidence of prey in their guts and were feeding predominantly on the copepodite stages and adults of Pseudocalanus sp. Based on laboratory feeding studies (Laurence 1981), the population densities of only the species Pseudocalanus sp. is rather low (0.01-0.1/liter) for survival of larvae of this size, but it is premature to make conclusions until all the potential prey items have been tallied. After 48 hours on the same site, there was some surface warming, a shallow thermocline formed at about 5-m depth, which suggests that at this rate, it would take about a week of calm, sunny weather for the water column to re-stratify to the same degree observed prior to the storm.

A shoal-water station (50-m depth) was occupied for 24 hours (41°06.6'N, 67°35.6'W) in the region where gadid larvae were believed to be carried onto the shoaler part of Georges Bank. Observations made here showed the water column to be well-mixed and the larval fish and zooplankton to be broadly distributed throughout the water column. Chlorophyll a vertical profile concentrations were somewhat higher at the shoal station (1-2 mg/m^3) with a noticeable increase in the bottom few meters. Fifty percent of the chlorophyll a values were attributed to the nannoplankton component (< 20 μm) which agreed with the particle size distribution observed in the water-bottle samples. The dominant net phytoplankton species (> 64 μm) were Chaetoceros sp., Peridinium sp., and Ceratium sp.

Drogue studies were conducted for 24.8 hours at the first fine-scale station (80 m) and at the shoaler station (50 m) located to the northwest. Both drogues were set to drift at 20 m. At the end of 2 tidal cycles, residual current drift at the deeper station was estimated as 13.7 cm/sec to the east, and at the shoaler station, 3.9 cm/sec to the northeast.

Four MOCNESS-10 m stations were made at the end of the cruise, 28-29 May, on a transect from the southeast to northwest corners of the bongo grid survey. Relatively few organisms were collected in the MOCNESS-10 m hauls at any station; however, a number of juvenile fishes and one squid were captured. At the southeast station (40°46'N, 67°00'W, 100-m bottom depth), high temperature

(> 20°C) and salinity (35.74 $^{0}/oo$) values were observed in the upper 15 m. The temperature profiles at this station were extremely variable and changed rapidly within a few kilometers hauling distance down to a depth of 50-70 m where the temperature was 6.3°C isothermal to bottom. This warmer surface layer extended onto the bank at least 10 miles inside of the 100-m contour (80-90 m bottom depth) to the site of the first fine-scale station at the beginning of the cruise. Gadid larvae were absent from the warm water surface samples. Based on laboratory rearing experiments (Laurence and Rogers 1976, Laurence 1978) and previous field studies (Colton 1959, Colton et al. 1968, Colton and Stoddard 1972), survival of haddock and cod larvae would be affected by temperatures greater than 13°C (haddock, > 9°C) and at the high temperatures of greater than 20°C observed on the southern part of the bank, the effect would be lethal to larvae within 24 hours. Following the cruise it was learned from the Atlantic Environmental Group of the National Marine Fisheries Service that warm-core Gulf Stream Eddy 81-C was re-forming near the southern edge of Georges Bank (see Figure 5) which would explain the high temperature water residing there as well as the northeasterly set of the drogues observed the previous week. Warm core rings typically have a clockwise circulation when well organized.

DISCUSSION

Butman et al. (1981) have summarized current measurements obtained on Georges Bank and adjacent shelf waters in several field studies conducted from 1978 to 1979 and concluded that the observed mean flow at 10 m has a permanent clockwise circulation around Georges Bank with a mean residence time of approximately 2 months for a particle moving along the 60-m isobath. However, the observations indicated that the circulation is not completely closed and that considerable variability occurs in the trajectory of an individual water particle. They inferred that the clockwise circulation around the crest of the bank may provide a mechanism for partial retention of the pelagic eggs and larvae of the important fish and shellfish, especially within the 60-m isobath. The loss of eggs and larvae south across the shelf/slope front has not been observed to any degree over the extensive time series of plankton surveys conducted by NEFC, but it can be assumed that any eggs or larvae transported off the bank do not survive in the warmer slope water and are lost to the recruited populations. Nevertheless, the development of warm-water eddies north of the Gulf Stream moving near the southern edge of Georges are believed to play an important role in the movement of shelf/slope water both on and off the bank (Mizenko and Chamberlin 1979, Celone and Chamberlin 1980) and the entrainment of organisms residing there.

The coincidence of match-mismatch of larval fish with their prey can occur spatially and temporally in both the horizontal dimension as they drift around Georges Bank in the clockwise gyre, and in the vertical dimension, particularly in the stratified area where the copepod population may be less abundant.

During spring most of the copepod population tends to develop along the northern crest of Georges Bank, where they are introduced as overwintering stages from the Gulf of Maine water, or reside in the well-mixed waters (Cohen

1976, Sherman and Jones 1980) where phytoplankton concentrations are about an order of magnitude higher than around the perimeter of the bank (O'Reilly et al. 1981, O'Reilly et al. 1980, Cura and Magnell 1981). This high primary productivity appears to be maintained by mixing on top of the bank and by the continuous upward transport of deeper nutrient-rich oceanic water along the northern edge by a number of physical processes both continuous and episodic (Cohen and Wright 1979).

The relation between the formation of a thermocline in the stratified waters around the perimeter of Georges Bank and the survival of haddock larvae and subsequent year-class strength is a second potentially important consideration. The thermocline is a concrete physical entity that can be located (perhaps even by remote sensing) and measured. Its formation is seasonally dependent and its approximate location is known from year to year. Thermocline formation, structure and duration can be interrupted by broad-scale physical events (storms, warm core rings, etc.) whose influence on the hypothesis could be measured. The thermocline is potentially important because biological productivity appears concentrated in this layer and the larval and juvenile haddock (Colton 1965) appear to be uniquely associated with it.

In spring at the time when the larval haddock are present, the thermocline is just beginning to form. At this time, there will be a transition from a vertically homogeneous water column prior to thermocline formation to a more stratified water column as depicted in Figure 3. The presence of the thermocline with the resulting greater degree of patchiness and structure of the plankton may be critical to the survival of the haddock larvae. There is a need to measure food availability for the haddock prior to, during, and following thermocline formation in order to determine the importance of this phenomenon.

CONCLUSIONS

During spring of 1981 our program activities focused on the fine-scale vertical and horizontal distribution of larval haddock, cod, and their prey and predators in relation to environmental variation on Georges Bank. Special electronic sampling gear and real-time data processing methods permitted broad spectrum, discrete vertical sampling in one of the most intensive studies of fish larvae to-date. Results from these spring cruises represent major findings in studies of larval fish survival:

- Confirmation of haddock and cod larvae and their copepod food organisms being transported from their northeastern Georges Bank spawning grounds southwest along the southern flank of the bank with some portion of the older larvae moving onto the shoals near Little Georges.

- Existence of egg and larval concentrations as cohesive mesoscale "patches" that can be followed as single cohort populations over relatively long periods of time even in the well-mixed waters of Georges Bank.

- Coincidence of haddock-cod larvae and their copepod food prey vertically within the narrow region of a thermocline (10-20 m depth) in stratified waters between well-mixed shoal waters (< 60-m bottom contour) and the shelf/slope waters (about the 100-m bottom contour).

- Effect of a major storm on survival of larvae through mixing of the water column, thereby destroying the larval fish-copepod coincidental stratification.

- Lethal effect of a Gulf Stream warm core ring (Eddy 81-C) impinging on the southern flank of the bank on fish larvae in the immediate vicinity.

In 1982, these activities will continue in the spring with better integrated electronic sensing and processing capabilities, but the main focus of our program, and use of ALBATROSS IV vessel time, will be devoted to studying advection of shelf water on Georges Bank (and residing larval fish and plankton populations) across the shelf/slope water front by the entrainment of shelf water from warm core rings passing westward just south of Georges. NSF has recently funded an interdisciplinary multi-institutional study of warm core rings that will run 3 years (at about $ 2 1/2 million yearly) with a preliminary cruise in September 1981 and a major field effort (4 month-long cruise periods, each with 2 or 3 ships) between April and October 1982. This project provides a remarkable opportunity for NEFC to conduct its own study of the interrelations of warm core rings with the shelf ecosystem and their implications for the fishery against a background of extraordinary rich and detailed investigation of these important features.

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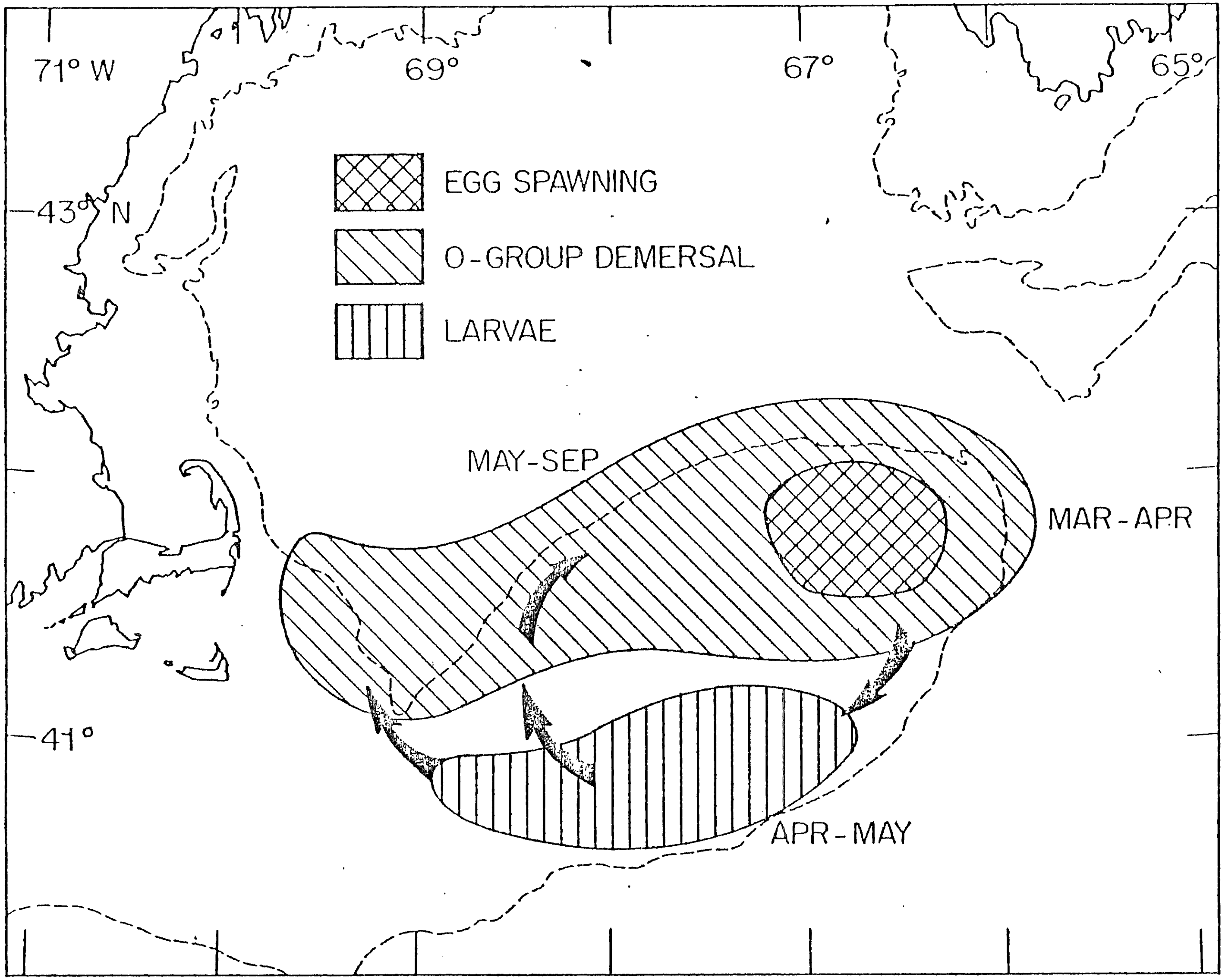


Figure 1. Principal haddock spawning area on Georges Bank and generalized larval drift (indicated by arrows) and areas where demersal 0-group haddock are most abundant 6-8 months later.

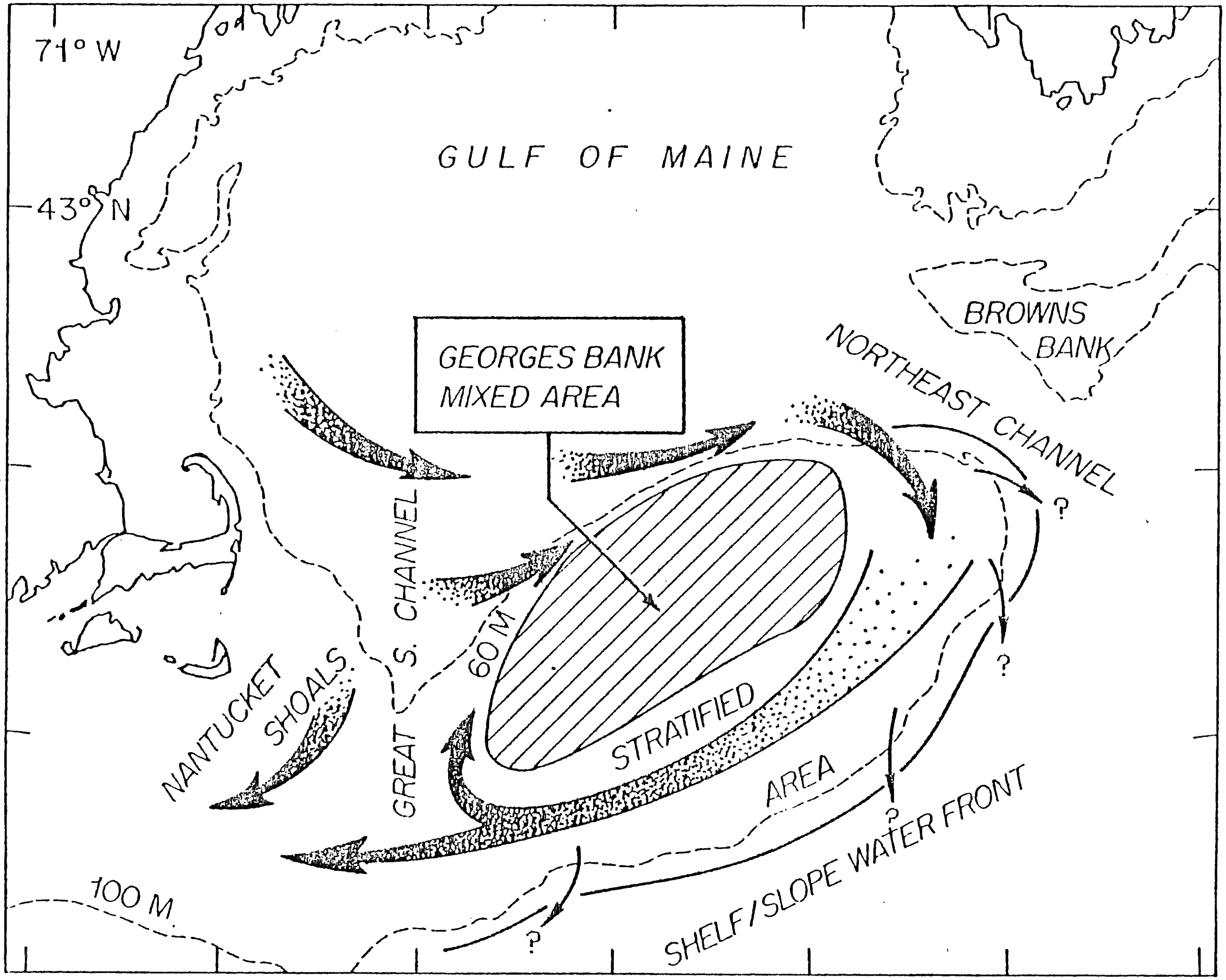


Figure 2. Schematic representation of the well-mixed and stratified waters on Georges Bank and mean circulation flow (arrows) during spring and summer.

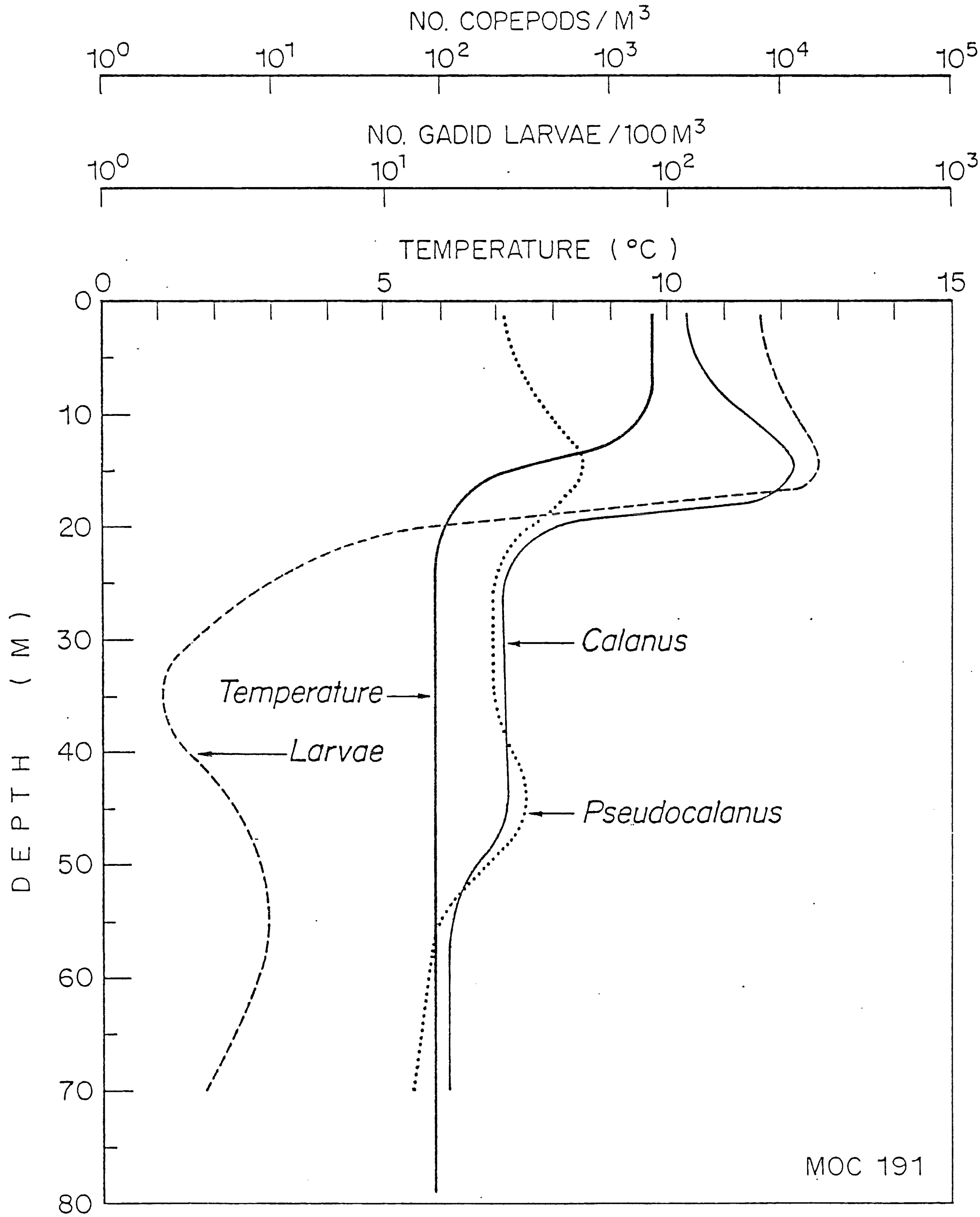


Figure 3. Vertical distribution of gadid (haddock and cod) larvae and dominant copepods (Calanus finmarchicus, Pseudocalanus sp.) in relation to thermocline on the Southeast Part of Georges Bank before storm. (MOCNESS-1m, 0.333-mm mesh, 21 May 1981, 2303-2358 D.S.T. 40°55'N, 67°16'W. Bottom depth: 78-80 m). Note different log-scales used for copepods and gadid larvae.

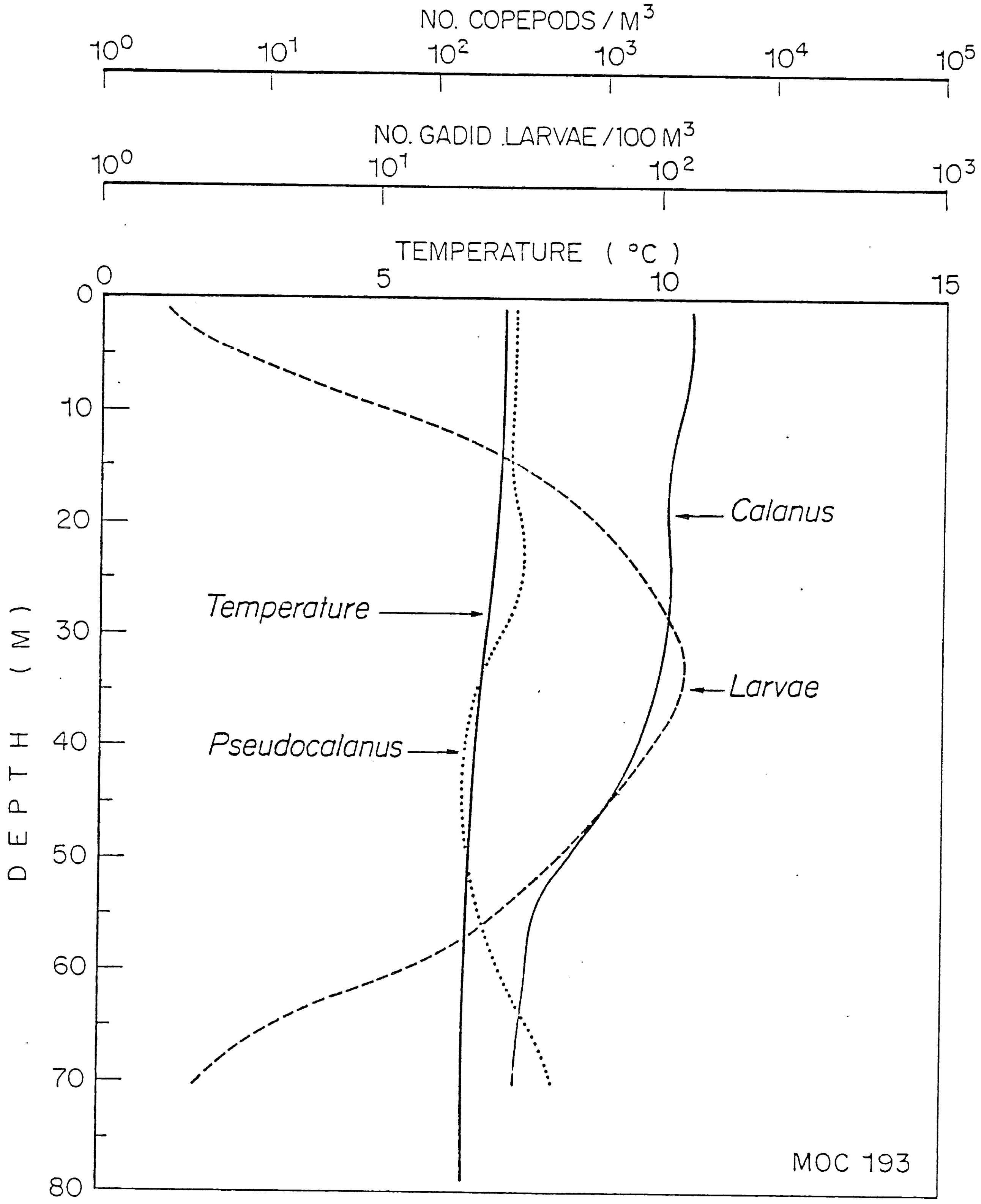


Figure 4. Vertical distribution of gadid larvae (haddock and cod) larvae and dominant copepods (Calanus finmarchicus, Pseudocalanus sp.) on the Southeast Part of Georges Bank after storm. (MOCNESS-1m, 0.333-mm mesh. 24 May 1981, 1835-1920 D.S.T. 40°55'N, 67°13'W. Bottom depth: 80 m). Note different log-scales used for copepods and gadid larvae.

Figure 5.

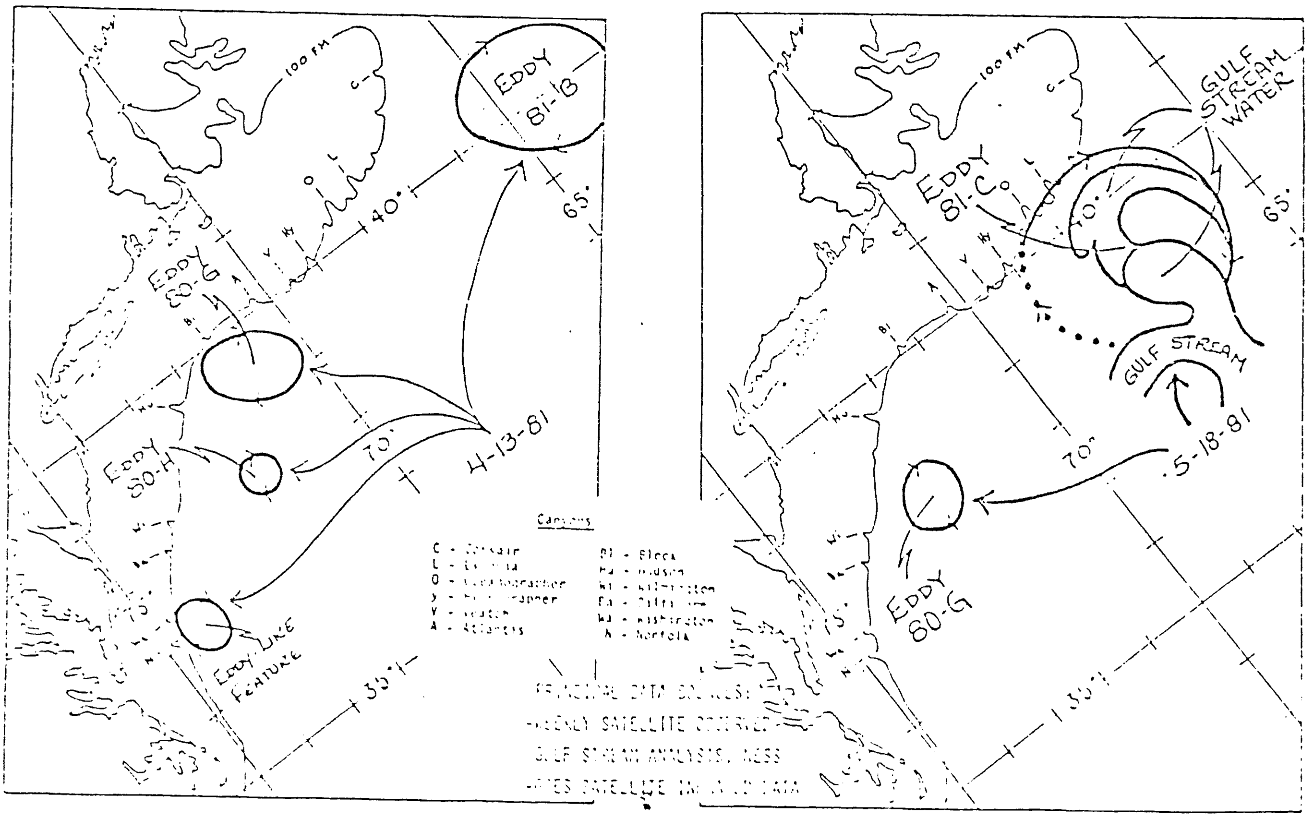
GULF STREAM EDDY LOCATIONS

The Atlantic Environmental Group of the National Marine Fisheries Service reports that two warm core Gulf Stream eddies were present off the northeast coast of the United States in mid-May.

Eddy 79-H travelled southwest and was resorbed by the Gulf Stream during early May, centered at about 37.0°N, 73.0°W, east of Norfolk Canyon. Eddy 80-G moved southwest about 180 km (97 nm) to a center position at about 38.3°N, 72.4°W, east of Baltimore Canyon. Eddy 81-C formed about April 24 by merging of Eddy 81-B with a Gulf Stream meander to the west of it. It extended about 200 nm E-W and 105 nm N-S when first clearly seen on April 28, centered at about 39.0°N, 65.4°W. Eddy 81-C apparently does not have as well organized a pattern of clockwise circulation as is typical of warm core rings. Its western boundary position is consequently uncertain. Gulf Stream water penetrating northward into the ring at 75.0°W in mid-May suggests a ring center position at about 39.3°N, 66.7°W, yet on May 15-16, trap fishermen found a surface current above 2 knots toward the NE, west of Oceanographer Canyon.

During the next 30 days Eddy 80-G may move southwest and become resorbed by the Gulf Stream east of Norfolk Canyon. If Eddy 81-C is not resorbed by the Gulf Stream it may move west to a center position south of Hydrographer Canyon.

Fishermen are requested to report unusual conditions or catches occurring in the vicinity of these eddies to the Director, Atlantic Environmental Group, National Marine Fisheries Service, RR7, South Ferry Road, Narragansett, Rhode Island 02882, by mail. Updates on eddy positions and general information on Gulf Stream eddies may be obtained by calling the Atlantic Environmental Group (401-789-9326).



LARVAL FISH ECOLOGY WORKING GROUP
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Contribution No. 7

COMMENTS ON EFFICIENCY OF NEFC MARMAP SURVEYS

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4.3.7 Comments on Efficiency of NEFC MARMAP Surveys, by Peter Berrien

Since late 1976, with implementation of the MARMAP program in its present form, approximately six cruises per year have been conducted in the Gulf of Maine, Georges Bank, southern New England, and Middle Atlantic Bight waters (Figure 1). These surveys are designed to sample or measure ichthyoplankton, zooplankton, and chlorophyll-*a* density, various hydrographic parameters, and primary production.

Now that some data resulting from these cruises have been analyzed it is reasonable to try and address some of the questions which always arise over such large-scale programs; namely, is sampling (in area and time) insufficient, adequate, or excessive in the attempt to attain major goals of the design?

The above question (concerning adquacy of sampling) can be addressed from three approaches, concerning the adequacy of: 1) geographic coverage; 2) sampling frequency over time, i.e. the time interval between cruises; and 3) the number of stations sampled on a cruise. My comments here are confined to the first of these three items, geographic coverage.

At the inception of any large-scale survey, such as those under MARMAP, investigators have to sample some areas out of ignorance in order to be sure of good geographic coverage of unknown spawning areas. If it later turns out that sampling, data handling, and analysis are too costly for the amount of information gained from certain areas, then perhaps the geographic coverage should be re-evaluated with possible reductions in mind. The question becomes: Can some areas sampled be eliminated, either partially or entirely in order to maximize the information gained from the resources expended? In the case of these surveys: Do we more than adequately cover spawning areas of the species of interest; or, are there areas which contribute only insignificantly to the total abundance estimate?

The accompanying tables list the relative amounts of information we have gained from four geographic areas for various species as eggs or larvae (Tables 1-4). Obviously the tables are incomplete - not all years are represented for all species; furthermore, and more importantly, not all species of interest are presented - the data were not yet available. Species omitted which would be of interest include butterfish, bluefish, summer flounder, and possible weakfish, redfish, scup, and hakes (*Urophycis* sp.). In the setting up of these tables some information from certain surveys was necessarily omitted. I only included data when all four subareas had been sampled; thus incomplete surveys were excluded from this compilation. In evaluation of the amount of information gained for a given species, it is important to compare the tabulated percent abundance against the percentages of area, stations, and survey time which each subarea comprises within the total MARMAP survey. These latter three values are given on the tables.

The Gulf of Maine appears to be quite important to the abundance estimate of herring and marginally so for silver hake and mackerel. For these three species the western portion within the Gulf of Maine contributed most occurrences while the central portion was generally quite void of eggs and larvae. The Gulf of Maine would undoubtedly be important to a census of redfish larvae also.

Georges Bank is important to abundance estimates of all species considered with the possible exception of mackerel. This area would probably figure prominently in a census of butterfish eggs and larvae.

Southern New England waters also appear to be important spawning and nursery areas for most species tabulated, except for herring. Cod and haddock vary from year-to-year in their utilization of these waters, formerly being more abundant than recently. In addition to those tabulated, this area would probably be important to census work for eggs and larvae of butterfish, bluefish, summer flounder, and weakfish.

The Middle Atlantic Bight is important to mackerel, and in some years to yellowtail flounder. This area can be expected to be important to census work on butterfish, bluefish, weakfish, and summer flounder. The high percentages under "all spp." for both eggs and larvae are heavily augmented in this area by anchovies, sea robins, hakes, bothid flatfishes, and cunner.

It is apparent from the above that each of the above geographic subareas sampled is important to some species of interest. Coverage appears to be adequate for spawning population estimates of Atlantic mackerel, yellowtail flounder, bluefish, butterfish, cod, haddock, summer flounder, herring, and sand lance. The only part of the MARMAP survey area which appears to be relatively non-productive of information is the central and north-eastern portions of the Gulf of Maine. It might be reasonable to reduce sampling intensity in that area. For two species of interest the areal coverage appears to be inadequate. We do not sample shorward enough to completely cover the spawning area of weakfish. Nor do we sample far enough seaward to completely describe the spawning area of silver hake. While we might consider a slight seaward extension of the survey area in order to adequately sample silver hake, it would be very difficult if not impossible to fully describe the spawning area of weakfish which spawns in bays and sounds as well as the near shore area of the continental shelf.

Table 1. Abundance in Gulf of Maine* waters, as percent of abundance in a total MARMAP survey.

	Spawning season ending in						
	1974	1975	1976	1977	1978	1979	1980
Eggs							
All spp.				7.8	10.6	5.8	
Limanda ferruginea				6.6			
Merluccius bilinearis						18.3	
Scomber scombrus				1.8			
Larvae							
All spp.				2.8	3.9	8.2	
Ammodytes sp.		3.2	3.0	0.2	3.4	2.5	
Clupea harengus					60.8	70.7	99.6
Gadus morhua		1.1		6.1	1.9	17.6	9.7
Limanda ferruginea				3.3	9.6	4.8	1.4
Melanogrammus aeglefinus	1.1	0.5	2.1	5.3	1.6	16.2	5.9
Merluccius bilinearis				0.5	6.0	19.8	
Scomber scombrus				5.4	30.9	2.1	

*The Gulf of Maine subarea comprised 38% of the area, 29% of the stations and approximately 32% of the sampling time within a total MARMAP survey.

Table 2. Abundance in Georges Bank* waters, as percent of abundance in a total MARMAP survey.

	Spawning season ending in						
	1974	1975	1976	1977	1978	1979	1980
Eggs							
All spp.				22.3	32.8	25.7	
Limanda ferruginea				36.4			
Merluccius bilinearis						37.8	
Scomber scombrus				0.7			
Larvae							
All spp.				28.2	13.3	18.8	
Ammodytes sp.		32.7	68.5	3.4	1.4	18.1	
Clupea harengus					30.9	28.3	0.1
Gadus morhua	24.3	66.9	47.1	85.0	95.3	72.4	87.5
Limanda ferruginea				23.2	48.7	42.3	25.6
Melanogrammus aeglefinus	44.7	53.6	96.1	84.7	98.4	75.2	88.0
Merluccius bilinearis				66.4	48.6	54.4	
Scomber scombrus				0.6	32.0	0.7	

*The Georges Bank subarea comprises 16% of the area, 16% of the stations, and approximately 17% of the sampling time in a total MARMAP survey.

Table 3. Abundance in southern New England* waters, as percent of abundance in a total MARMAP survey.

	Spawning season ending in						
	1974	1975	1976	1977	1978	1979	1980
Eggs							
All spp.				51.9	29.9	49.4	
Limanda ferruginea				55.5			
Merluccius bilinearis						33.1	
Scomber scombrus				89.7			
Larvae							
All spp.				56.4	44.3	34.2	
Ammodytes sp.		30.5	23.2	86.0	52.3	44.0	
Clupea harengus					8.3	1.0	0.3
Gadus morhua	69.8	19.7	39.7	8.2	1.5	7.8	2.6
Limanda ferruginea				49.9	39.7	44.5	67.4
Melanogrammus aeglefinus	54.2	45.9	1.7	9.9		8.7	6.1
Merluccius bilinearis				32.9	42.9	22.6	
Scomber scombrus				41.0	32.9	71.1	

*The southern New England subarea comprises 23% of the area, 25% of the stations and approximately 24% of the sampling time within a total MARMAP survey.

Table 4. Abundance in Middle Atlantic Bight* waters, as percent of abundance in a total MARMAP survey.

	Spawning season ending in						
	1974	1975	1976	1977	1978	1979	1980
<u>Eggs</u>							
All spp.				18.0	26.7	19.2	
Limanda ferruginea				1.5			
Merluccius bilinearis						10.8	
Scomber scombrus				7.8			
<u>Larvae</u>							
All spp.				12.6	38.5	38.8	
Ammodytes sp.		33.6	5.3	10.4	42.9	35.4	
Clupea harengus							
Gadus morhua	5.9	12.3	13.2	0.6	1.2	2.2	0.1
Limanda ferruginea				23.6	2.0	8.3	5.6
Melanogrammus aeglefinus							
Merluccius bilinearis				0.2	2.5	3.2	
Scomber scombrus				53.0	4.2	26.1	

*The Middle Atlantic Bight subarea comprises 23% of the area, 29% of the stations and approximately 28% of the sampling time within a total MARMAP survey.

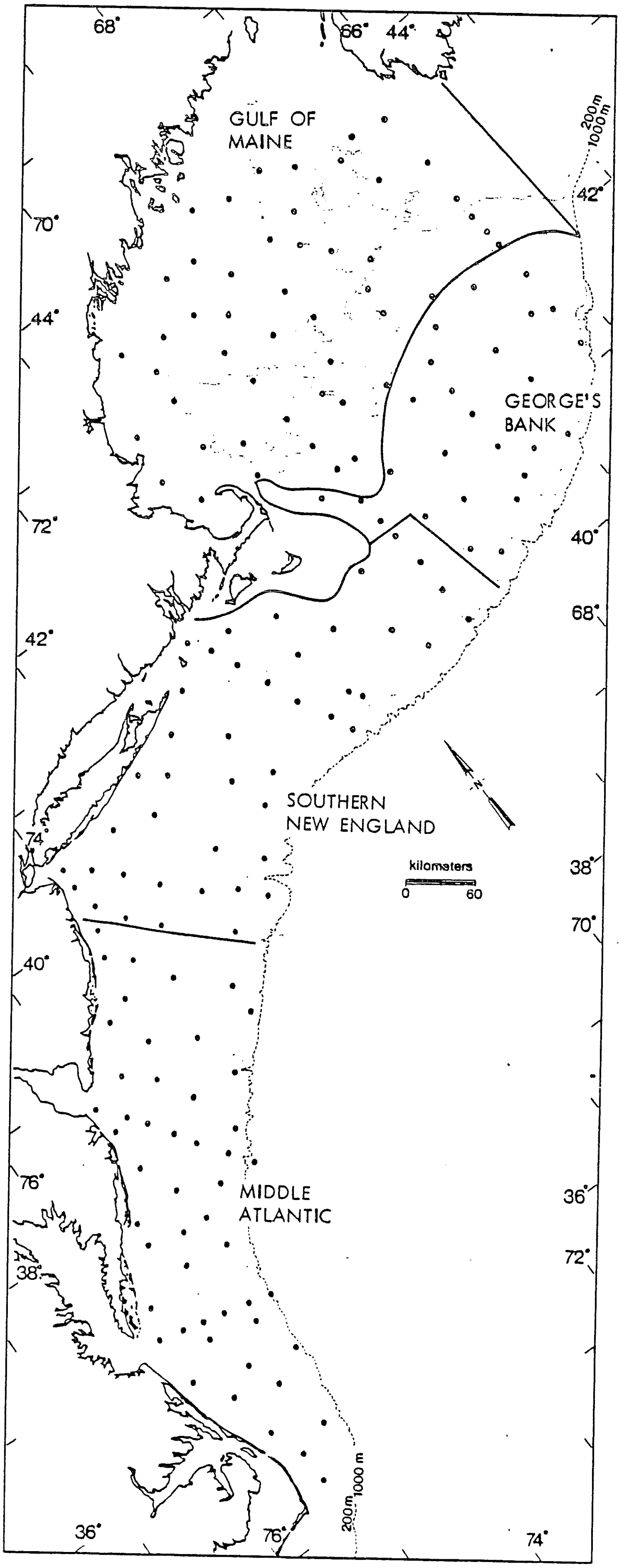

Figure 1. MARMAP survey area, showing subareas and sampling stations.

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Lowestoft, Suffolk, U.K.
July 1-3, 1981

Contribution No. 8

MEASURING THE EFFECT OF THE VARIABILITY OF EGG DENSITIES OVER SPACE AND TIME ON EGG ABUNDANCE ESTIMATES

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4.3.8 Measuring the Effect of the Variability of Egg Densities over Space and Time on Egg Abundance Estimates, by Michael Pennington and Peter Berrien

Abstract

Based on the results of ichthyoplankton surveys conducted during the spring and summer of 1977 and 1979 off northeastern United States, it is shown that with bimonthly surveys, adequate estimates of total seasonal egg production can be made for three species. For these species egg production curves appear to be fairly smooth over time with peak production lasting a month or longer. The smoothness of the production curves is the major reason why cruises which are widely spaced, with respect to the life span of eggs, produce estimates of total spawning stock size which compare favorably with other independently derived estimates.

Introduction

Egg surveys often produce estimates of spawning stock size which are consistent with estimates derived from other data (see e.g. Saville 1956; Simpson 1959; Berrien, Naplin and Pennington 1979; Berrien 1981). Although the estimated precision of egg surveys is usually based only on the variability of egg densities over space with the time component being ignored (Saville 1964), the reasonable results obtained by the surveys indicate a true precision which is not substantially lower than the stated precision. This suggests, since the time interval between surveys is often much longer than the life span of an egg, that daily total egg production in an area is fairly continuous over time for many species.

In this paper a method is described which measures the effect of varying production over time on the precision of estimates of total seasonal production based on a sequence of cruises. From survey results for three species, Atlantic mackerel (*Scomber scombrus*), yellowtail flounder (*Limanda ferruginea*) and silver hake (*Merluccius bilinearis*), estimates of the variability due to time are derived and combined with estimates of spatial variability to ascertain the approximate precision obtainable by bimonthly egg surveys.

Methods

The Data

Data analyzed in this paper were collected during MARMAP (Marine Resourses Monitoring Assessment and Prediction) ichthyoplankton surveys in 1977 (mackerel and yellowtail) and 1979 (silver hake). The MARMAP surveys cover much (250,000 km^2) of the continental shelf off the Northeast Coast of North America from Cape Hatteras, North Carolina to Nova Scotia (Figure 1). For a detailed description of sampling procedures, including the methods used to calculate the egg densities, see Berrien *et al*. (1979) and Berrien (1981).

Variability Over Space

The surveys generally cover the entire region shown in Figure 1, only parts of which contain the eggs of any particular species. For each species the proportion of non-zero station values is used to estimate the proportion of the total area surveyed where eggs of the species occur, and the non-zero values are used to estimate the mean egg density in the areas of occurrence. The distribution of the log of the non-zero values was found to be normally distributed (Berrien et al. 1979). A distribution which contains a proportion of zeros and whose non-zero values are log-normally distributed is call Δ-distribution by Aitchison and Brown (1957). For the estimation of mean egg densities, estimators based on the Δ-distributions have been found to be much more efficient than the ordinary sample statistics (Pennington 1980). The estimator (k) of the mean and its variance (var(k)) for the Δ-distribution are given by (Aitchison 1955; Pennington 1980):

$$k = \frac{n_1}{n} \exp(\bar{y})\ G_{n_1}(s^2/2) \qquad n_1>1$$

$$= \frac{x_1}{n} \qquad n_1=1$$

$$= 0 \qquad n_1=0$$

and

$$\mathrm{var}(k) = \frac{n_1}{n} e^{2\bar{y}} \left[\frac{n_1}{n} G_{n_1}^2 (s^2/2) - \frac{n_1 - 1}{n - 1} G_{n_1} \left(\frac{n_1 - 2}{n_1 - 1} s^2\right)\right] \qquad n_1>1$$

$$= \left(\frac{x_1}{n}\right)^2 \qquad n_1=1$$

$$= 0 \qquad n_1=0,$$

where n is the sample size,
n_1 is the number of non-zero values,
$\bar{y}$ is the sample mean of the non-zero $\log_e$ values
s^2 is the sample variance of the log values
x_1 is for $n_1=1$, the single non-zero values,

and

$$G_n(t) = 1 + \frac{n-1}{n} + \sum_{j=2}^{\infty} \frac{(n-1)^{2j-1}}{n^j (n+1)(n+3)\dots(n+2j-3)} \cdot \frac{t^j}{j!}$$

Both k and var (k) are minimum variance unbiased estimators (Pennington 1980). The above formulas were used to estimate the mean egg density and its variance for a particular time (cruise), and the results for each cruise were integrated over time to produce an estimate of total seasonal production along with an estimate of the variability due to spacial fluctuations in density (Berrien *et al.* 1979).

Variability Over Time

A sequence of egg surveys is in effect, most often a systematic sample taken over time. If the production curve (eggs produced as a function of time) is a smooth continuous curve, a systematic sample can be much more efficient than random surveys (Cochran 1977). For a series of k surveys taken, for example, at monthly intervals, let $T_{t_1,\ t_2 \ldots t_k}$ denote the estimate of the total egg production based on the k surveys. Then the variance of $T_{t_1,\ t_2 \ldots t_k}$ is given by (Rao, p. 97, 1973):

$$V(T_{t_1,t_2 \ldots t_k}) = E[(T_{t_1,t_2 \ldots t_k} | t_1,t_2 \ldots t_k)] + V[E(T_{t_1,t_2 \ldots t_k} | t_1,t_2 \ldots t_k)]. \tag{1}$$

The first term on the right hand side of equation (1) is the expected variance due to spacial differences, and the last term is the variance of the expected abundance for a particular sequence taken over all possible sequences of monthly surveys.

In planning an egg census, the adequacy of the sampling interval can be estimated by conducting two surveys, each of the desired frequency. For example, if the available resources can support for the long term, bimonthly cruises, then a test program of two bimonthly surveys of the desired spacial intensity, both with a random start, would be conducted. Each survey produces an independent estimate of the total production. Denoting these estimates by T_1 and T_2, then the variability of bimonthly surveys is estimated by

$$(T_1-T_2)^2/2. \tag{2}$$

Equation (2) is an unbiased estimator and includes the variability due to space and time. From it, estimates of the variability due to time alone can be obtained.

For the data analyzed in this paper, the variability of bimonthly surveys due to time was measured indirectly using the total production curve generated by a sequence of fairly intensive overlapping cruises. The estimated production curve is taken as fixed and two estimates of total production, each based on points two months apart on the curve, were made. The variability between the estimates was calculated and used to estimate the variability due to time (the last term in equation (1)). This value was added to an estimate of spacial variability to produce a rough estimate of the total variability of seasonal egg production estimates based on bimonthly surveys.

Results

Tables 1-3 summarize the statistics used to estimate the egg production at various times for each stratum and for the total area. Also given are estimates of the standard error due to spacial variability at the times sampled. From the tables it can be seen that though the estimated error of the individual density estimates for each stratum are relatively large, the average densities (k) do not vary erratically over time, but for most strata, rise to a peak and then decline.

The daily egg production curves for the entire survey area are shown in Figures 2-4. As is the case for each stratum, the most marked feature of the total production curves is its smoothness over time. Also, for the entire region taken as a whole, each species appears to have a rather extended period of intensive egg production.

Table 4 contains for each species the estimates of the total seasonal production (the area under the production curves), and two estimates of production based on points two months apart on the curve. Figure 5 displays graphically how the bimonthly estimates are calculated for yellowtail. The 5th column in Table 4 gives the estimated coefficient of variation due only to temporal variability, and the last column contains the total coefficient of variation for bimonthly surveys with a spacial sampling intensity large enough to produce for each survey estimates of the same level of precision as given in Tables 1-3.

Discussion and Conclusions

There are various ways to estimate the variance of the sample mean from a single systematic sample after making some assumptions (Cochran 1977). In this paper, the analysis of the data is complicated by the fact that sampling was neither random nor systematic through time. Where practical, unbiased estimates of the variance can be made by dividing the effort into two (or more) systematic samples with random starts. Again, if T_1, T_2 denote the results from the two surveys, then

$$T_1 + T_2/2$$

and

$$(T_1-T_2)^2/4$$

will be unbiased estimates of the mean egg density and of its variance, $V(T_1+T_2/2)$, respectively.

There are other possible sources of uncertainty in egg abundance estimates which have not been addressed here. Errors could result from insufficient coverage of spawning area and season due either to inadequate survey design or to vessel operations and the vagaries of weather. For instance, an apparently important spawning area of silver hake in the western Gulf of Maine was not adequately sampled in the summer resulting in egg estimates that are probably low. Another possible, but less worrisome source of bias in egg census work, could arise through choice of a water column temperature which does not accurately reflect conditions experienced by an egg sample in question. The application of an inaccurate mortality rate to egg catches would bias resulting production levels. However, this effect is minimized by the use of the youngest stage eggs to derive the final egg census estimates. Beyond egg production estimates, errors in any of the following parameters on adults could bias the resulting population estimates: the length-frequency distribution, male-female ratio, percent mature at size, and fecundity at size.

Perhaps the best way to assess the accuracy of egg surveys is to compare their results with other available estimates. For Atlantic mackerel, a spawning stock estimate of 1.2×10^9 fish was obtained from the egg survey, which compares favorably with 1.4×10^9 fish derived through cohort analysis (Berrien et al. 1979). The estimate for yellowtail (1.4×10^8 fish) also appears to be quite reasonable, although no other independent estimate of abundance exists for comparison (Berrien 1981). An estimate of the abundance of silver hake based on the egg surveys has not yet been calculated.

In general, the precision of egg surveys for a particular species will depend on how smooth its production curve is over time. For the species considered, the curves appear to be both smooth and broad enough so that bimonthly surveys would provide estimates of sufficient accuracy for detecting large changes in the populations. It should be stressed though, that the data are only from one year for each species. But if the shape of the production curves proves to be similar for other years, then the use of egg surveys for the estimation of fish abundance would appear to offer a feasible method of monitoring major fluctuations in spawning stocks. It represents the only way of estimating absolute abundance of species for which no fishery exists, and probably is cost effective in cases where fishery statistics are inadequate to provide accurate VPA assessments. A definitive comparison between these methods would require rigorous evaluation of all the sources of sampling error associated with both VPA and egg production methods.

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TABLE 1. Atlantic mackerel egg production estimate.

Stratum	Cruise	n	n_1	n_0	$\bar{y}$	s^2	k	Std. Error of k	Area (km^2)	Eggs Spawned in Stratum Per Day (no. x 10^{12})	Sampling Midpoint Date	Days Represented	Eggs Spawned, Represented by this Effort in this Stratum (no. x 10^{12})
1	D-77-3	15	0	15					16560	0	Mar. 23	21.628	0
1	D-77-4(pt. 1)	17	3	14	-1.744076	1.060294	0.0427	0.0386	16560	0.0007	Apr. 14	21.1875	0.0150
1	D-77-5(pt. 1)	17	0	17					16560	0	May 5	34.5	0
1	D-77-7(pt. 2)	17	0	17					16560	0	June 22	49.25	0
1	[Yub-77-2 D-77-9]	17	0	17					16560	0	Aug. 11	50.25	0
2	D-77-3	54	0	54					67288	0	Mar. 29	20.5	0
2	D-77-4(pt. 1)	68	44	24	-0.040103	3.553738	3.3292	1.6044	67288	0.2240	Apr. 19	14.1875	3.1782
2	D-77-4(pt. 2)	57	42	15	1.709243	6.402071	76.2885	61.3461	67288	5.1333	Apr. 26	10.25	52.6163
2	D-77-5(pt. 1)	66	34	32	2.149910	4.928335	42.0080	30.1872	67288	2.8266	May 9	12.9375	36.5696
2	D-77-5(pt. 2)	69	35	34	2.590489	4.041763	43.7950	26.3836	67288	2.9469	May 22	23.5625	69.4358
2	D-77-7(pt. 2)	69	7	62	1.636568	1.680508	1.0140	0.7700	67288	0.0570	June 25	42.1875	2.8783
2	[Yub-77-2 D-77-9]	58	0	58					67288	0	Aug. 15	50.5	0
3	Go-77-1	18	0	18					14131	0	Mar. 6	39.625	0
3	Alb-77-2	8	0	8					14131	0	Apr. 15	23.5	0
3	D-77-4(pt. 1)	8	0	8					14131	0	Apr. 22	7.375	0
3	D-77-5(pt. 1)	7	7	0	1.217970	1.098071	5.2838	2.6046	14131	0.0747	May 11	22.25	1.6613
3	D-77-5(pt. 2)	8	6	2	2.418879	7.586451	90.7456	224.1528	14131	1.2823	May 26	24.375	31.2567
3	D-77-7(pt. 2)	8	2	6	2.489205	3.077634	7.5254	5.9276	14131	0.1063	June 29	40.8125	4.3400
3	Yub-77-2	9	2	7	0.277717	1.204928	0.3863	0.4493	14131	0.0055	Aug. 15	47.25	0.2579
4	Go-77-1	70	0	70					84794	0	Mar. 21	39.625	0
4	Alb-77-2	54	1	53	n.a.	n.a.	0.0110	0.0110	84794	0.0009	Apr. 29	37.8125	0.0353
1	[Nog-77-2 D-77-7(pt. 1)]	81	67	14	0.927658	5.005552	22.6866	11.7406	84794	1.9237	June 4	50.0	96.1850
4	Yub-77-2	54	1	53	n.a.	n.a.	0.0074	0.0074	84794	0.0006	Aug. 7	64.0	0.0402
5	Go-77-1	14	0	14					19137	0	Apr. 1	26.125	0
5	Alb-77-2	12	0	12					19137	0	Apr. 27	65.625	0
5	Yub-77-2	10	0	10					19137	0	Aug. 10	105.125	0
6	Alb-77-2	19	0	19					29837	0	May 6	38.625	0
6	D-77-7(pt. 1)	18	2	16	-1.223048	0.099645	0.0335	0.0236	29837	0.0010	June 14	38.625	0.0386
7	Alb-77-2	5	0	5					9299	0	May 12	23.0	0
7	Nog-77-2	9	7	2	1.799050	2.630087	11.5437	11.6128	9299	0.1073	June 4	43.8125	4.7030
7	Yub-77-2	7	0	7					9299	0	Aug. 8	64.625	0
8	Alb-77-2	7	0	7					9734	0	May 9	91.75	0
8	Yub-77-2	3	0	3					9734	0	Aug. 8	91.75	0

The estimated total egg production is 3.032×10^{14} eggs

Table 2. Yellowtail flounder egg production estimate.

Subarea	Survey	n	n_1	$\bar{y}$	s^2	k	Std. Error of k	Area (km^2)	Eggs Spawned in Subarea Per Day ($\times 10^{-9}$)	Sampling Midpoint Date	Days Represented	Eggs Spawned Represented by this Effort in this Subarea ($\times 10^{-12}$)
1	1	15	0					16560	0	24 Mar	21.47	0
1	2	17	0					16560	0	14 Apr	21.09	0
1	4	17	0					16560	0	5 May	34.48	0
1	6	17	0					16560	0	22 Jun	49.28	0
1	7	17	0					16560	0	11 Aug	50.32	0
2	1	54	15	2.47529	1.79704	7.3429	3.2372	67288	49.4090	29 Mar	20.58	1.0168
2	2	68	22	2.99793	2.01189	16.3336	6.5099	67288	109.9054	19 Apr	14.20	1.5612
2	3	57	28	2.56954	2.37508	19.3472	7.5061	67288	130.1831	26 Apr	10.26	1.3363
2	4	66	24	2.40451	2.20831	11.1384	4.4725	67288	74.9478	9 May	13.18	0.9874
2	5	69	22	2.99576	2.09949	16.6960	6.7946	67288	112.3443	23 May	23.54	2.6446
2	6	69	0					67288	0	25 Jun	41.95	0
2	7	58	0					67288	0	15 Aug	50.47	0
3	1	18	3	0.37156	0.93012	0.3226	0.2214	14131	0.4559	7 Mar	39.57	0.0180
3	2	8	3	3.43819	0.69344	14.5323	9.0516	14131	20.5356	22 Apr	13.04	0.2678
3	3	8	6	3.41184	2.12710	50.4353	29.8236	14131	71.2701	15 Apr	23.42	1.6691
3	4	7	5	4.22099	2.67768	123.0481	82.9708	14131	173.8792	11 May	16.60	2.8873
3	5	8	3	5.00699	1.26764	82.3491	57.1399	14131	116.3675	26 May	24.40	2.8388
3	6	8	1	n.a.	n.a.	2.0588	2.0588	14131	2.9092	29 Jun	40.84	0.1188
3	7	9	0					14131	0	15 Aug	47.29	0
4	1	70	15	2.31562	2.55894	6.6399	3.4207	84794	56.3027	21 Mar	39.70	2.2352
4	3	54	24	2.49982	2.83162	19.6971	8.9085	84794	167.0197	30 Apr	37.81	6.3150
4	5	81	50	3.58450	2.39818	70.2166	21.4594	84794	595.3949	4 Jun	49.98	29.7608
4	7	55	3	2.19381	0.52486	0.5786	0.3776	84794	4.9066	8 Aug	64.05	0.3143
5	1	14	1	n.a.	n.a.	0.1229	0.1229	19137	0.2351	1 Apr	26.08	0.0061
5	3	12	2	3.06265	9.68158	16.2830	16.0688	19137	31.1608	27 Apr	65.57	2.0432
5	7	10	0					19137	0	10 Aug	105.06	0
6	3	19	2	1.42497	1.32494	0.5908	0.4980	29837	1.7628	6 May	38.43	0.0677
6	5	17	5	2.00359	2.00446	4.4649	2.9390	29837	13.3220	14 Jun	38.43	0.5120
7	3	5	0					9299	0	12 May	23.00	0
7	5	9	4	1.56137	0.65554	2.6784	1.4214	9299	2.4906	4 Jun	43.87	0.1093
7	7	7	2	1.86779	1.37042	2.5204	2.0873	9299	2.3438	8 Aug	64.74	0.1517
8	3	7	0					9734	0	9 May	91.82	0
8	7	3	0					9734	0	9 Aug	91.82	0

The estimated total egg production is 56.8616 x 10^{12} eggs (std. error = 10.3592 x 10^{12}).

Table 3. Silver hake egg production estimate.

Subareas and Surveys	n	n_1	$\bar{y}$	s^2	k	Std. Error of k^2	Area (km^2)	Eggs Spawned in Subarea Per Day ($x10^{-10}$)	Sampling Midpoint Date	Days Represented	Eggs Spawned* Represented by this Effort in this Subarea ($x10^{-11}$)
SA I											
DE-79-05	55	17	3.5958	2.16233	29.6166	13.4509	64847	19.2055	9 May	48.00	92.1864
AL-79-06	57	7	4.0334	3.34712	24.1338	17.0789	64847	15.6501	26 Jun	49.25	77.0766
BE-79-01	54	15	3.2439	1.13832	11.9154	4.4029	64847	7.7268	16 Aug	51.75	39.9863
AL-79-11	55	4	2.5816	4.03047	4.0599	2.5797	64847	2.6328	8 Oct	53.00	13.9536
SA II											
DE-79-04	24	3	2.1854	0.12368	1.1580	0.6674	45892	0.5315	15 Apr	30.50	1.6209
DE-79-05	31	15	4.2292	2.67606	106.6125	54.5951	45892	48.9266	15 May	31.25	152.8957
AL-79-06	31	13	4.4462	3.54942	158.0185	95.8705	45892	72.5179	5 Jul	48.50	351.7118
BE-79-01	28	14	4.1749	1.58625	65.7399	27.2497	45892	30.1694	20 Aug	36.70	110.7216
BE-79-03-I	9	5	3.4317	1.02206	25.2338	13.0805	45892	11.5802	18 Sep	22.50	26.0558
BE-79-03-II	10	3	4.4326	5.91463	105.6383	95.8339	45892	48.4795	5 Oct	13.50	65.4474
AL-79-11	31	16	3.3152	1.23062	24.8412	8.7337	45892	11.4001	14 Oct	10.00	11.4001
SA III											
DE-79-04	11	0					54504		21 Apr	30.50	
DE-79-05	37	7	4.9579	4.48470	134.3747	102.4626	54504	73.2409	20 May	40.75	298.4568
AL-79-06	37	20	4.7777	1.86629	150.6529	58.3595	54504	82.1119	20 Jul	43.25	355.1338
BE-79-01	37	22	3.7929	1.08949	43.8993	12.5339	54504	23.9269	25 Aug	32.50	77.7624
BE-79-03-I	17	3	1.9967	0.00000	1.2996	0.7019	54504	0.7083	14 Sep	24.00	1.7000
BE-79-03-II	16	4	2.8286	0.67707	3.2269	4.3727	54504	1.7588	3 Oct	18.75	3.2977
AL-79-11	40	7	3.2265	1.54784	8.1652	4.5671	54504	4.4504	21 Oct	19.00	8.4557
SA IV											
DE-79-05	15	5	2.4248	0.68441	4.8964	2.6742	34638	1.6903	23 May	154.00	26.1189
AL-79-11	17	0							25 Oct	154.00	
SA V											
DE-79-04	18	0					51980		26 Apr	31.50	
DE-79-05	32	2	2.6346	0.69963	1.0279	0.8155	51980	0.5343	26 May	63.50	3.3931
BE-79-01	28	7	4.9508	2.57690	94.6020	61.0779	51890	49.1741	31 Aug	76.50	376.1822
AL-79-11	18	2	1.8077	0.06664	0.6866	0.4810	51980	0.3579	28 Oct	57.50	2.0583

*The estimated total egg production is 20.95615 x 10^{13} eggs (std. error = 4.3926 x 10^{13}).

Table 4. Estimated total egg production from the complete survey and from bimonthly surveys starting March 1 (T_1) and April 1 (T_2). The 5th column is the coefficient of variation when time is the only factor included and the last column is the C.V. due to both time and space.

Species	Est. Total Egg Production ($x10^{-14}$)	$T_1(x10^{-14})$	$T_2(x10^{-14})$	C.V. x 100 due to time	C.V. (time and space) x100 for bimonthly surveys
Atlantic mackerel	3.0	3.5	3.1	7%	23%
Yellowtail flounder	0.6	0.5	0.6	17%	24%
Silver hake	2.1	2.1	2.5	14%	25%

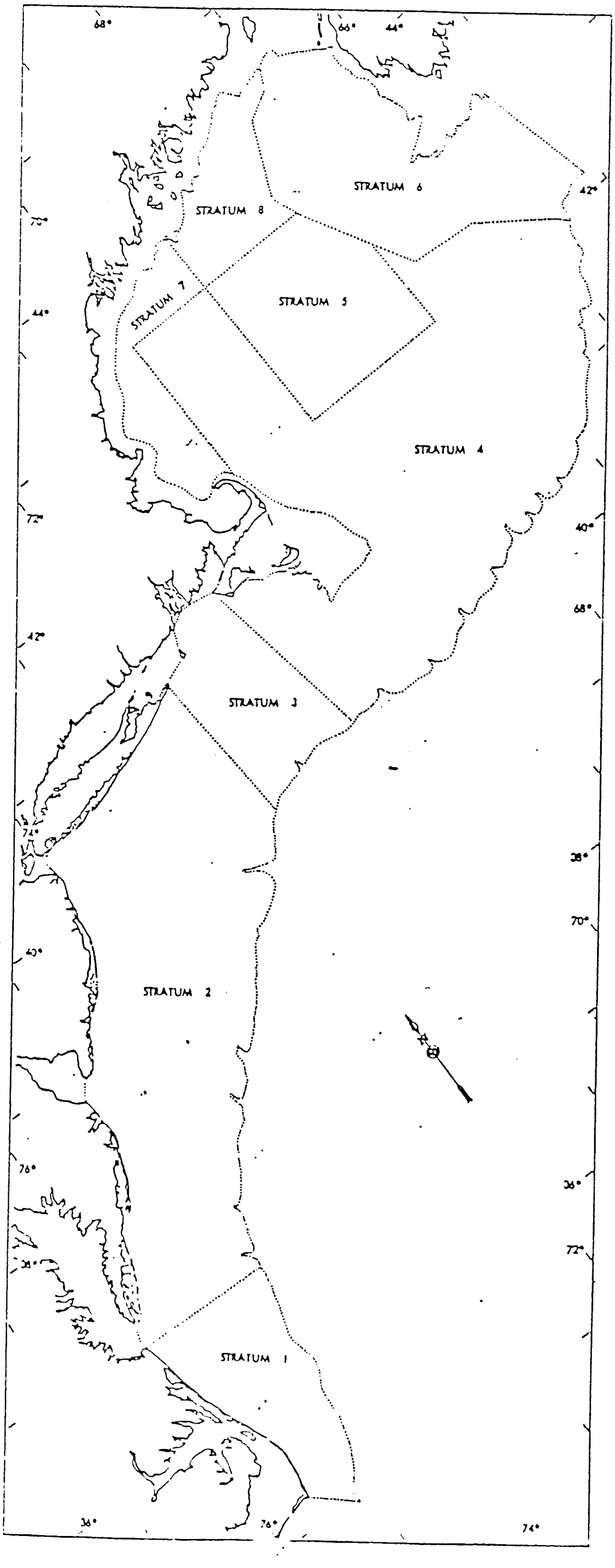

FIGURE 1. -- Total area and stratum boundaries for seven ichthyoplankton surveys (1977).

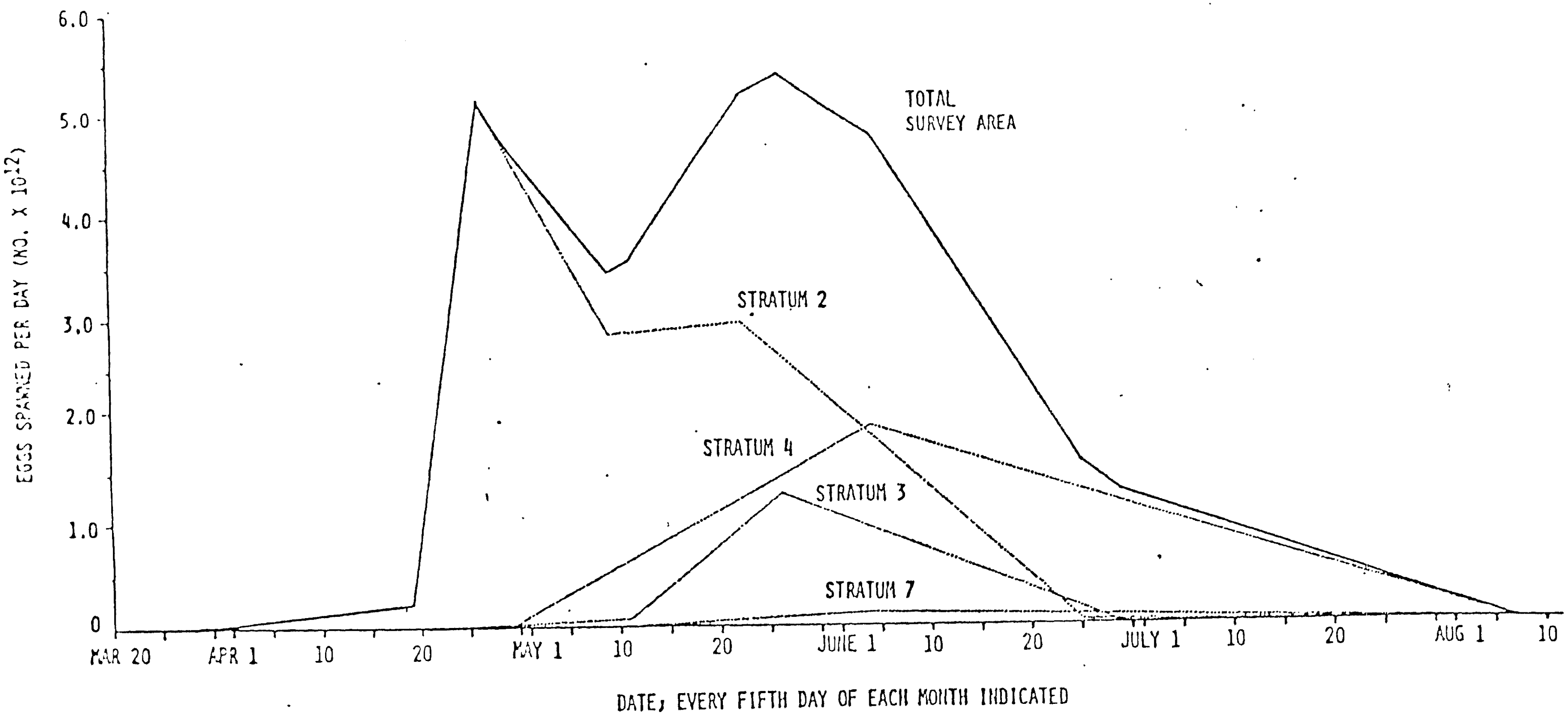

Figure 2. Estimated production curve for Atlantic mackerel in four strata and in the total survey area (1977).

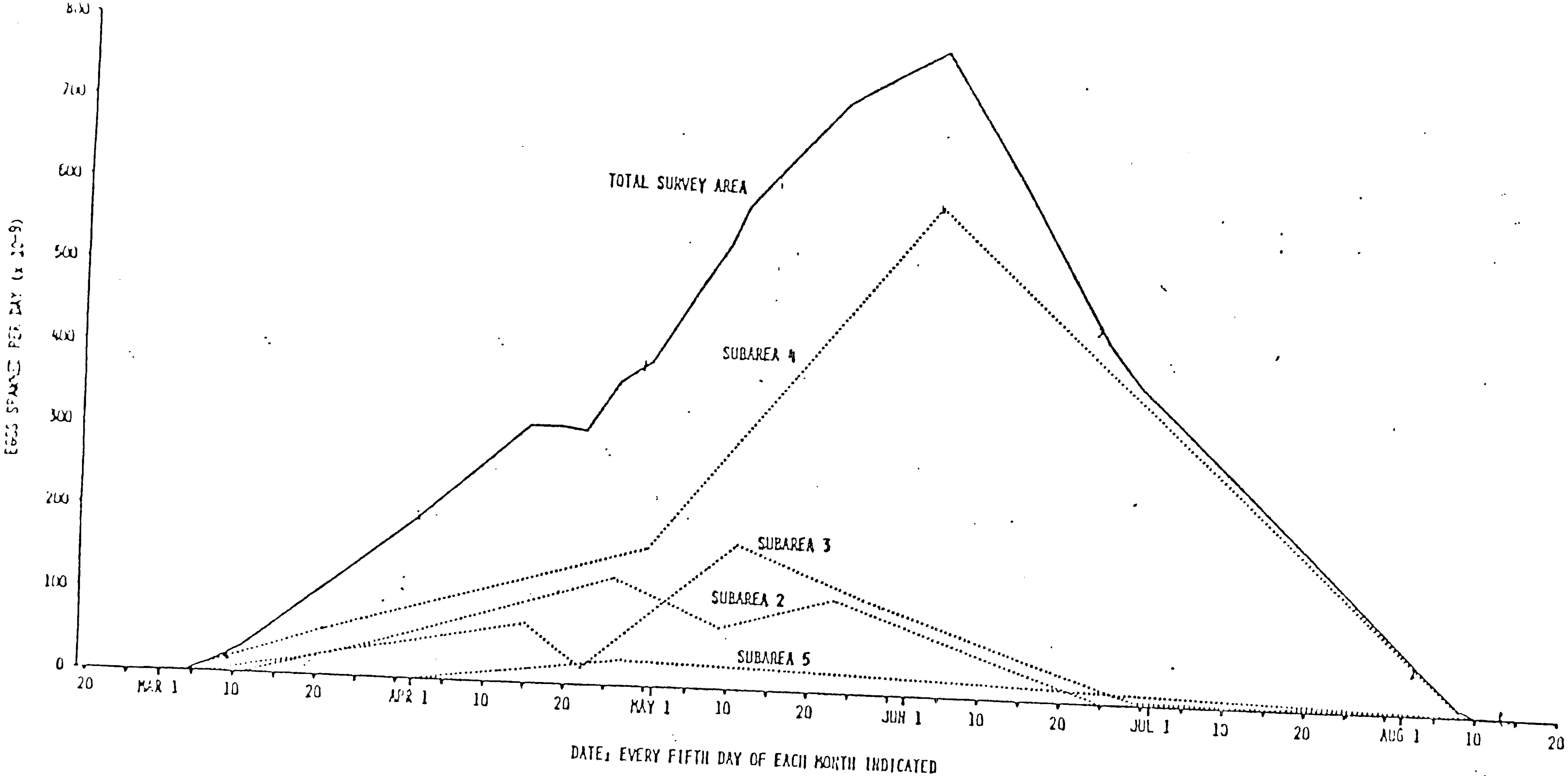

Figure 3. Estimated production curve for yellowtail flounder in four strata and total survey area(1977).

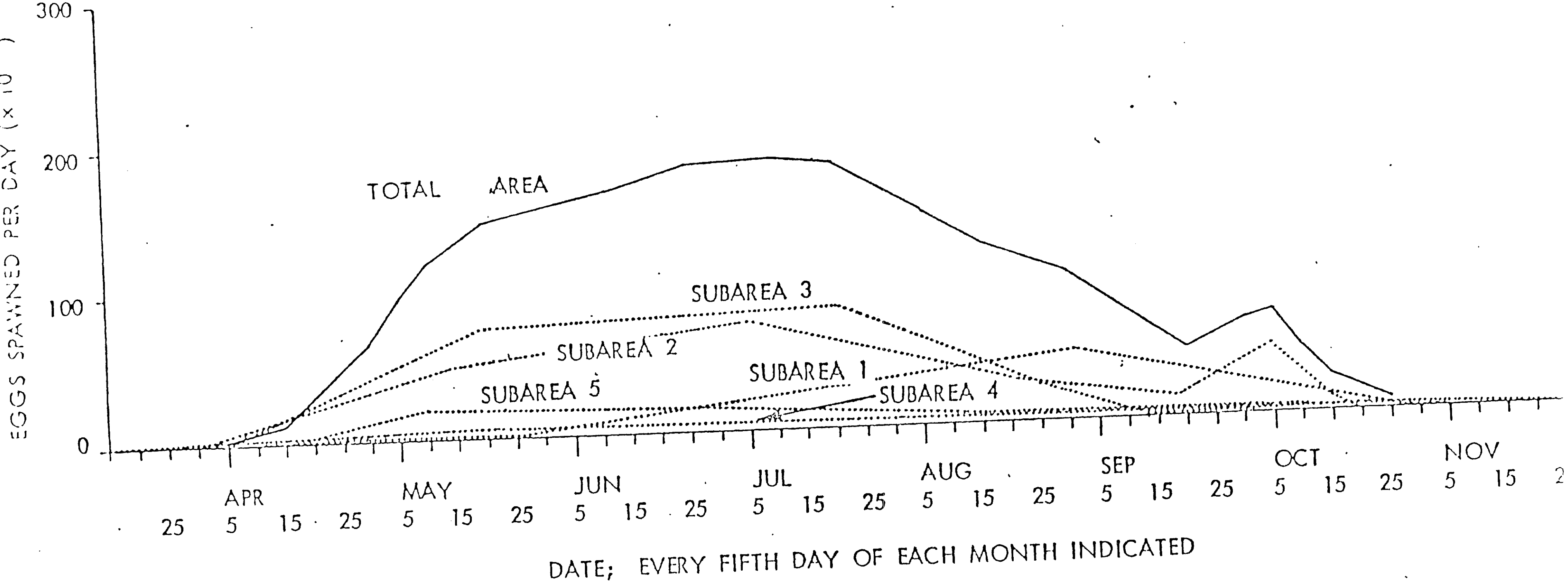

Figure 4. Estimated production curve for silver hake in four strata and in the total survey area(1979).

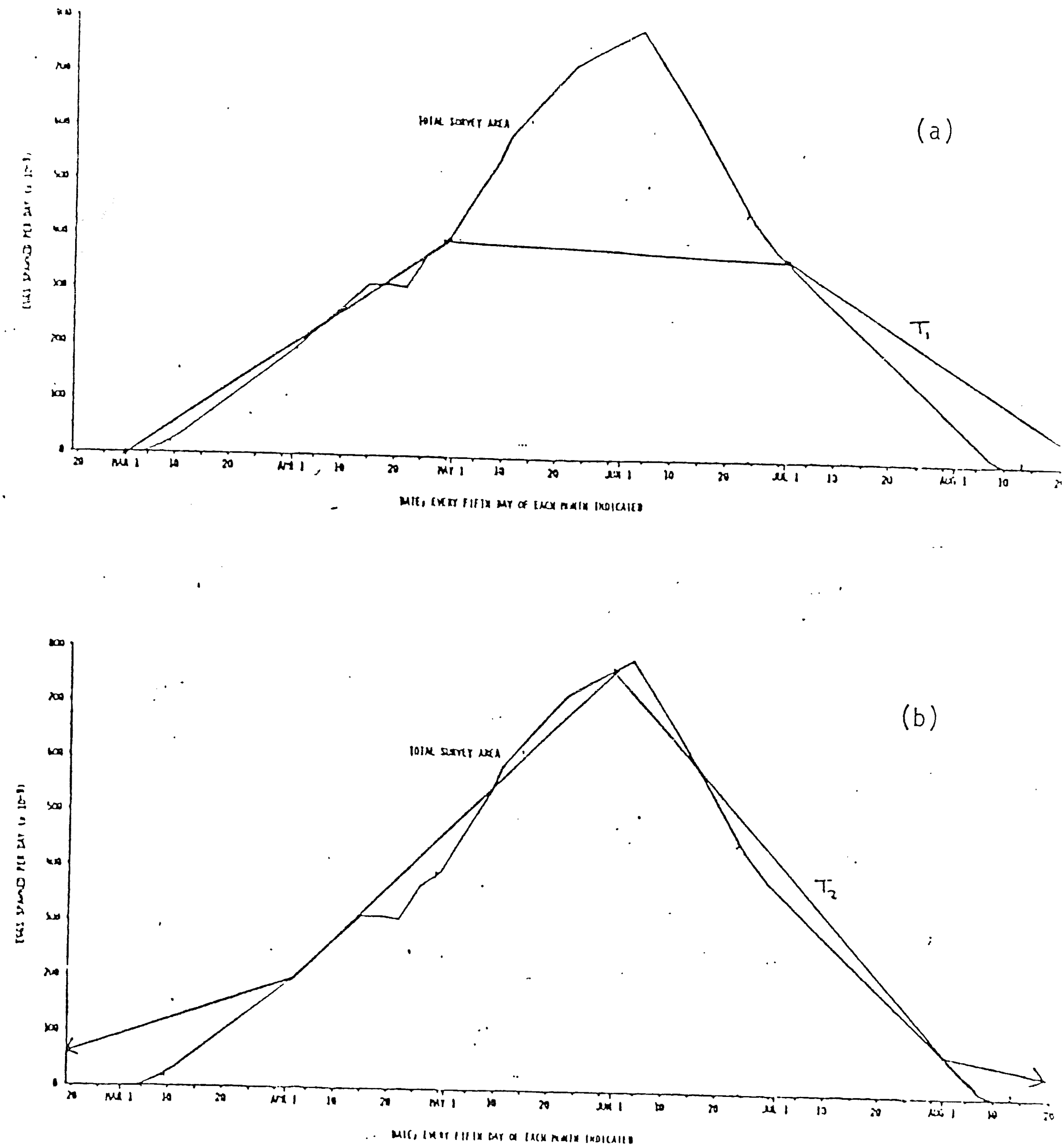

Figure 5. Derivation of the estimates of production from bimonthly surveys starting (a) March 1 and (b) April 1 for yellowtail flounder. Areas under the curves, T_1 and T_2, are the estimates of production.