International Council for the
Exploration of the Sea

C.M. 1987/L:28
Biological Oceanography Committee

REPORT OF THE WORKING GROUP ON LARVAL FISH ECOLOGY

TO THE BIOLOGICAL OCEANOGRAPHY COMMITTEE OF ICES

Hirtshals, Denmark 17-19 June 1987

---

*)General Secretary
ICES, Palgaede 2-4
DK-1261 Copenhagen K
Denmark

Table of Contents

1. PARTICIPANTS

The Working Group convened its fourth meeting at the North Sea Center, Hirtshals, Denmark, on 17-19 June 1987 (Appendix 1). Members present were: J. D. Neilson, CANADA; V. Christensen, Kr. V. Hansen, P. Munk, H. Paulsen, T. Kiorboe, K. Richardson, DENMARK; U. Brenning, GERMAN DEMOCRATIC REPUBLIC; K. Brander, ENGLAND; J. Bartsch, FEDERAL REPUBLIC OF GERMANY; F. Hovenkamp, THE NETHERLANDS; A. Johannesen, E. Moksness, S. Tilseth, NORWAY; M. Heath, SCOTLAND; K. Sherman, USA (Chairman).[1] J. Neilson (St. Andrews), M. Heath (Aberdeen) and K. Brander (Lowestoft) kindly served as rapporteurs for the meeting.

2. TERMS OF REFERENCE

The meeting provided a forum for ICES scientists studying larval fish ecology to compare the results of their studies and evaluate strategies for obtaining a better understanding of the recruitment process during the early life stages of fish. Discussions focused on the following terms of reference (ICES C. Res. 1986/2:31):

2.1 To evaluate the results of recent studies on larval herring growth and mortality in relation to circulation and recruitment processes in the North Sea.

2.2 To evaluate recent progress in linking the results of ichthyoplankton predator-prey studies to the recruitment process within the Scotian Shelf and Georges Bank ecosystems.

2.3 To review progress in other studies of larval and early post-larval fish ecology undertaken by countries within the ICES area in relation to recruitment processes.

3. RESEARCH ACTIVITIES

Members of the Working Group presented summaries of recent research on larval fish ecology within the ICES area. It was apparent from the presentations that considerable effort is underway on research that is already contributing to important tests of hypotheses on the linkages among the physical, biological, and chemical influences on the recruitment of new cohorts of fish, in the ICES area.

The Working Group papers that served as the focus of the review and evaluation are included in the Annex. The presentations provided a lively forum for discussions and set the framework for the evaluation of the research strategies and hypotheses under investigation.

---

1. Should additional information be desired, a list of the addresses of the meeting attendees is given in Appendix 2.

Projects listed below are presently underway.

3.1 **Canada**

3.1.1 Fisheries ecology program on Browns Bank haddock

- physical/chemical/biological oceanographic studies
- spatial and temporal variation in egg and larval abundance, vertical distribution, horizontal distribution, and drift; otolith microstructure

3.1.2 Silver hake investigations on Scotian Shelf--joint program with U.S.S.R.

- "0" group abundance surveys used to calibrate VPA analyses
- trophic interrelations studied by gut contents analysis

3.1.3 Studies on cod and haddock on Georges Bank

- vertical distributions of eggs and larvae determined and the consequences for advection and grazing considered
- interactions of larvae with ectoparasites
- vertical migratory behavior of juvenile cod and haddock studied, and the consequences for prey selectivity considered

3.1.4 Herring studies in the Bay of Fundy

- larval surveys for VPA calibration
- juvenile surveys for abundance estimation
- examination of spawning strategies in relation to hydrographic features

The annual fall Bay of Fundy and southwest Nova Scotia larval herring survey completed its standard grid of 163 stations. Additional sampling for chlorophyll and water clarity was made at several stations for comparison with satellite sea surface temperature and color images. In addition, a new cooperative program was begun with scientists from the U.S. Maine Dept. of Marine Resources to investigate the transboundary nature of the herring population in coastal waters of eastern Maine and southwestern New Brunswick. Three surveys were conducted (early September, late September, late October) to locate major herring spawning sites in the Bay of Fundy and central coastal Gulf of Maine, and to examine the subsequent dispersal of larvae. Detailed hydrographic information and samples of potential larval food organisms were also collected.

Canadian studies on herring included: analysis of southwestern Scotian Shelf and Bay of Fundy larval herring survey data from 1972-1985 to determine its

reliability and precision as an indicator of parent stock abundance, and for comparison with similar data for the eastern Atlantic; theoretical studies on stock concepts in marine teleosts and stock structures in Atlantic herring; studies on the use of the terms "passive drift", "migration", and "retention" in relation to the distribution of plankton; and stock-recruitment relationships in Atlantic herring.

3.1.5 Other studies

- examination of flatfish stock structure from Scotian Shelf Ichthyoplankton Surveys

Information on the distribution and timing of appearance of flatfish eggs on the Scotian Shelf, obtained during the Scotian Shelf Ichthyoplankton program, was used with other data to examine whether existing management boundaries adequately reflect stock structures of these fishes. Preliminary results indicate the present management units are less than optimal. Larvae of winter flounder were sampled during spring and summer from an estuary adjacent to the mouth of the Bay of Fundy to examine their horizontal distribution and feeding relationships relative to the numerous, but transient, riverine fronts that occur in this area. An investigation of the potential for regular exchange of ichthyoplankton between Georges and Browns Banks has also been initiated, with particular application to stock structure and recruitment problems in these two regions.

3.2 **Denmark**

Danish recruitment research (1984-1987) is focused mainly on herring in the North Sea.

3.2.1 Laboratory studies

Various aspects of herring larval ecophysiology are being examined:

3.2.1.1 Feeding ecology and food selectivity of larval herring

Experiments have been conducted on initiation of exogenous feeding upon exhaustion of yolk reserves; feeding during the larval stage and growth at low, naturally occurring food concentrations (5-10 nauplii or 1 copepodite per liter).

3.2.1.2 Digestion physiology of herring larvae

Radioimmunological methods have been implemented to study the dynamics of digestive enzymes. Experiments have been designed and carried out to study which chemical and mechanical cues trigger the release of trypsinogen in the larval gut.

3.2.1.3 Growth energetics of herring embryos and larvae

Rapid growth and an efficient utilization of available food seem to be crucial for the survival of fish larvae in the sea. Empirical studies and theoretical considerations have shown that herring larvae and probably fish larvae in general are particularly efficient compared to other, similar sized planktonic organisms in transforming assimilated matter into body mass.

3.2.1.4 Related studies

- improvement of copepod cultivation techniques for improvision of larval prey in laboratory experiments. "Cold-preservation" of copepod eggs.
- development of methods for field estimates of production of larval food (copepods, secondary production) on a routine basis.
- development of immunological methods for field studies designed to identify larval predators.

3.2.2 Field studies

3.2.2.1 Field experiments during the last four years have been conducted between September and February. Early autumn studies have been carried out in the northwestern North Sea ("Buchan area"). Later in the season the study area has been extended to cover larger areas of the North Sea. The experiments have included:

- patch studies aimed at estimating growth and survival rates
- studies of the relationship between hydrography and the distribution and drift of larvae
- studies of the relationship between hydrography and plankton-dynamics aimed at identifying the larval food environment
- studies of current speed and direction using moored buoys

3.2.2.2 Denmark also routinely participates in the annual ICES International Herring Larvae Survey in September and the International Young Fish Survey and IKMT Survey in February.

3.3 **England**

3.3.1 Open sea investigations

- large-scale ichthyoplankton surveys for assessment of herring, mackerel, sole, and nephrops
- dispersion and survival studies on herring larvae in the central North Sea

- comparative study of North Sea and Irish Sea ecosystems in relation to the disparity in fish production between the two areas. A joint program with IMER, MBA (Plymouth), and School of Ocean Sciences Menai Bridge

3.3.2 In-situ experimental studies

- in-situ enclosures used in a pilot study designed to examine predation pressure on herring larvae in an estuarine situation

3.4 **France** (See Appendix 3)

3.5 **Germany, Federal Republic**

3.5.1 Fertility studies

- North Sea sole (Rosenbloom C.M. 1985/G:69, 70)
- North Sea sprat (Alheit C.M. 1986/H:58 and C.M. 1987)
- Baltic Sea, Bornholm Basin, cod and sprat (Mueller started)

3.5.2 Feeding ecology

- simultaneous sampling of larvae and food organisms, biochemical analysis for identification of nutritional status for herring larvae in southern and northern North Sea, and for mackerel larvae in Celtic Sea (Clemmesen C.M. 1985/L:36; Clemmesen C.M. 1987; Ueberschaer C.M. 1987)
- comparison of food supply and feeding of myctophid and carangid larvae in NW Africa upwelling area

3.5.3 Growth and age structure

- otolith reading, comparison between species and spawning groups of North Sea and Baltic (mainly Baltic herring) (Ndomahina, in progress)

3.5.4 Mortality estimates

- eastern North Sea sprat and dab eggs: daily mortality rate--sprat 60-73 percent, dab 19-41 percent; survival until hatching--sprat 1-0.14 percent, dab 5-16 percent (Lucassen manuscript)
- southern Baltic (Bornholm Basin) cod eggs daily mortality rate 21-29 percent, survival until hatching 0.1 percent (Wieland C.M. 1987)

3.5.5 Vertical distribution and migration

- herring larvae--North Sea (in progress)

- cod eggs--Bornholm Basin (Wieland C.M. 1987)
- mackerel eggs and larvae--Celtic Sea (Roepke C.M. 1987)

3.5.6 Comparative study on the planktonic environment in herring spawning grounds of southern and northern North Sea (Schadt manuscript)

3.5.7 Pollution effects

- viability of larvae related to gonad contamination (Rosenthal et al. C.M. 1986/E:21)

3.5.8 Drift models

- herring larvae--North Sea (Bartsch and Backhaus C.M. 1987)

3.5.9 Future activities

- concentration on recruitment processes in North Sea sprat and herring, and in southern Baltic sprat and cod. Aspects to be considered: fertility, mortality of eggs and larvae, feeding ecology of larvae, growth and age distribution, small-scale distribution in space and time of larvae and food organisms, modelling of larval drift.

- patch study on larval herring development in northern North Sea, September 1987

3.5.10 Oceanic studies (See Appendix 4)

3.6 **The Netherlands**

3.6.1 Field studies on plaice recruitment

- main factors influencing year-class strength identified as operating during egg and/or larval stages

- ctenophores (*Pleurobrachia*) and crustaceans (*Crangon*) identified as major predators during the settlement phase

3.6.2 Field and laboratory program

- examination of otolith increment formation in plaice larvae with the objective of estimating growth and drift rates

3.7 **Norway** (See also Appendix 5)

A multispecies investigation program, HELP (Appendix 5), is being carried out at the Institute of Marine Research, Bergen. The program started in

1986 and studies the distribution of fish eggs and larvae in oil exploration areas north of 62°N. The objectives of HELP are to:

- obtain detailed knowledge of distribution in space and time of the most important commercial fish species during their early life stage along the Norwegian coast
- study the reproductive biology of the same species
- study the recruitment mechanisms of the Norwegian spring-spawning herring and the Arcto-Norwegian cod
- study the physical factors affecting both the transport-dispersion and the living condition of the early life stages of fish.

The program also develops methods for counting growth rings in larval otoliths, besides counting, sizing, and staging of eggs based on pattern recognition method.

At the University of Tromso, one project on cod studies the level of egg quality and survival potential of fish larvae from varying egg quality. In addition, two field studies are being carried out, one on Halibut to determine the natural occurrence and environment of its pelagic larvae/postlarvae, and to study their biology and ecology. The other study is on Arctic fish fauna, with special reference to the Greenland halibut. The study is concentrated on natural occurrence, environment, vertical distribution, size composition, length/weight relationship, and feeding ecology of its larvae.

In addition, the following projects are concerned with rearing techniques:

- Mass culture of plaice fry
- Rearing of Halibut larvae in sub-arctic environment
- Ecology basis for rearing fish fry in differently sized mesocosms.

3.8 **Portugal** (See Appendix 6.)

3.9 **Scotland**

3.9.1 Open sea studies

- larval drift of herring and mixing of populations on nursery areas studied by biochemical genetics.
- advection and dispersion processes. Studies of the linkage between UK shelf hydrography and herring larvae. Studies of meteorological forcing of shelf circulation.
- vertical migration of herring larvae studied in relation to light and mixing processes.

- spatial relationships between herring larvae and production rates of copepods and phytoplankton.
- opportunistic observations of predation by sand eel on newly hatched herring larvae.

3.9.2 Modelling studies

- trophic interactions and modelling of larval and juvenile fish growth and survival
- modelling of grazing behavior and prey size selection by herring larvae
- modelling of the vertical distribution of herring larvae in relation to light and mixing

3.9.3 Experimental investigations

- enclosure studies of predator-prey interactions between larval and juvenile herring in relation to avoidance reaction, prey size, prey starvation, and predator size
- nutritional studies on larval herring--rearing on artificial diets; lipid composition in relation to condition
- "green gut" phenomenon in cod larvae--attributable to digestion of copepod fecal pellets

3.9.4 Assessment related ichthyoplankton surveys

- International Herring Larvae Surveys
- International Young Fish Survey
- Mackerel Egg Surveys

3.9.5 Program for winter 1987-88

The ACE (Autumn Circulation Experiment) Program--study of the overwinter advection and ecology of North Sea herring larvae. A joint program with Denmark and Norway. (See Appendix 7.)

3.10 **United States--Northeast Shelf Ecosystem**

3.10.1 Groundfish recruitment studies in the Northwest Atlantic

- joint investigations with Canada on Georges Bank Ecosystem
- studies on the relationship between demography of eggs and larvae, and subsequent recruitment

3.10.2 Laboratory investigations

- studies on the growth ration of larval and juvenile cod and haddock

3.10.3 Open-sea process studies involving simultaneous sampling of physics and biology

- studies to determine if food concentration on Georges Bank is adequate to support the larval and gadoid populations between March and June

- studies to determine the extent, if any, of catastrophic starvation mortality (none found based on preliminary results)

- studies to determine the extent, if any, of catastrophic mortality due to advection of larvae off Georges Bank (none found based on preliminary results)

3.10.4 Modelling studies

- early results of Georges Bank ecosystem modelling indicate that recruitment is predation controlled at the "O" group stage

3.10.5 Future strategy

- to simultaneously sample larvae, post-larvae, and predators and their biophysical environment in order to describe multispecies predator-prey interactions relative to mortality rates

4. EVALUATION OF COD AND HADDOCK STUDIES

4.1 Canada--Scotia-Fundy Region

Substantial progress was made in field and laboratory studies concerning the ecology of early life history stages of gadids off southwest Nova Scotia and in the Gulf of Maine during 1986.

Analyses of samples collected in 1985 from tidally-mixed and stratified waters of Georges Bank indicate the diel vertical distributions of juvenile (0-group) cod and haddock differ depending on the quantity and type of zooplankton prey available. In the mixed water mass, where prey were abundant, juvenile cod and haddock both occurred deep in the water column and preferred the same type of prey. In the thermally-stratified water mass, where prey were less abundant, juvenile cod and haddock differed in their prey preferences and occupied separate portions of the water column (haddock being shallower than cod), reflecting the vertical distributions of their preferred prey items. These results have substantial implications for the design of surveys for juvenile gadids.

Analysis of these samples also indicated an important interaction between juvenile gadids and the copepod ectoparasite *Caligus* sp. It was found that

juveniles of both cod and haddock were heavily infested with this ectoparasite. However, infestation on haddock was predominantly about the head region, suggesting that *Caligus* sp. ectoparasitism may be an indirect source of mortality for young haddock because they are more liable to predation. *Caligus* sp. were also found to be a significant component of the fishes' diet, particularly for cod at the stratified site where zooplankton were less abundant.

Three field programs involving juvenile gadids were conducted in 1986. The first was a cooperative experiment with United States scientists (National Marine Fisheries Service) on Georges Bank to compare the abilities of the International Young Gadoid Pelagic Trawl and the MOCNESS sampler to collect pelagic 0-group cod and haddock, and to determine potential avoidance reactions to these gears.

This experiment also examined the mesoscale distributions of temperature, salinity, nutrients, chlorophyll, zooplankton, 0-group cod and haddock, and potential predators (dogfish) across a tidal front on the southern flank of Georges Bank. The second field program involved further joint Canadian-U.S. research on juvenile cod and haddock on Georges Bank, but used a submersible to make *in-situ* observations of gadid abundance and behavior. Preliminary results indicate visual observations of abundance were often much higher than estimates derived from research trawls, and that 0-group cod were distributed very close to the bottom during daylight, but made forays off the bottom at night. These cooperative studies are planned to continue in 1987. The third field program involved the annual cooperative Canada-U.S.S.R. autumn survey for juvenile silver hake on the Scotian Shelf. This survey included expanded coverage from the central core area. A general study was also completed examining the use of juvenile fish surveys for obtaining year-class strengths and recruitment estimates, based on surveys for cod, haddock, silver hake, and herring. Changes in availability to survey gear due to diel or ontogenetic vertical migrations pose particular problems for the development of abundance estimates. It was concluded that midwater trawl surveys should be used with caution for estimates of abundance, but are necessary for studies of distribution, behavior and stock structure.

Using data obtained through the Fisheries Ecology Program, the influence of vertical distribution of haddock eggs and larvae through a variable current field on horizontal distribution was described. Advection of eggs off of Browns Bank in a northerly direction was described, along with a tendency for later egg stages to be found deeper in the water column than early stages. Possible ecological implications of those observations included spatial coincidence with prey of suitable size, and in the vertical sense, avoidance of predation. The results indicate a need to revise the hypothesis of retention of haddock eggs and larvae on Browns Bank, recently suggested in the literature.

Laboratory studies of gadid ecology involved examination of larval cod condition when exposed to various prey densities. The weight/length index was not correlated with prey density for early larvae, while body height standard-

ized for length appeared to be a more sensitive index of larval condition. The ability of a larva to avoid a simulated predator was positively correlated with rearing prey density. The results of a buoyancy experiment indicated poorly fed larvae may occur nearer the water surface, and thus be more vulnerable to predation, or cause a sampling bias in ichthyoplankton studies. Further techniques such as energy release, RNA/DNA ratios, and histological examination are now being used to assess condition of larval cod and haddock reared under various feeding regimes. Two of these techniques have not previously been applied to these species.

4.2 **Northeast Continental Shelf Ecosystem groundfish recruitment studies**[2]

The Northeast Fisheries Center of the National Marine Fisheries Service has been studying the recruitment problem for Northeast Continental Shelf Ecosystem groundfish stocks for the past 15 years. The overall strategy of the research has been to view the problem within the context of marine ecosystem studies with a goal of providing the scientific basis for multispecies fisheries management. A three-tiered approach has been used incorporating mesoscale time-series, process-oriented field studies, and laboratory research activities focused on the early stages of the first year of life. The chronology of this strategy had its inception with mesoscale survey cruises for early life history stages under the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program. Concurrent with the MARMAP surveys were experimental laboratory studies to establish the critical quantitative and functional parameters of developmental physiology and trophodynamics of eggs and larvae. Process-oriented field research was carried out in the ICNAF larval herring program.

In 1980 these three research approaches were brought together in a coordinated effort to study cod and haddock larval growth, survival, and recruitment on Georges Bank. The results of previous laboratory work, field work, and literature surveys were used to formulate hypotheses about larval starvation and prey requirements for successful growth and survival. Modelling was used as a tool to synthesize the results of this research. In 1982, ancillary field research was conducted to determine the effects of advection of water off the continental shelf by warm core rings on survival of early life stages of fishes. The information gained from these studies was considerable; however, it did not reveal a single dominating factor controlling variable survival during the egg or larval stages.

The lack of consistent critical mortality mechanism in the egg and larval stages, coupled with modelling efforts and estimation of field mortality rates pointed toward the possibility of predation-controlled mortality of gadids during the juvenile stage. Therefore, in 1984, the emphasis of recruitment

---

2. Excerpted from the document - "Proposed Strategies for Recruitment Research on Haddock and Cod within the Northeast Continental Shelf Ecosystem" by G. C. Laurence, E. Cohen, M. Grosslein, and R. G. Lough. National Marine Fisheries Service, Northeast Fisheries Center, Narragansett Laboratory Reference No. 87-02 (MARMAP Contribution FED/NEFC 87-03).

research was shifted to sampling juveniles in the field and determining their predators and predation rates. Through May of 1987, a great deal about the biology of juveniles and their distribution on Georges Bank has been learned; recent observations indicate that predation by other demersal species on haddock juveniles may be extensive.

Based on these findings, studies planned for the 1988 through 1990 period will be focused on quantitative measures on mortality for both haddock and cod from the egg stage through the juvenile stage. The studies will include a rigorous reevaluation of the density-dependent and density-independent sources of variability in the levels of mortality among annual recruitment cycles of the 1988, 1989, and 1990 year classes. Considerable effort will be directed toward the testing and evaluation of samplers suitable for quantitatively sampling juvenile stages of haddock and cod. The full text describing the evaluation of studies on the early life stages of haddock and cod is given in Appendix 8.

4.3 Norway

Arcto-Norwegian cod stock recruitment studies

The Institute of Marine Research in Bergen has been studying the recruitment problem for the Arcto-Norwegian cod stock for the past 11 years. The spawning behavior of the stock has been monitored for the past 10 years. The spawning season starts in late February, early March, and ends early in May. The peak spawning, however, is very stable and fixed in time to the 1st week of April. More than 50% of the egg biomass is spawned during a 14-day-period.

The spawning stock migrates from the Barents Sea to the Lofoten area, Northern Norway. During migration the spawning stock follows the transition layers between the Norwegian coastal current and the Atlantic water masses, which have a constant temperature and salinity all through the year. More than 60% of the Arcto-Norwegian spawning stock spawn in the in the Lofoten Archipelago Area. The eggs ascend to the surface after fertilization and are trapped in the Norwegian Coastal Current. The eggs and larvae are transported northwards to the nursery grounds in the Barents Sea by the Norwegian Coastal Current.

The environmental conditions in the Norwegian Coastal Current are strongly influenced by meteorological conditions, particularly during winter/early spring. Southwesterly winds, associated with the passage of depressions, increase water temperature, cause upwelling, and occasionally reverse the current system in the Vestfjord. This area is recognized as the main spawning site in the Lofoten Archipelago. These features lead to retention of eggs and larvae in the Vestfjord, which has better feeding conditions than the open ocean water on the west side of the Lofoten Archipelago. Northeasterly winds, on the other hand, cause low water temperature, downwelling, and increased current speeds. These conditions lead to increased egg incubation time and rapid transport of eggs and larvae out of the Vestfjord area. Most of the eggs will consequently hatch on the west side of the Lofoten islands,

which has lower average food particle densities than the Vestfjord area. A study of the recruitment processes has been carried out in the coastal current ecosystem in this area. This study has included environmental factors, circulation patterns, production of prey organisms, feeding, and egg and larval mortality estimates.

A comparison between long-term observations of the mean March temperature in the Vestfjord and the year-class strength calculated from VPA analysis has shown that strong year classes are never produced in years of low temperatures. Both strong and weak year classes, however, are produced in years with higher water temperatures.

Mortality estimates of egg and early larval stages compared with post-larval and 0-group abundance indices has shown that the year-class strength is established during the first two months after peak spawning. These findings strongly indicate that critical-mortality mechanisms in the egg and larval stages point toward environmentally-controlled mortality as regulatory factors in year-class variability.

5. EVALUATION OF THE NORTH SEA HERRING STUDIES

5.1 Denmark

North Sea Larval Herring, 1984-1986

A spawning area off the Scottish east coast has been studied for a three-year period. Estimates have been made of larval growth and survival, and relationships between hydrographic processes, distribution, and drift of larvae and plankton dynamics (food environment).

The spawning grounds in the Buchan area are located near a horizontal density discontinuity, or front. Although the front is primarily a consequence of the interaction between tidal mixing and water depth, its precise location and intensity depends on heat input and wind mixing events. Patches of newly-hatched larvae can be found both in the frontal region, itself, and in the isothermal water located to the west of the front. Newly-hatched larvae appear to be transported towards the front. Thus, the largest concentrations of ca. 7-9 mm larvae are recorded in the frontal region, itself, and these larvae appear to be transported south/southeast along the frontal boundary. Movement of larvae along the boundary has been calculated to be of the order of 2-4 km d^{-1}.

Primary and secondary production (measured as calanoid egg production) and, thus, the production of the larvae's prey items, tend to peak in the frontal region. By November, larvae are distributed throughout the western North Sea and copepod egg production has fallen to virtually nill.

Special emphasis has been devoted to consideration of larval food competition as a potential mechanism of density-dependent regulation of recruitment. Comparisons between estimates of the proportion of the water mass that larvae may clean for food particles per day with estimates of daily

known rates of potential food organisms (copepod eggs, copepods, and other ca. 50-500 l size plankton organisms) have revealed that the two are of the same order of magnitude in the centers of larval distribution. The implication is that herring larvae in the Buchan area may, at times, significantly impact on the abundance of potential food organisms and, thus, potentially compete for food.

Spawning in the Buchan area seems to take place in distinct pulses over a somewhat prolonged period (1-1.5 months) of time and on at least 3 or 4 local spawning grounds. Thus, groups of herring larvae are widely distributed in the area. The changes in larval distribution, size, and abundance were followed through a series of extensive surveys over a prolonged period of time (2-5 weeks). Effort has been put into development of analytical techniques to separate larval cohorts based on size, distribution, and horizontal distribution information. Estimated mortality rates are fairly low, 3-5% d^{-1}. Estimates of growth rates show that growth increases with larval size, from ca. 0.15 to ca. 0.25 mm d^{-1} for 10-16 mm larvae, and suggest that larvae are limited by food availability.

5.2 Germany, Federal Republic

Advection of larvae: numerical simulation of the advection of herring larvae in the North Sea

By means of a 3-D nonlinear numerical finite difference model, the circulation of the North European shelf sea is calculated (1969-1982). The effects of the tide, stratification, and wind stress are included in the simulations.

The data derived from the circulation model serves as a basis for an advection + diffusion model, which simulates the drift of tracers across the North Sea from spawning to nursery grounds. The tracers simulate herring larvae and the simulation includes an active part (besides the passive drift), which is a simple model of light dependent vertical migration.

Results of the simulations show, firstly, the importance of the variable meteorological forcing (on the drift route taken and endpoint reached in February) and secondly, the importance of the vertical distribution of the larvae (Bartsch et al., 1987). A comparison of model results with larval distributions from IYFS surveys showed that a favorable circulation is a necessary condition for recruitment success, but not a sufficient one, i.e., other factors must also play an important role. Finally, hypotheses and questions are formulated which should be addressed by marine biologists.

The simulation of the advection of larvae is a powerful tool for addressing the problem of recruitment and the role circulation plays in that process, and should be included in forthcoming recruitment studies.

References: Backhaus and Bartsch, ICES C. M. 1985/C:30 and Bartsch and Backhaus, ICES C. M. 1987 (to be published ICES 1987.

5.3 Scotland

Herring larvae hatching in September and early October on the Continental Shelf north and west of Scotland are closely associated with the Scottish Coastal Current and their distribution is delineated by that of water of salinity less than 35.1. The coastal current originates as a low salinity outflow from the Irish Sea, Firth of Clyde, and west of Scotland Sea lochs, and is driven by the density difference between the inshore waters and water of Atlantic origin from further offshore. However, the flow may be moderated by wind events over the northeast Atlantic which have a significant effect on sea level gradients, and also by tidal rectification.

Larvae hatching from spawning beds close to the current zone (e.g., west of the Outer Hebrides, Sule Skerry) may be rapidly advected around the north of Scotland and into the North Sea. Residual drift velocities of up to 12 km/day have been observed. However, larvae from other, more inshore spawning sites (e.g., Cape Wrath) may not be advected so quickly, and can be found in near-shore waters off the North of Scotland, at least until late November. A preliminary study of the genetic relationships between recently-hatched larvae from sites around the U.K., and overwintered larvae in the North Sea the following spring, has provided some direct evidence of a significant contribution to the late larval population in the North Sea by spawning areas to the west of Scotland.

The vertical distribution of herring larvae during their transport by the Coastal Current has been studied in the area west of the Orkney Isles. The core of the current in this area is in the boundary between isothermal and stratified water, and in this situation the larvae are restricted to the surface mixed layer. In the isothermal water inshore of the current, larvae are distributed throughout the water column. In this case the center of mass of the larvae is dependent upon wind-induced mixing processes, whilst in both environments the larvae show positive phototrophism, being more aggregated during daylight than at night. The responses to light and mixing processes may have important consequences for the coincidence in space of larvae and their prey items. The results of the field observations on vertical distribution variability are being used in a modelling exercise. This is intended to be the first step towards the ability to accurately represent herring larvae as actively migrating tracers in an advection and circulation model (see contribution from FRG).

The horizontal spatial relationships off the north of Scotland between herring larvae and primary and secondary producing particles in the water are very complex. However, in general, primary and secondary producers are inversely related in their distribution whilst the larvae are most abundant inbetween the zones of high phytoplankton and copepod zooplankton biomass. The interactions of vertical distribution of larvae and prey items in the water column, daily illumination cycles, and prey size are being considered in a modelling study. Early results and comparisons with open-sea observations of gut contents and in-situ growth rates indicate a reasonable degree of success by this approach.

Enclosure experiments have been conducted on the susceptibility of herring larvae to predation by both passive (*Aurelia*) and active (juvenile herring) predators. Initial studies were aimed at investigating the hypothesis that starvation resulted in an increased susceptibility of larvae to predation by *Aurelia*. These experiments were subsequently repeated using the active predator. The results did not indicate any significant increase in vulnerability as a result of starvation, and confirm the conclusions of laboratory bench type video studies carried out at the SMBA Laboratory in Oban. However, the enclosure experiments were susceptible to more than one interpretation due to variations in the size of larvae used in replicate studies. More recent experiments have therefore been carried out to examine the question of larval size in the relationship and these are continuing.

In relation to predation studies, some opportunistic observations in the Firth of Clyde (west coast of Scotland) have indicated the possible significance of sand eel (*Ammodytes*) as a predator on newly-hatched herring larvae. During a grab survey of a spring spawned egg bed in shallow water (16 m) on Ballantrae Bank, sand eels were captured together with eggs and substrate. During the egg-hatching period these fish were found to have large numbers (several hundreds) of newly-hatched larvae in their stomachs, but there was no evidence of predation by sand eels directly on the eggs.

Other experimental studies in progress, or recently concluded, include:

- a study of the "green gut" phenomenon in cod larvae, now believed to be a consequence of ingestion of copepod faecal pellets. The nutritional significance of these observations is unknown.

- lipid/fatty-acid composition of herring larvae in relation to nutritional status.

- rearing of herring larvae on artificial diets. Six weeks survival in the laboratory on a pelleted diet has now been achieved.

5.4 **Evaluation of the results of recent larval herring growth and mortality studies within the North Sea Ecosystem in relation to circulation features and recruitment processes.**

Within the last 3-4 years, two hypotheses, in particular, have stimulated great debate as to the origins of recruitment variability in North Sea herring. First, was the "retention" hypothesis of Iles and Sinclair, which was originally based upon observations of herring larvae distributions on Georges Bank in the northwestern Atlantic (Iles and Sinclair, 1982). Second, was the "advection failure" hypothesis of Corten (1985, 1986). In the first case, the observations on Georges Bank were extrapolated to the North Sea and it was suggested that larvae were retained within areas delineated by tidal fronts, and that the size retention area determined maximum biomass for a particular stock. In the second, it was noted that the change from poor recruitment by the 1976-1978 year classes in the North Sea, to a good recruitment in subsequent years was correlated with a major distributional change in the late larval stages in February. The so-called "anomalous" distributions in the

mid-late 1970's were attributed to unusual circulation in the North Sea.

In 1985, Backhaus and Bartsch presented the results of an advection simulation model designed to account for the drift of larval herring in terms of a 3-dimensional hydrodynamic model of the North Sea driven by wind fields. The latest developments in this model were presented to this Working Group by the FRG representative. This important contribution to the recruitment studies on North Sea herring has two major implications for the so-called "retention" and "advection failure" hypotheses. First, larvae are only retained within the tidally energetic regions suggested by Iles and Sinclair, under very specific vertical migration conditions, and in the Orkney/Shetland area, retention seems most unlikely under any circumstances. Secondly, years in which "larvae" in the advection model were unsuccessful in reaching the so-called nursery areas in the southeastern North Sea also corresponded to observations of poor recruitment. However, the converse was not true. In other words, "successful" advection is necessary but not sufficient for the survival of larvae.

The conclusions of the Backhaus and Bartsch model of larval drift with regard to the likelihood of retention phenomena, are supported by the open-sea field observations of advection carried out by participants in this Working Group (See reports by Denmark, England, and Scotland).

Both the Corten "advection failure" hypothesis, and the advection model require some assessment of the suitability of various regions of the North Sea for the subsequent survival of overwintered larvae. So far, this has been based upon the supposed distribution of metamorphosed "0" group fish later in the year (June/July) which appears to be predomi-nantly in shallow water (<10 m) off the Danish coast, and close inshore off the Scottish east coast. However, there is little appreciation of the probability of survival of a larva metamorphosing in the central part of the North Sea, or in particular, how far from the shallow water environment an individual would have to be before it would then be unable to survive an active swimming migration to reach that site.

The advection model also regards all areas of the North Sea as equally favorable for the survival of overwintering larvae during the advective period. In practice, the studies on grazing, and the production rates of potential food items carried out by Danish and Scottish participants in the Working Group indicate that this is probably not the case. Certain hydrographically-defined regions appear to be particularly productive during the 1-2 months immediately post-hatching, and significantly, the distribution of larvae in the areas studied generally corresponded to the areas of highest productivity.

Observations of the late autumn/early winter production of potential prey organisms indicates that this is negligible, so that overwintering larvae are presumably dependent upon standing biomass for food supply. However, timing of the onset of primary and secondary production processes in the spring appears to vary between the shallow areas of the southern and central North Sea, especially the Dogger Bank, where significant production was ob-

served in late February 1987 (Danish results) and the northern North Sea where the onset is at the end of March/early April (historical records). Preliminary observations of the stomach contents of larvae in February (Scottish and Danish results) support a theory that the timing of the onset of spring production may be significant for the growth and/or survival of larvae since the quantity and diversity of items in the stomachs of southern larvae was greater than in larvae from northern areas.

In conclusion, there have been very significant advances towards an understanding of recruitment in North Sea herring, particularly with regard to the modelling activities in FRG. Field investigations have provided important verification of the advection processes, and information on the spatial and temporal relationships between larvae and their prey. However, advection variability is not sufficient in itself to account for the recruitment variability. Starvation has not been directly implicated as a significant factor, but there are no indications as to the origins of any predation mortality.

An extremely important point to come out of the advection modelling is the significance of vertical distributions for the advection of larvae. There have been some studies of vertical migration behavior (see Scottish results) but there is a requirement for a better understanding of this, including the ontogenetic variability. This aspect of larval ecology will be investigated in detail during a joint field program to be undertaken by Danish, English, Norwegian, and Scottish scientists during the winter of 1987/1988.

6. CAUSES OF MORTALITY IN EARLY LIFE

The national reviews of results describe many different kinds of studies directed at finding the causes of mortality in early life. The participants attempted to group and discuss these under the generic headings of predation, advection, starvation, and competition, but in many cases mortality is due to a combination of factors and cannot be classified as simply as this.

Predation is viewed as a major factor in regulating recruitment in the NW Atlantic, where it may operate after the pelagic stage. Recent U.S. groundfish recruitment studies on Georges Bank have attempted to quantify this predation mortality on juvenile gadoids, but there are considerable sampling problems.

Canadian work suggests that juvenile cod and haddock (particularly the latter) may become more prone to predation as a result of heavy infestation by an ectoparasite (*Caligus* sp.).

Work in the Netherlands has identified *Pleurobrachia* and *Crangon* as predators on larval plaice during immigration and settlement, but they probably do not have a major effect on recruitment.

Advection and hydrographic conditions can affect survival indirectly by carrying larvae away from feeding areas, dispersing their food, bringing them into contact with predators, or slowing their growth rate. Norwegian studies of cod larvae in the Vestfjord show that short-term advective changes, caused

by the passage of weather depressions, affect survival rates. These studies are particularly interesting because they suggest that recruitment is determined within two months of spawning, and because very short-term (3-4 day) meteorological events may play a part. In the case of recruitment of North Sea herring, advective processes may also be a factor, but the time scale is much longer (perhaps six months). In both of these cases, particular environmental conditions may be necessary for good survival (and recruitment), but not in themselves sufficient: "good" environmental conditions can result in either good or bad year classes if other factors intervene.

The numerical simulation of the advection of fish larvae can be applied to many species and shelf areas where advection seems to play a role in recruitment. The major limiting factor is the availability of a suitable three-dimensional circulation model for the specific area of interest. For the North Sea this model is available (Institute fur Meereskunde, Hamburg) and has been used to study the advection of herring larvae in the North Sea and there is a possibility of using it for other species.

Competition and starvation are implicated as potential causes of mortality in Danish studies on Buchan herring. Grazing rates by herring larvae are of the same order as production rates of potential food organisms.

7. RECOMMENDATIONS

7.1 Terms of Reference for Workshop on Otolith Microstructure of Young Fish

It is proposed that a workshop on the otolith microstructure of young fish be convened at the Northeast Fisheries Center, Woods Hole. Timing would be five days in September, 1988. The convener will be Dr. R. G. Lough.

Recent important work has been completed in the field of otolith microstructure examination, which has taken investigations beyond the routine examination of correspondence between increment formation and days. These new advances include age-structured estimates of larval drift, condition, and precise estimates of survival. The time is now opportune to review these significant new advances, and to reassess the utility of otolith microstructure examination for studies of larval ecology. [illegible] will include such applications, related co[illegible] methodology, new techniques, and the effects of environmental variables on increment formation would also be welcome.

Since the meeting will be in a workshop format, participants are encouraged to bring examples of their own preparations. In cases of species where problems have been perceived in interpretations of otolith microstructure, such as Arcto-Norwegian larval cod, interested parties should bring sufficient material to allow the workshop to conduct "blind" comparisons, and allow other scientists to prepare their own material using various techniques.

7.2 Request for Assistance from the Fish Capture Committee

Following a discussion of the problems of obtaining quantitative samples of pelagic fish larvae and demersal 0-group fish, the group recognized that it would be useful to have help from scientists working on gear technology and fish behavior. It is proposed that the Fish Capture Committee be requested to discuss this matter, suggest how their expertise could be brought to bear and report back to the Biological Oceanography Committee.

There are several different sampling requirements and a number of different gears in use, but certain problems are common and could benefit from a coordinated approach through ICES.

Three specific requirements are:

- sampling of large, pelagic larvae (for which the Methot Isaacs Kidd (MIK) trawl has come into fairly widespread use),
- sampling 0-group fish on or close to the bottom, and
- gear for obtaining vertical profiles of larvae.

The Working Group was concerned that where new gear is being developed it should be calibrated, used in a standard way, and its performance should be evaluated in relation to the species and size range, which it is intended to sample. This will require consideration of gear design, instrumentation (e.g., devices for measuring volume sampled) and fish behavior.

The possibility of cooperation through ICES to evaluate gear should be explored. This could involve the use of flume tanks, high frequency acoustics, video observation, and various gear comparisons.

7.3 Comparative Studies of Cod and Haddock

There is a strong case for applying comparative studies of larval fish ecology to the recruitment problem (e.g., Bakun, 1985). The Working Group thought it useful to prepare a checklist of characteristics of spawning and larval life, which could be used as a basis for comparing stocks of a species from different areas. The purpose of such a checklist would be to provide a background for each stock and to outline the factors, which appear to affect recruitment variability. For example in the northeast Atlantic, cod spawn early in the year and the areas in which they spawn may be related to the areas where primary production starts early. The checklist may help to clarify this relationship, and also to refine the hypotheses concerning the links between primary and secondary production and year-class success in cod. Such hypotheses may require quite radical rethinking if they are to explain the apparently different spawning strategy of cod in the NW Atlantic.

The Working Group proposed that the checklist should initially be applied to cod and haddock, and K. Brander (Lowestoft) offered to act as coordinator. Contributions for any North Atlantic cod or haddock stock would be wel-

come, as would suggestions for amplifying and improving the checklist. It would be useful if the information contained in the checklist could be from publications.

All contributions would be circulated with copies of all checklists on condition that unpublished data could only be used with permission of the person supplying it.

Checklist of biological and environmental data for comparing spawning strategies of stocks in different areas

Species:

Stock and area distribution:

Timing of spawning: date, year-to-year variability; time of day; timing in relation to the production cycle and in relation to other fish species.

Location of spawning: geographic location, extent and variability; location in relation to hydrographic features and in relation to other species (including potential food producers); larval drift and retention.

Biological details: fecundity; egg size; typical egg and larval densities; incubation rate; size of larvae at hatching, size of yolk sac in relation to total larval size; larval development rate; egg and larval mortality rate; first feeding of larvae and food composition.

Recruitment: stock to which they recruit and whether they are the only contributor, a major contributor, a minor contributor, or a variable contributor? Evidence of year-class variability (e.g., from young fish survey of VPA). Earliest time when year-class strength can be predicted. Hypotheses to account for year-to-year variability. Linkages with other species (e.g., predation, competition, linked fluctuations in recruitment).

Bakun, A. 1985. Comparative studies and the recruitment problem: Searching for generalizations. CalCOFI Rep. Vol. XXVI, 1985.

7.4 Terms of Reference for Next Meeting

The participants recommended that the Working Group should reconvene in Aberdeen for a period of three days in June during 1989 with the following terms of reference.

7.4.1 Review recent interdisciplinary approaches (biology, hydrography, and modelling) in larval fish ecology studies to the recruitment problem, with special emphasis on the significance of advection and predation processes.

7.4.2 Review the results of the effort to obtain a check list of spawning characteristics in relation to the ecology of early life stages of cod and haddock from different ecosystems.

The primary objective of the Working Group is to review current status of research on early life history problems, and help focus and direct national research efforts. Given the infrequency of Working Group meetings and the lack of similar opportunities for discussions with scientists from the entire ICES area, nations involved in such activities are urged to participate.

APPENDICES

APPENDIX 1 - Agenda

ICES Working Group on Larval Fish Ecology
Nordsøcentret, Hirtshals Denmark
17 to 19 June 1987

17 June 1987

0900	Greetings and Briefing on the Nordsøcentret	V. Hansen
0915	Meeting objectives in relation to the ICES terms of reference; appointment of rapporteurs	K. Sherman
0930	Brief Overview: Growth and Survival in Early Life History Stages- Hypothesis Testing At-Sea and in the Laboratory	National representation
1030	Coffee Break	
	Belgium: Studies and Results	National
	Denmark: Studies and Results	representation
	Norway: Studies and Results	
	Iceland: Studies and Results	
	The U.S.S.R.: Studies and Results	
	Finland: Studies and Results	
1200 - 1300	Lunch	
1300 - 1830	England: Studies and Results	
	The Netherlands: Studies and Results	
	Scotland: Studies and Results	
	The Federal Republic of Germany: Studies and Results	
	Canada: Studies and Results	
1830	Adjourn	

18 June 1987

0900 - 1200	Ireland: Studies and Results	National
	France: Studies and Results	representation
	Poland: Studies and Results	
	Portugal: Studies and Results	
	Spain: Studies and Results	
	The United States: Studies and Results	
	Other pertinent studies	
1200	Lunch	
1330 - 1500	Summary and generic classification of studies as possible contributions to ICES Recruitment studies	
1500 - 1700	Reporting Assignments for Other Items	

19 June 1987

0900-1200	Finalize summary reports of larval fish ecology studies in the North Sea Ecosystem; Barents Sea Ecosystem; Norwegian Sea Ecosystem; Irish Sea Ecosystem; Iberian Ecosystem; Baltic Ecosystem; Northeast Continental Shelf Ecosystem; Scotian Shelf Ecosystem; Labrador Ecosystem
1200 - 1300	Lunch
1300 - 1830	Review Reports and Consider Future Coordination
1830	Adjourn

APPENDIX 2 - Participants

NAME	ORGANISATION	PHONE/TELEX
John D. Neilson	Canada Dept. Fisheries & Oceans St. Andrews, N.B. Canada E06 x 0	(506) 529-8854
Villy Christensen	Danish Institute for Fisheries and Marine Research Postbox 101 DK 9850 Hirtshals Denmark.	08-944500 Telex 67765
Kr. Vagn Hansen	Danish Institute for Fisheries and Marine Research, Postbox 101 DK 9850 Hirtshals Denmark.	08-944500 Telex 67765
Peter Munk	Danish Institute for Fisheries and Marine Research, Charlottenlund Castle DK 2920 Charlottenlund, Denmark.	01-628550 Telex 19960
Helge Paulsen	Danish Institute for Fisheries and Marine Research, Postbox 101 DK 9850 Hirtshals Denmark.	08-944500 Telex 67765
Thomas Kiørboe	Danish Institute for Fisheries and Marine Research, Charlottenlund Castle DK 2920 Charlottenlund Denmark.	01-628550 Telex 19960
Katherine Richardson	Danish Institute for Fisheries and Marine Research, Charlottenlund Castle DK 2920 Charlottenlund Denmark.	01-628550 Telex 19960
Keith Brander	Fisheries Laboratory, Lowestoft Suffolk, U.K. nr 33 OHT	0502-62244
Joachim Bartsch	Institut für Meereskunde Hamburg, W. Germany Troplowitz Str.7, 2000 Hamburg 54	4123-5748
Ulrich Brenning	Wilhelm-Pieck University Rostock Freiligrathstr. 7/8 DDR-2500 Rostock	

NAME	ORGANISATION	PHONE/TELEX
Frans Hovenkamp	Netherlands Institute for Sea Research P.O. Box 59 1790 AB Den Burg, Texel The Netherlands.	(0) 2226-541
Arne Johannesen	Department of Fisheries Biology University of Bergen P.O. Box 1839 N-5024 Bergen, Nordnes Norway.	
Erlend Moksness	Biological Station Flødevigen N-4800 Arendal, Norway	+4741.20580
Snorre Tilseth	Institute of Marine Research P.O. Box 8170 N-5011 Nordnes, Norway.	47 5 327760
Mike Heath	Marine Laboratory P.O. Box 101, Victoria Road Aberdeen, Scotland.	(0224) 876544
Kenneth Sherman	National Marine Fisheries Laboratory, Narragansett Rhode Island, USA.	401 782 3211 Telex 927512

APPENDIX 3. Prepared by A. Herbland, IFREMER, Nantes Cedex, France

The French research on recruitment is concentrated on three species in selected ecosystems, based on a multidisciplinary approach (biotic and abiotic) and involves laboratory and in situ research.

SOLE

The area of study is the northern part of the Bay of Biscay.

Adults: Fecundity.

Egg and larvae: Distribution and abundance by annual surveys.
Estimation of mortality rates.
Effects of starvartion on growth. Indexes of starvation: RNA/DNA, ATC, morphological, histological, lipids, and free amino acids.
Ageing and quality of growth with otoliths lecture.

Metamorphosis and Post-larvae: Distribution and mechanisms of colonisation of nursery relative to tidal cycles, river flow and nycthemeral cycles.

Juveniles: Abundance and distribution of groups 0, 1 and 2 in 3 nurseries - hypothesis of the limiting trophic capacity to be tested.
Genetic polymorphism (electrophoresis and multivariate analysis).

CIRESOL. CIRCULATION AND RECRUITMENT OF SOLE (see section 3.2.2.2)
Joint study of physical and chemical oceanography.

SCALLOP

The area of study is the "Baie de St. Brieuc" (north Bretagne).

Adults: Influence of the external factors on the sexual maturation and spawning: temperature and nutrition effects on atresia and allocation of energy and viability of gametes.

Larvae: Distribution and abundance: vertical distribution - relation with thermal gradients and tidal cycles.
Nutrition: effect of starvation on growth and mortality. Rythms of nutrition (in situ studies).
Ageing.

Post-larvae and juveniles: Growth, fixation, competition with other species and predation.
Estimation of abundance by a new sampler (AQUAREVE).

OYSTER

Two areas of study: "Bassin d'Arcachon" et "Bassin de Marennes-Oléron".

Adults: (Marennes-Oléron)	Influence of external factors on Gamatogenesis.
	Quality and viability of gametes.
Larves: (Arcachon)	Role of environmental factors on the growth and mortality.
	Trophic capacity of the bassin.
	Role of nanoplankton: quality and quantity - experimental studies of grazing. Competition with other grazers.

HISTORICAL STUDIES

Program CLIMAPECHE - Long-term studies of the fisheries fluctuations in relation to climate variations.

Species:	Herring, sardine, mackerel.
Area:	French fisheries.
Parameters:	Air temperature, water temperature, river flows, winds and pressure variations.

TROPICAL STUDIES

Shrimps in Senegal: relationship between salinity (via the rain intensity) and the recruitment; capture and the migration of shrimps in the estuary of the river Casamance. (and French Guyana)

Sardinella of Congo, Ivory coast, Senegal. Identification of critical phases.

ACADEMIC STUDIES ON NON COMMERCIAL SPECIES

1. A multiparametric study (plankton, benthos, current measurements, sediment dynamics and modelisation) is in progress in the eastern part of the "Baie de Seine". The objective is to study the feasibility of following the emission, the dispersion and the fixation of eggs and larvae of four common benthic species (one bivalve and three polychaetes).

2. Various recruitment-related studies in the "Bassin d'Arcachon" on mollusques (three species), crustaceans (two species) and polychaetes (three species).

   These studies include: process of dissemination, estimation of mortality, energetic measurements in larvae, biochemical analysis for geographical links, role of hydrodynamics near the bottom, importance of substrate type, allocation of energy.

3. Growth and nutrition in larvae of urchins (Villefranche/Mer).

1/ Scallop : *Pecten Maximus* (from J. BOUCHER)

During the last two years, 8 spawnings and 7 cohorts of larvae and post larvae were produced by the Pecten's population in the "Baie de St Brieuc" (west channel).

Some spawnings gave low numbers of larvae (early july 1985) or no larvae (late june 1986). The number of larvae depends on the quality of the ovocytes. The quality of the first spawning in the season depends on the coincidence between the energetic cycle (germinal/somatic) of the adult and the window (temperature of the water) allowing the reproduction. In that window the number of spawnings and their quality depend on the temperature and food avaibility. This process changes from one year to the other with hydrobioclimatic conditions.

For example, the number of spawnings leading to a larval cohort has been reduced from 5 to 2 from 1985 to 1986 and the cycle was 15 days later in 1986. The same delay was observed in the temperature and phytoplankton cycles.

Conclusion

The first source of variation of recruitment is linked with the variation of the real fecundity induced by the external energetic conditions. This process leads to a secund source of variation, according to the date of production of the last cohorts. Their survival depends of the time of growth before winter and probably of the winter conditions.

The second source of variation takes place at the level of larval and post larval stages, also linked with meteorological conditions : it is the dispersion by circulation acting in different ways :

(1) transport of larvae out of the sites allowing the fixation or out of the Bay ;

(2) transport of the larvae on sites more or less propitious to the survival of the cohorts during their first year.

2/ Sole : *Solea vulgaris* (very preliminary results after two years of study)

At the opposite of Pecten, it seems that the fecundity would not be a "critical stage" : the individual variations, ± 20 % in three different geographic areas (Mediterrannée, Bay of Biscay, Channel) are low comparing with later variations in the cycle.

For the larval stages, the following scenario can be proposed : the adults spawn preferentially in march (february to early april) in offshore water at a depth of 50 to 70 m, where the temperature is always higher than 8-9° C. The eggs (with high mortality) and larvae seem to stay on the area during several weeks and show the picture of diffusion processes.

Physical and behavioral studies are in progress to study the mechanism of such a "retention" (ILES and SINCLAIR's hyothesis) and how the larvae go to the coastal nurseries.

Ageing and indice of starvation (experimental and in situ) are also in progress, but difficulties in obtaining larvae in laboratory in 1986 have lead to start again in 1987, with success : important results and comparisons of age, size, morphological, histological and biochemical indices of starvation are expected.

Temperature seems to be the signal of colonization of estuaries and bays, according to high tidal coefficients.

Nycthemeral vertical migrations are clear. The larvae are planctonic during the night and benthic during the day. The tidal vertical migrations are less obvious.

From the analysis of stomach contents, it can be concluded that the food is benthic, thus the vertical migration have not a trohic origin.

When the predator *Pleurobrachia* sp is abundant, no larvae are sampled : exclusion process or predator-prey relationship ? The former seems to be likely.

For the juveniles stages (in the coastal nurseries) the importance of the variability in sampling has been particularly studied (see report).

High variability from year to year have been observed in the numbers of juveniles and the decrease of the year strenght.

In certain limits, there is no correlation between the number of group 0^- and II^-. In that case, the egg larval abundance would have little effect on the year strenght.

P. S. : In early 1987, the cruise CIRESOL has been performed on the spawning area. It was a clear technological success : 7 fixed moorings with maregraphs, current meters, thermistances chains, 9 drifting Argos buoys, during 7 weeks. One month of cruise with Bongo and collaboration with canadian scientists (FORTIER and GAGNE) with the Bioness and V Fin.

The vertical and horizontal distribution of currents and hydrological variation will be assess and compared to the vertical and horizontal distributions of eggs and larvae. Samples for indice of starvation and age have been also preserved as well as microzooplancton, chlorophyll and nutrients.

Results next year !

UNIVERSITÄT HAMBURG

INSTITUT FÜR
HYDROBIOLOGIE UND
FISCHEREIWISSENSCHAFT

Institut für Hydrobiologie und Fischereiwissenschaft
Olbersweg 24, D 2000 Hamburg 50

Prof. Dr. W. Nellen

Informal Report of the Research on Larval Fish Ecology by Dr. Nellen's group at the University of Hamburg.

- Part of the present METEOR cruise is aimed at small scale distribution and variability of fish larvae and plankton. It is a joined programme of fishery biologists and planktologists and both groups study intensively under comparative aspects three areas in the Arabian Sea, each of which is different in its ecological charakter. In every area grids, 80 by 40 sm in size, are repeatedly surveyed to get an idea about the biological structure within the upper 100 to 150 m of the epipelagic zone where most of the fish larvae spend their early life period and which, therefore, should be important for larval survival. Distribution of plankton and ichthyoplankton is resolved vertically and horizontally with help of a modified MOCNESS we have constructed especi-

ally for this expedition. A "Multi Net" is used to catch the small plankton organisms which may serve as larval fish food. Further, sedimentation rates of plankton is collected simultaneously at different depths with help of 3 sediment traps, the variability of plankton and detritus sedimentation, respectively, over time can be resolved by these traps also because they work with rotating buckets, the revolution rate of which can be timed.

Aside of distribution and variability questions we will analys stomach contents of the larvae and their histological and biochemical status (see below). Of interest is whether different ecological situations do cause different morphological and physiological features in the larvae. An important question is how species are adapted to changing environmental conditions. With help of a newly designed big post larval net we hope to get access to little fish which metamorphose or have metamorphosed already to get an idea about fish-fish predation.

You find a description of the whole expedition's programme attached. Larval fish research is done during legs 3a to 3c.

- Biochemistry of fish larvae are subjects of a research project, started two years ago. An improved highly sensitive, rapid and easy to handle procedure for determination of the nutritional state on fish larvae is described. A technique has been found which allows to measure proteolytic enzyme activities in the individual fish larvae. Another approach to determine their nutritional condition are RNA / DNA analyses. The ratio of both is a good indicator. A method, to analyse single larvae was found as well. As both methods are useful tools to test the "starvation" hypothesis we now are going to work with them in the field, for instance on board of R.V. METEOR just now. Before this analyses have been done on larvae reared in the lab under different conditions.

- With help of the MOCNESS vertical stratification and patchiness of mackerel eggs and larvae have been investigated on the western spawning ground a year ago. The results indicate that mackerel eggs have stage-depending vertical distribution patterns. The existence of a diurnal length-depending vertical migration pattern of mackerel larvae is clearly shown. Parallel to this mackerel eggs had been sampled repeatedly by a Gulf III sampler on a 30 by 30 sm grid to determine variability of distribution patterns which may cause problems in the egg sensus for stock assessment. The samples are still being sorted.

- Comparative analyses of plankton composition and plankton biomass in the Orkney-Shetland and the English Channel area were done during the time when in each of the regions herring larvae were abundant, i.e. September and January, respectively. Four years, 1982 to 1985 were investigated and compared. Diversity of the zooplankton was much higher in the northern area and so was plankton density. Biomass of net plankton was 0.2g dry substance . m^{-2} in the southern area and 2.0 g dry weight . m^{-2} respectively, in the northern one. Though herring larvae had to live under quite different conditions in any of the two regions stomach analyses did not show any difference with regard to good or bad feeding conditions.

- Studies on age and growth by analysing ring structures at larval otholits is subject of a current Ph.D. thesis. On one hand different species of larvae, partly caught in the sea, partly grown in labs, are investigated to find out differences in the characters of ring structures, on the other hand larval populations of two distinct herring stocks (Downs- and Schlei-Fjord) are compared with regard to their growth pattern. Both grow up under very different ecological conditions, the one in a highly productive area where densities of herbivorous copepods are extremely high during the appearance of the herring larvae. The conditions under which the larvae of the other stock have to survive are almost contradictory.

- In lake Starnberg the feeding conditions of coregonid larvae have been investigated during two time periods, a) when the larvae which hatched in the lake itself appear in the water and b) when 50 - 100 Mio larvae which hatched in hatcheries at very low temperatures are stocked relatiively late in the year into the lake. Feeding conditions for the larvae which originate from the hatcheries seem to be better as zooplankton densities were much higher in May compared to March. Larvae catches, done with a ringtrawl towed just below the surface during the day at stations scattered over the whole lake gave an estimate that about 90% of all larvae originate from the hatcheries. So, they contribute very likely substantially to stock recruitment. Why larvae born in the lake itself are so rare is not known yet. I think that the hatching rate of eggs incubating under natural conditions is very low.

- A rich ichthyoplankton material caught along a section 300 sm long, and perpendicular to the Equator in the middle of the Atlantic Ocean was analysed. The section had been sampled repeatedly over about 6 months in 1979. With the help of cluster analyses ichthyoplankton communities which varied by time, hydrography, and area, as well could be discriminated. Three distribution patterns of species were found:

- species which appeared at distinct places and periods, (Gonostomiatidae, Myctophidae, Sternoptychidae)
- species, which were more abundant north of the Equator (Paralepididae, Scombridae, Nomeidae)
- species which are especially found south of the Equator (Gobioidae, Bothidae).

It has not been yet tried to find correlations between the composition of certain fish larvae groups and environmental parameters. Altogether 190 species and 62 families have been identified in the area.

- A joined survey on sprat larvae and the environmental conditions under which they grow up have been discussed between Stephen Coombs, Jürgen Alheit, Dietrich Schnack and myself. Comparative investigations will be done in the Irish Sea, the North Sea, and the Baltic. We hope to establish a research project on this which will be supported financially to exchange scientists and students for more intensive communication.

APPENDIX 5

FISH LARVAE INVESTIGATIONS IN NORWAY

by

Erlend Moksness
Biological Station Flødevigen
Institute of Marine Research
4800 Arendal, Norway

A. SINGLE SPECIES INVESTIGATIONS

The different prosjects are grouped according to species. Types of investigations (field, enclosure, laboratory etc.) are speciefied for each prosject.

Cod

Project: Egg quality and larval survivial potential in marine fishes.

1. Objective: Field studies indicate that as much as 30% of young stages of fish eggs may have morphological and chromosomal abberations to such an extent that they will not survive. The aim is:
- Investigate the level of egg quality, both in situ and in large spawning tanks, through the spawning season.
- Study the survival potential of fish larvae from varying egg quality.

2. Participants: Elin Kjørsvik, Department of Aquatic Biology, Institute of Biology and Geology, University of Tromsø, Norway.

3. Area: The activity will include both field studies in fjords near Tromsø and experimental studies.

4. Activity in 1987: Experimental studies of egg quality and larval functional development and survival in cod (Gadus morhua). Morphological observationsof the quality of eggs from a spawning cod stock kept in a large enclosure.

5. Litterature: Kjørsvik, E. & S. Lønning 1983. Effects of egg quality on normal fertilization and early development of the cod, Gadus morhua L. J. Fis. Biol. 23: 1-12.

Kjørsvik, E., A. Stene & S. Lønning 1984. Morphological, physiological and genetical studies of egg quality in cod (Gadus morhua L.). In: E. Dahl, D.S. Danielssen, E. Moksness and P. Solemdal (Editors), The Propagation of Cod, Gadus morhua L. Flødevigen rapportser., 1, 1984: 67-86.

Herring

Project: Ageing herring larvae

1. Objective: Ageing Atlanto-Scandian Herring larvae by daily zones in their otoliths. Software and hardware based upon similar equipment at Southwest Fisheries Center, La Jolla, USA.

2. Participants: Tom Andersen, University of Oslo, and Erlend Moksness, B.S. Flødevigen.

3. Area: Laboratory.

4. Activity in 1987: Develop software program for Apple Macintosh computer and test the program

5. Reporting: None

Plaice

Project: Mass culture og plaice fry.

I. Objective: Stocking of natural habitats and fish farming habitats to exploit biomass.

2. Participants: Stig Skreslet, Nordland Research Institute, Bodø

3. Area: Research Laboratory, Nordland College, Bodø.

4. Frequency: Running project.

5. Activities: 1986: Initial testing of combined hatching and nursery tank, and air-lift feeder regulating the release of artemia nauplii
1987: Technical preparations in new laboratories
1988: Feeding experiments with artemia and algal suspension.

6. Reporting: Internal report series, Nordland Research Institute, Bodø.

Halibut

Project: Rearing of halibut (Hippoglossus hippoglossus) larvae in a sub-arctic environment.

1. Objective: Investigate growth and survival of halibut larvae in sub-arctic conditions, by using large plastic bags (10) floating in the sea. The larvae are given a diet of natural zooplankton enriched with cultured phytoplankton.

2. Participants: Elin Kjørsvik, Department of Aquatic Biology, Institute of Biology and Geology, University of Tromsø, Norway. Chris Hopkins, Department of Aquatic Biology, Institute of Biology and Geology, University of Tromsø, Norway. Tore Haug, Department of Marine Biology, Tromsø Museum, University of Tromsø, Norway. Gjørn Gulliksen, Department of Marine Biology, Tromsø Museum, University of Tromsø, Norway.

3. Area: The experiment is carried out at Blåmannsvik Research Station near Tromsø.

4. Activity in 1987: The experiments were started in April 1987.

Project: In situ studies of the pelagic larvae of some Arctic fishes with special emphasis on Greenland halubut (Reinhardtius hippoglossoides).

1. Objective: The University of Tromsø is engaged in studies of Arctic fish fauna. As a part of these studies, the natural occurrence, environment, vertical distribution, size composition, length/weight relationships and feeding ecology of the larvae of

some Arctic fishes, with special emphasis on the commercial important Greenland halibut, are investigated.

2. Participants: Inger-Britt Falk-Petersen, Institute of Fisheries, University of Tromsø, Tromsø, Norway. Bjørn Gulliksen, Department of Marine Biology, Tromsø Museum, University of Tromsø, Norway. Tore Haug, Department of Marine Biology, Tromsø Museum, University of Tromsø, Tromsø, Norway. Elin Kjørsvik, Institute of Biology and Geology, University of Tromsø, Tromsø, Norway. Wim Vader, Department of Zoology, Tromsø Museum, University of Tromsø, Norway .

3. Area: The west coast of Spitsbergen from Isfjorden to Smeerenburgfjorden.

4. Activity in 1987: Ichthyoplankton trawl surveys (also with registration of hydrographical data) in Spitsbergen coastal areas in July/August.

5. Litterature: Falk-Petersen, I.-B., Frivoll, V., Gulliksen B., Haug, T. & Vader, W. In subm. Age/size relations and food of two snailfish species, Liparis gibbus and Carproctus reinhardti, from Spitsbergen waters. Polar Biol.

Project: In situ studies of Atlantic halibut (Hippoglossus hippoglossus)
larvae.

1. Objective: To determine the natural occurrence and environment of Atlantic halibut pelagic larvae/ biology and ecology.

2. Participants: Bjørn Gulliksen, Department of Marine Biology, Tromsø Museum, University of Tromsø, Tromsø, Norway. Tore Haug, Department of Marine Biology, Tromsø museum, University of Tromsø, Tromsø, Norway. Stein Hjalti Jakupsstovu, Fiskirannsoknarstovan, Debesartrød, Torshavn, The Faroes. Svein Sundby, Institute of Marine Research, Directorate of Fisheries, Bergen, Norway.

3. Area: Finnmark in Northern Norway and the Faroe Bank areas to the west of the Faroes.

4. Activities in 1987: Ichthyoplankton trawl surveys (also with registration of hydrographical daga) in Finnmark, North Norway in March and May.

5. Litterature: Haug, T. & Sundby, S. 1987. A preliminary report on the natural occurrence and ecology of Atlantic halibut, Hippoglossus hippoglossus, postlarvae and young immature stages. ICES CM 1987. Demersal Fish Committee, in prep.

Turbot

Project: Ecological basis for rearing fish fry in different-sized mesocosms.

1. Objective: To understand the phytoplankton and zooplankton succession patterns in enclosures ranging from 10 $m^3$to 100 000 m^3, and to manipulate abiotic parameters in order to channalize energy-flow through potential prey organisms.

2. Participants: Cand. scient. Kjell Naas, marine ecology, modelling phytoplankton. Cand. scient. Leif Berg, marine ecology, zooplankton.

3. Area/Frequency: Monitoring: 1982 - 1980
Manipulation: 1984 - 1988
Modelling: 1987 - 1990
Reporting: 1988 - 1990

4. Activities in 1987: A 23000 m predator-free, seawater pond has been fertilized from February to June, resulting in a very high production and a high zooplankton concentration of almost exclusively Acartia. In June 500 000 newly hatched turbot larvae were released and monitored.

5. Status/Reporting: The break-through achieved in 1983 on cod-fry rearing was reported at ICES CM 1993 - 1985.

B. MULTI SPECIES INVESTIGATIONS

HELP
The Egg- and Larvae Programme
of
Institute of Marine Researc, Bergen, Norway

Background: New oil and gas field on the central and northern Norwegian continental shelf are now at the stage of exploration. To a large extent these areas overlap with the distribution area of the fish eggs and -larvae of the most important commercial species. In 1986 a national programme to study the consequences on fish eggs and larvae of oil exploration north of 62°N was established. The programme is given the acronym HELP (Havforskningsinstituttets Egg- og larveprogram) and is supposed to last for five years. In addition to the Institute of Marine Research's own resources, external yearly fundings of approximately USD 1.2 million is put into the programme.

1. Objectives

The objectives of HELP is to:

- obtain detalied knowledge of the distribution in space and time of the most important commercial fish species during their early life stage along the Norwegian coast.
- Study the reproductive biology of the same species.
- Study the recruitment mechanisms of the Norwegian spring-spawning herring and the Arcto-Norwegian cod.
- Study the physical factors affecting both the transport-dispersion and the living condition of the early life stages of fish.

2. Strategy and methodology: The following elements are included in the programme:

- Investigations on spawning area, spawning period and spawning/hatching pattern and intensity.
- Investigation on the distribution in space and time of fish eggs and -larvae. Their distribution will be monitored until 4-5 months after hatching.
- Investigations on the circulation pattern on the shelf as a function of external forces like fresh water outflow, wind and bottom topography.
- Development of both dynamic numerical and laboratory models to describe the transport and dispersion of the spawning products.
- A recruitment mechanism study including environment, production of prey organisms, feeding, mortality, vertical migration etc. is carried out on the Norwegian spring-spawning herring and the Arcto-Norwegian cod.

The sampling equipments include vertical plankton nets, 1 and 10 m^2 MOCNESS, in situ plankton pumps, water bottles and pelagic trawls. A number of Argos drifting buoys are used to map the circulation pattern.

trawls. A number of Argos drifting buoys are used to map the circulation pattern.

Methods of automatic counting of primary growth rings in larval otholiths are in progress. Plans are made for counting, sizing and staging of eggs based on the pattern recognition method. A genetical, biochemical (isoelectric focusing) approach for identification of eggs has been developed.

APPENDIX 6

ICHTHYOPLANKTON STUDIES IN PORTUGAL AT INSTITUTO NACIONAL DE INVESTIGAÇÃO DAS PESCAS, PORTUGAL.

by

Maria H. AFONSO
Emília CUNHA
Plácida LOPES
Teresa MOITA
Teresa NETO

Instituto Nacional de Investigação das Pescas
Av. de Brasília. Algés-Praia
1400 Lisboa. PORTUGAL

Pedro Ré

Departamento de Zoologia e Antropologia
Faculdade de Ciências da Universidade de Lisboa
Rua da Escola Politécnica
1200 Lisboa. PORTUGAL

ICHTHYOPLANKTON PROJECTS ALONG THE PORTUGUESE COAST

Sardine, *Sardina pilchardus*(Walbaum), fishery in Portugal is one of the most important fishing activities with 50% of the total fish landings. The stock, generally accepted as being one for management purposes, has been evaluated, since 1979, by the Working Group for the Appraisal of Sardine Stocks in Divisions VIIIc and IXa of ICES through Virtual Population Analysis (V.P.A.) and more recently by acoustic methods. It was recognized by the representatives of that Group the necessity of an independent fishery method to provide a stronger basis for the assessment and management of the sardine stock.

Several ichthyoplankton surveys were carried on since 1978 in Divisions VIIIc and IXa of ICES along the portuguese coast.

1. Ichthyoplankton Surveys between Cabo Espichel and Vila Real de St° António (1984).

In 1984, three ichthyoplankton surveys were undertaken in April, May and June along the southwest and southern coast of Portugal (Figure 1). The aims of these surveys were:

(i). to study the distribution and abundance of fish eggs and larvae;
(ii). to relate ichthyoplankton data with physical and chemical environmental parameters;
(iii). to attempt the estimation of the main spawning areas of several fishes with economical importance in Portugal - sardine , hake, *Merluccius merluccius* (L.), horse mackerel, *Trachurus trachurus* (L.) and mackerel (*Scomber scombrus* L.).

The samples were collected using a Bongo 60 (333 and 505 µm) and FAO nets (505 µm). Larval stages belonging to 30 different families were sampled. The most abundant species was sardine. Concentration of more than 2000 eggs /m² were found about 100 meters depht, in front of Lagos (April) and near Sines (June).

Results concerning sardine larvae showed that they were most abundant (concentration of more than 100 larvae/m²) in May, south of Sines, at 20 meters depht and in front of Vila Real de St° António, between 10 and 100 meters bathymetrics.

2. Planktonic Production Cycles and their Relationship with the Early Life History Stages of Sardine (1985, 1986 and 1987).

In August 1985, a new project was implemented in order to determine spawning area and seasons of sardine. The aims of this project were :

(i). evaluation of the spawning seasons and intensity;
(ii). determination of the spawning areas;
(iii). distribution, composition and phytoplanktonic biomass;
(iv). distribution, composition and zooplanktonic biomass;
(v). description and characterization of nutrients cycles.

Since then four plankton surveys, complemented with oceanographic studies, were carried on (two in 1985 and two in 1986), covering the portuguese coast (Figure 2).

Also growth and ageing of larval stages studies using daily microgrowth increments (sagittae) were pursued. Daily growth rates were estimated and otolith microstructure was related with life history events.

FAO nets (505 μm) were used on those surveys.

3. Basis for the Estimation of Sardine Spawning Biomass from Egg Production Method in Divisions VIIIc and IXa of ICES.

On July 1986, a Portuguese/Spanish "Workshop on the Standardization of the Methodology to be Used in the Study of the Early Life History of Sardine" was held in Vigo. During this workshop it was agreed by the participants that the "Egg Prodution Method for the Estimation of Spawning Stock Biomass" (Lasker, 1985) should be implemented in portuguese and spanish waters.

This project intends to create the necessary experience and data basis in order to provide the possibility to estimate the spawning stock biomass of sardine in 1988, through the new Egg Production Method (Lasker, 1985).

In order to achieve this goal, it will be necessary to get information on:

- Daily production of sardine eggs
- Batch fecundity in sardine
- Spawning frequency in sardine

Since October 1986, monthly cruises are undertaken for the determination of the peak spawning seasons of sardine. The sampling covers four transepts off the portuguese coast (Figure 3).

4. Basis for the Implementation of a Sardine Recruitment Program in Portuguese Waters.

It was recognized by the representatives participating in the Working Group for the Appraisal of Sardine Stocks in Divisions VIIIc and IXa of the

International Council for the Exploration of the Sea that the present state of the sardine fishery would be improved by:

(i). better knowledge about the time and area of spawning, both through ichthyoplankton surveys and sexual maturity sampling of landings, in order to obtain the data required for estimating spawning stock biomass from egg surveys and to improve the current understanding of the stock;

(ii). continued acoustic surveys and improvements in the methodology in order to obtain independent estimates of the population size. It would be desirable to carry out a complementary acoustic survey in the spawning season, probably in combination with ichthyoplankton surveys as mentioned above. It is also necessary to obtain further information on the environmental conditions of the sea and some aspects of fish behaviour, such as schooling, migrations and geographical distribution;

(iii). preparation of age composition data disaggregated by quarters instead of semi-annually as at present;

(iv). participation in the SARP (Sardine and Anchovy Recruitment Project) in the Iberian Peninsula. The Working Group considers this to be of the utmost interest and requests that ICES support the implementation of this project in this area.

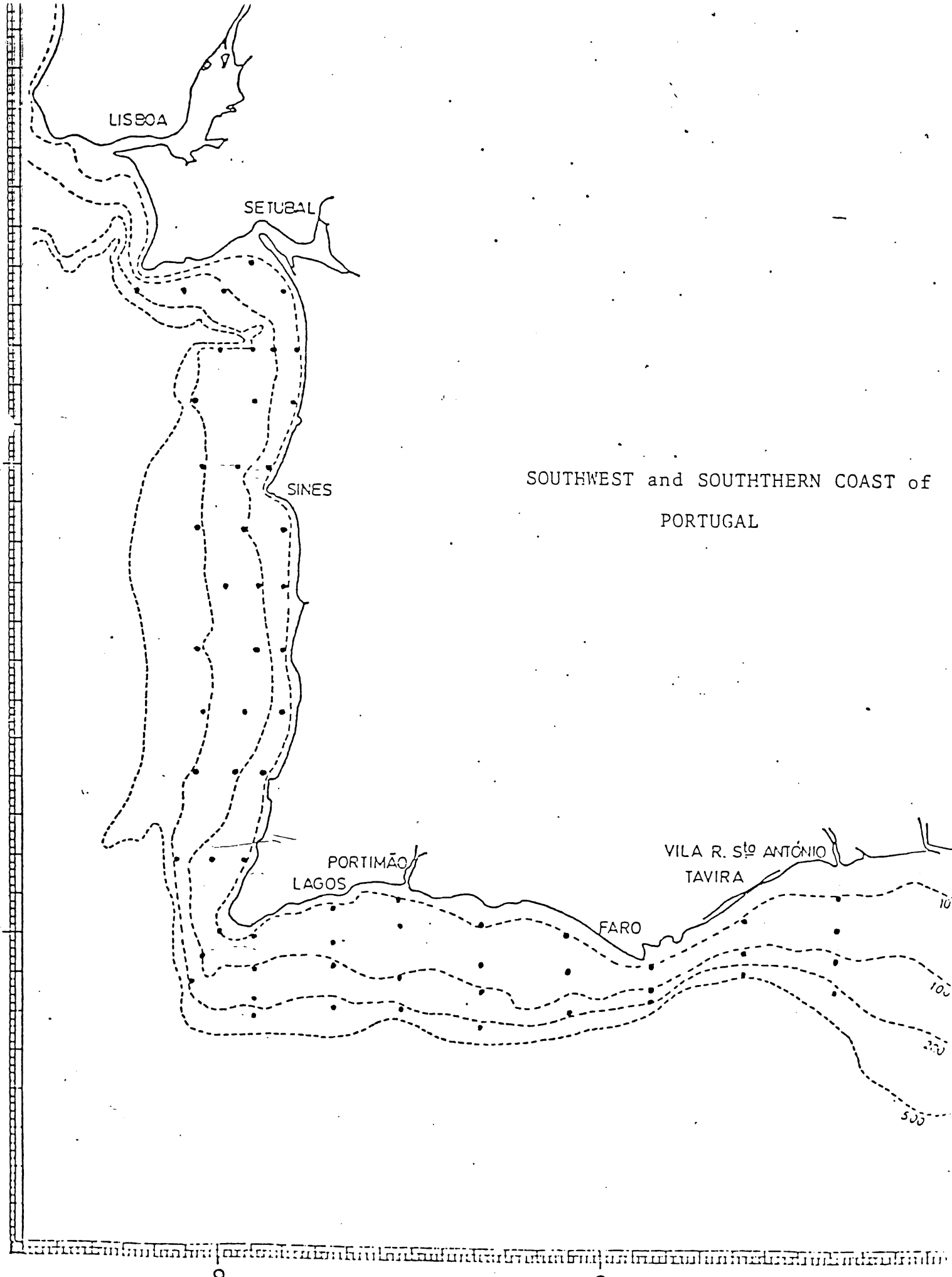
Depending on the acquisition of the know-how on SARP techniques and on the availability of funding, a SARP-type project could readly be implemented in Portugal since there is a great deal of information already available on the species, and a large fishery is based on these sardines.

The ultimate aim of the investigation is to provide the understanding of the cause and effect relationship in this fish population.

5. Ichthyoplankton Surveys Between Caminha and Cabo de S. Vicente.

In 1987 another ichthyoplankton project was started along the west portuguese coast (Figure 4). The purpose of this project is the study of hake and horse mackerel fish eggs and larvae as a contribution for the delimitation of the main spawning areas and patterns of species structures for larval fish assemblage.

Three surveys were programmed for 1987. The first one was already undertaken in February and two others are planned for June and October.



SOUTHWEST and SOUTHTHERN COAST of PORTUGAL

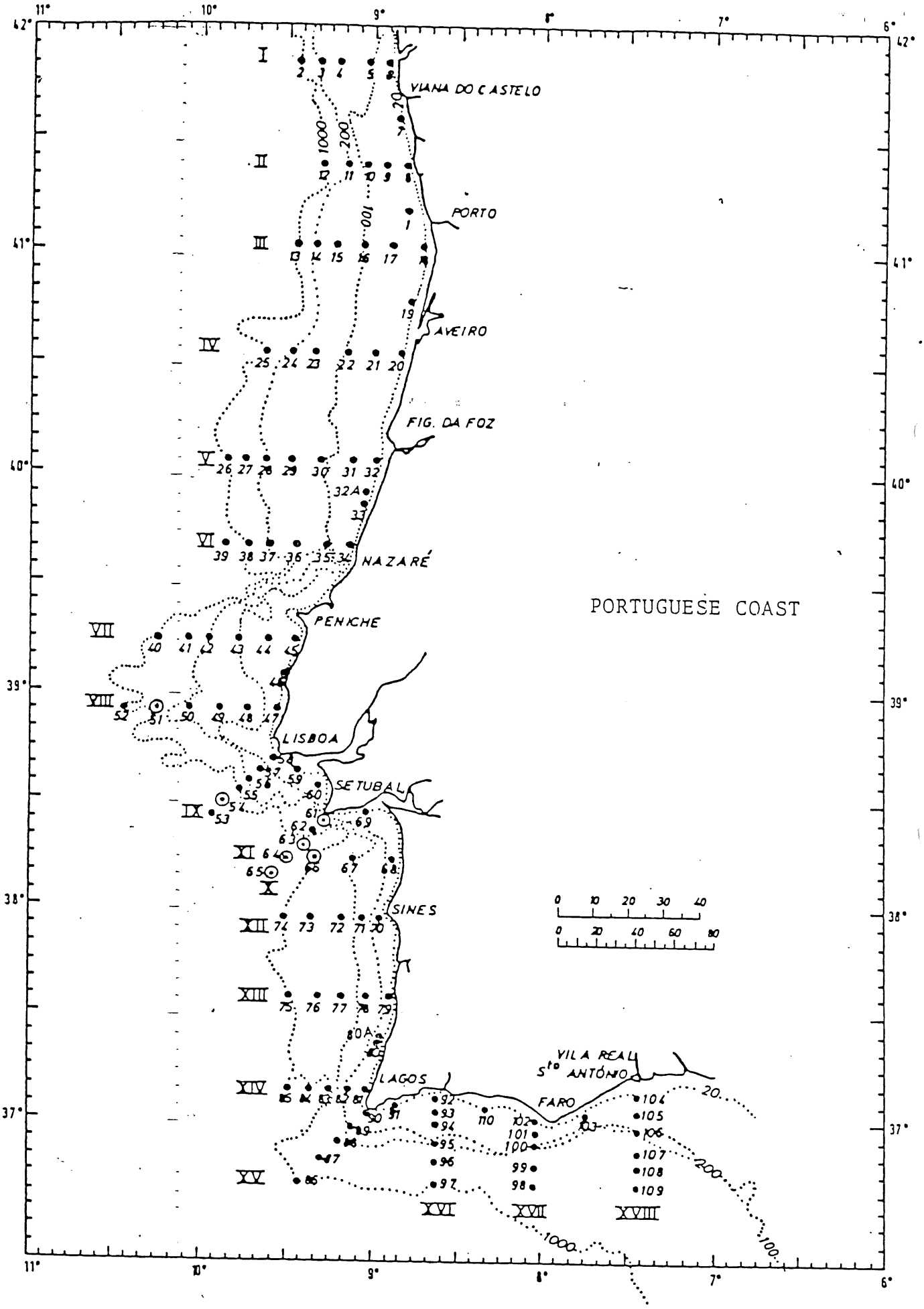


Fig.2 - Plankton survey (1985 and 1986)

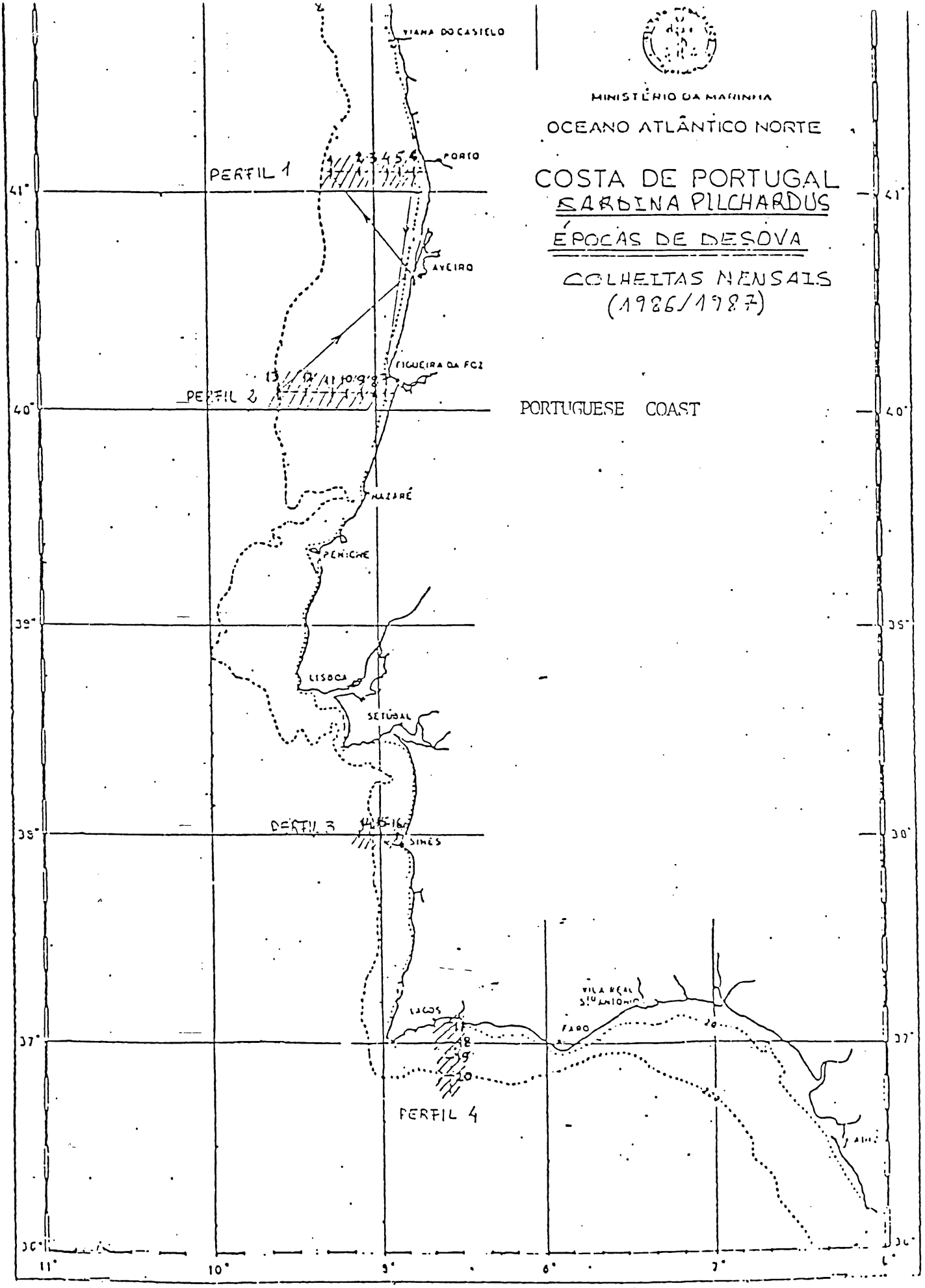


Fig. 3 - Ichthyoplankton survey (1986 and 1987)

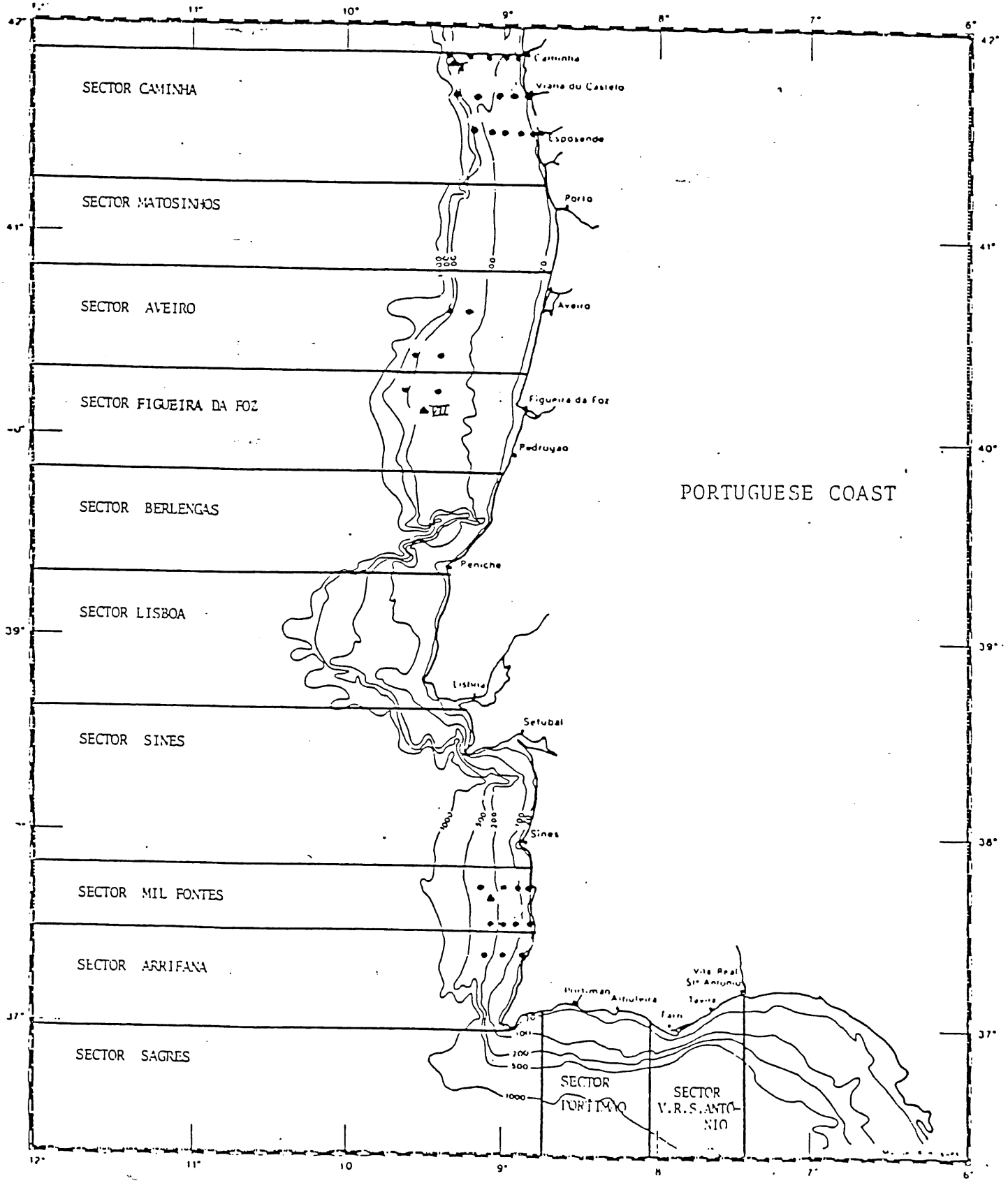


Fig.4 - Ichthyoplankton survey (1987)

APPENDIX 7

PROPOSED AUTUMN CIRCULATION EXPERIMENT IN THE NORTHERN NORTH SEA

PROJECT DESCRIPTION

Participating Laboratories

Institute of Marine Research, Bergen	Roald Saetre
Geographical Institute, University of Bergen	Martin Mork
Marine Laboratory, Aberdeen	Mike Heath, Tony Martin
	Bill Turrell
Danish Sea Fisheries Institute, Copenhagen	Katherine Richardson

Also involved, on the west coast of Scotland:

University College of North Wales	Ed Hill
Dunstaffnage Laboratory, Oban	David Ellett
Proudman Oceanographic Laboratory, Bidston	J. Howarth, John Huthnance

Background and Objectives

During the early autumn, herring larvae hatch around the Scottish coast. Their distribution is limited to Scottish coastal waters, the so-called 'Dooley Current', which marks the offshore boundry of this water, acting as a major transporter of larvae from the west and north of Scotland into the North Sea. The current is believed to flow across the North Sea, approximately along the 100m isobath, and to enter the Skagerrak and merge with the Norwegian Coastal Current. The western part of the current enters the North Sea between Orkney and Shetland, and then flows south to approximately the latitude of Peterhead before turning eastwards. Herring larvae are dispersed south and eastwards by this current.

By February, autumn spawning larvae are widespread throughout the North Sea, and there is evidence that many of the larvae found at this time in the Skagerrak, and off the Danish coast, have originated from spawning sites in Scottish waters. Furthermore, there have been suggestions that the 'success' of the larvae in reaching the eastern North Sea has a considerable bearing on their survival and subsequent recruitment to the adult stocks. An understanding of the processes leading to variability in overwinter transport, which is believed to be a largely passive process, is therefore fundamental to an appreciation of recruitment variability in the herring.

Little is known of the circulation in the northern North Sea at any time of year, but particularly in the winter. The FLEX and JONSDAP experiments in the 1970s attempted to study this circulation during the spring and summer period but were not very successful in identifying the main current stream across the North Sea. However, to the north and west of Scotland, the current does appear to be relatively narrow (approximately 20 miles) and to follow the 100m isobath eastwards. Towards the eastern side of the North Sea, the current seems to merge with the strong inflow of Atlantic water from the north along the edge of the Norwegian trench, and the combined flow enters the Skagerrak off the northern tip of Jutland.

A programme known as SCAPINS was conceived in recent years, and was intended to provide a comprehensive account of the circulation patterns in the North Sea during summer and autumn, with particular emphasis on the period of breakdown of stratification. SCAPINS had as one of its main objectives, the study of biological processes affecting the survival and growth of herring larvae. A working group was convened at ICES in December 1985 to produce a detailed program of investigations, and further discussions were held during the Shelf Seas Hydrography Working Group meeting in May 1986. It became clear however that the various research efforts being conducted in the North Sea during the summer of 1987 could not readily be combined to produce a coherent program. There were very large gaps in the coverage of the North Sea and hydrographers and biologists could not agree on the survey strategy.

However, the Aberdeen, Bergen and Copenhagen Laboratories all have an interest in the autumn circulation in this area and it was apparent that they could combine in a program of research on the autumn/winter circulation of the northern North Sea, with particular emphasis on the transport of herring larvae from the north and east of Scotland to the Skagerrak.

A cooperative research programme has been planned for 1987/88 to:-

1. Trace the route taken by the 'Dooley Current' as it flows across the North Sea from the west side of Orkney to its entry into the Skagerrak.

2. Assess the relative importances of wind, sea level and density on the flow rate and route of the current.

3. Determine the importance of the current as a transporter of herring larvae.

SCOPE OF THE PROJECT

Research Vessel Facilities

A timetable of research vessel cruises contributing to the study of currents and herring larvae in the area during 1987/88 is shown in the attached table. The combined effort of the three participating nations provides coverage in time over the period August - February.

Current Measurements

Three instruments for measuring currents will be used during the investigations, with the opportunity of intercalibration.

1. Current meters will be deployed on moorings by all three participants. The locations of the various moorings are shown on the attached chart. The Scottish moorings will be deployed to obtain a good measure of the transport in the western side of the area. The Danish moorings will be positioned to study the processes in the area where the current turns sharply eastwards off Peterhead, and in particular to estimate

any current flow southwards along the east coast of Scotland. The Norwegian moorings will be positioned to monitor the inflow of water along the edge of the Norwegian trench.

2. Acoustic Doppler Current Profiler (ADCP) measurements will be carried out from the Norwegian research vessel 'Hoke Mosby' during September. A towed undulating hydrographic recorder will be deployed at the same time, so that computed geostrophic currents can be compared with the measured current profiles. Measurements will be made along the lines of current meter moorings for intercalibration purposes, and then on a series of regularly spaced north-south survey lines across the North Sea, designed to straddle the current zone. The Marine Laboratory hope to charter the RV 'Challenger' during January 1988 for studies on herring larvae. 'Challenger' is fitted with an ADCP, and if an experienced operator is available then further current profile measurements could be carried out.

3. Satellite tracked (Argos) drifting buoys will be deployed along the ADCP survey lines, and along the mooring lines in the western part of the area. The Norwegians have 15 buoys available for deployment and these will be released in groups of 3 along each survey line, one with a drogue at a depth of 60m, the others with drogues at 30m. The Marine Laboratory, Aberdeen will deploy its own buoys in the outer Moray Firth as shown in the attached chart.

4. Sea Level Gradients have been shown to account for a large proportion of the variability in the current flow on the west coast of Scotland. A detailed study of sea surface topography is already planned with IOS, SMBA and UCNW Bangor, and coincides in time with the investigations in the North Sea. This will involve deployment of sea-bed and shore mounted tide gauges, and the collection of altimetry data from the GEOSTAT satellite. The Norwegians will not be directly involved in this work, but have suggested that they may have sea level data available from oil platforms operating in their sector of the North Sea.

Studies on Herring Larvae

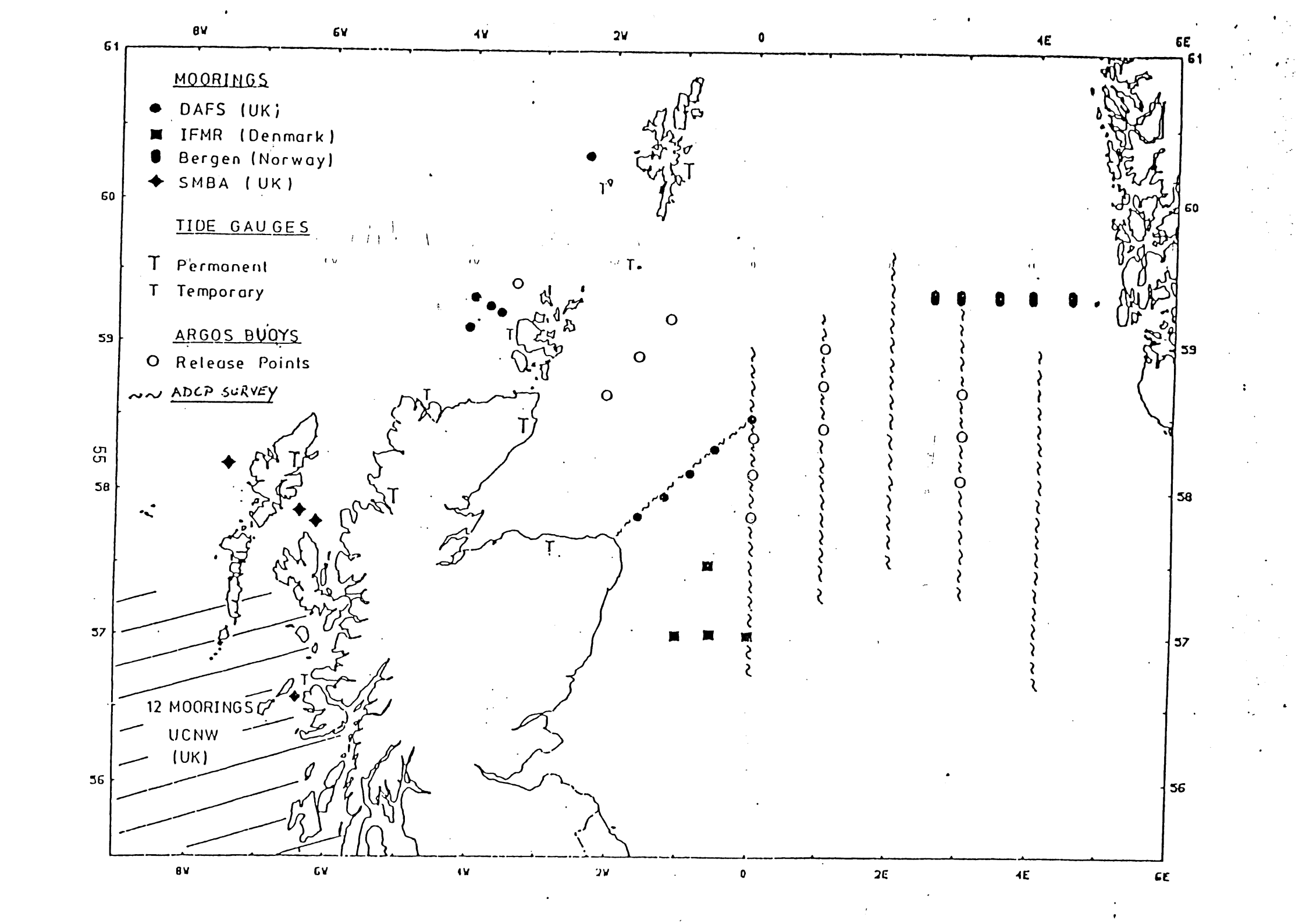
Investigations on herring larvae will mainly involve Scottish and Danish scientists. Detailed proposals have still to be formulated. The Norwegians will however, perform routine plankton sampling with the standard Gulf III during their hydrographic studies, to increase the scope of the investigation.

Further Links and Exchange of Data

The ICES Shelf Seas Working Group will be informed of the joint proposals at its meeting in Bergen in May. In due course, when full details of the Scottish, Norwegian and Danish and other UK contributions have been formulated, fine details of cooperation during the field studies will be agreed, particularly during the second half of October when both the Scottish and Norwegian vessels will be working in the area at the same time. A meeting is planned in Aberdeen in the spring of 1988, to collate and analyse the full data sets from the participating laboratories, and to prepare drafts of the results for publication.

RESEARCH VESSEL PROGRAMS IN THE NORTHERN NORTH SEA 1987/88

VESSEL	NATIONALITY	DATES	MAIN OBJECTIVES
M. Sars	Norway	9 June-6 July	Hydrography
Eldjarn	Norway	24 June-13 Aug.	Acoustic survey/ Hydrography
Clupea	Scotland	7-22 September	International Herring Larval Survey
Charter	Scotland	21 days Sept.	International Herring Larval Survey
Scotia	Scotland	9-29 September	Hydrography
Hoke Mosby	Norway	15-30 September	Hydrography
Dana	Denmark	15 Sept.-10 Oct.	IHLS/Biology
(Challenger	Wales (UCNW)	29 Sept.-14 Oct.	West Coast Hydrography)
Scotia	Scotland	7-27 October	Biology/Hydrography
M. Sars	Norway	19 Oct.-12 Nov.	Hydrography
Eldjarn	Norway	10 Nov.-10 Dec.	Hydrography
Dana	Denmark	11 Nov.-6 Dec.	Biology/Hydrography
(Challenger	Scotland(SMBA)	21 Nov.-6 Dec.	West coast Hydrography)
(Challenger	Wales (UCNW)	8-22 December	West coast Hydrography)
Challenger	Scotland	21 days January	Biology/Hydrography
Scotia	Scotland	6-26 January	Hydrography
(Challenger	Wales (UCNW)	3-22 February	West coast Hydrography)
Scotia	Scotland	3-23 February	International Young Fish Survey
Dana	Denmark	February	International Young Fish Survey
(Challenger	Scotland(SMBA)	25 Feb.-10 Mar.	West coast Hydrography)


MOORINGS
DAFS (UK)
IFMR (Denmark)
Bergen (Norway)
SMBA (UK)
TIDE GAUGES
T Permanent
T Temporary
ARGOS BUOYS
Release Points
ADCP SURVEY
12 MOORINGS
UCNW
(UK)
8W
6W
4W
2W
0
2E
4E
6E
61
60
59
58
57
56
55

AUTUMN CIRCULATION EXPERIMENT (ACE) IN THE NORTH SEA

1987-1988

BIOLOGICAL INVESTIGATIONS ON HERRING LARVAE

M.Heath* and K.Richardson+

* - Marine Laboratory Aberdeen, Scotland.
\+ - Institute for Fisheries and Marine Research, Denmark.

15 June, 1987

CONTENTS

INTRODUCTION

Since 1984 the Danish and Scottish Institutes have been carrying out open sea investigations on the early stages of autumn spawned herring larvae in northern UK coastal waters, with the objective of understanding the physical and biological processes affecting the growth, mortality and distribution of the larvae. The long term purpose of the work is to account for recruitment variability in herring stocks in terms of meteorological and hydrographic events. The fundamental hypothesis is that the major determinants of survival during the first year of life of the autumn spawned herring are experienced during the larval phase. Mortality may be a consequence of predation or starvation, but on the basis of data collected over last decade it appears that the main feature distinguishing years of low mortality from those of high mortality is the success or failure of shelf-sea water currents to deliver overwintering larvae to suitable areas for life post-metamorphisis.

The overwintering period (December/January) has so far not been studied by either of the Institutes, and this document describes a programme coordinating the efforts of both Institutes on an investigation of this stage in the larval life history. This programme forms the biological component of ACE - a Danish/Norwegian/Scottish study of the autumn/winter circulation in the northern North Sea and the west coast of Scotland. The biological interest in 1987/88 is primarily in the North Sea, but the west coast hydrographic work is essential for a full understanding of the water circulation system.

SUMMARY OF RECENT INVESTIGATIONS

The studies carried out in the last 3 years have been restricted to the first 6-8 weeks following hatching (late August - November). The method used by both teams of investigators has been the so called 'patch study' principle whereby attempts were made to identify discrete cohorts of larvae derived from a single spawning site and follow the evolution of the population over a period of time. The results of these studies can be summarised as follows:

A. Scottish Investigations (West of Scotland and Orkney/Shetland area).

1. Larvae hatching on the shelf to the west and north of Scotland are closely associated with the Scottish Coastal Current, and their distribution is contained by water of salinity greater than 35.1%. Short term variations in the current system are clearly reflected in the advection and dispersal of the larvae.
2. The Coastal Current originates as a low salinity outflow from the Irish Sea, Firth of Clyde and west of Scotland sea-lochs. The flow northwards along the west coast of Scotland is driven by the density difference between the inshore waters and water of Atlantic origin lying further offshore, but may be modified by tidal rectification and by sea-level gradients resulting primarily from the wind velocity distribution over a large area of the north-east Atlantic. The route taken by the current is determined by an interaction of sea-bed topography and Coriolis force, such that the core of the flow approximately follows the 100m isobath.
3. The Coastal Current transports larvae from the north and west of Scotland into the North Sea via the Orkney-Shetland Channel.
4. Zooplankton biomass in the Current appears to be higher than in surrounding waters. Herbivore grazing rate appears to be the main factor limiting phytoplankton biomass during the autumn - there is no evidence that nutrient limitation is a significant feature.
5. The vertical migration of the larvae may have very significant consequences for their grazing potential, and also for their retention in the Coastal Current system. The main environmental factors influencing their migratory behaviour are still being investigated.

B. Danish Investigations (Western North Sea south of 57°,50'N).

1 The spawning grounds in the Buchan area are located near a horizontal density discontinuity or front. Although the front is primarily a consequence of the interaction between tidal mixing and water depth, its precise location and intensity depends on heat input and wind mixing events. Patches of newly hatched larvae can be found both in the frontal region itself and in the isothermal water located to the west of the front. Newly hatched larvae appear to be transported towards the front. Thus, the largest concentrations of ca. 7-9 mm larvae are recorded in the frontal region, itself, and these larvae appear to be transported south/southeast along the frontal boundary. Movement of larvae along the boundary has been calculated to be of the order of 2-4 km/d.

2 Primary and secondary production (measured as calanoid copepod egg production) and. thus, the production of the larvae's prey items, are

significantly higher in the frontal region than in surrounding waters during the late summer/early autumn.

3 By November, larvae are distributed throughout the western North Sea and copepod egg production in this region has fallen to virtually nil.

In addition to the patch studies carried out in the autumn/early winter, some investigations of herring larvae have been carried out during the International Young Fish Survey (IYFS). An examination of the stomach contents of larvae caught by the Scottish vessel in the survey during 1986 and 1987 showed considerable variation in the species composition of prey items from area to area, and also in the biomass of prey in the stomachs. In general, larvae caught in deep water (>80m) in the northern part of the North Sea contained few prey items per larva, whilst in the southern and central area, stomachs were found to contain approximately an order of magnitude more items, and a greater diversity of species. Adult stages of copepods apparently formed the major part of the diet. A survey carried out from the Danish vessel just after the 1987 IYFS found active primary production and relatively high numbers of copepods in the Dogger Bank area. Herring larvae caught in this area were found to have adult copepods in their stomachs. Thus there is some evidence for greater food availability for larvae on the Dogger Bank than in the remainder of the North Sea, during late winter. As relatively large concentrations of herring larvae are found on or near the Dogger Bank in most years (IYFS data), this area may be important for the overwinter survival of larvae.

PROGRAMME FOR INVESTIGATIONS IN 1987/88

General Objectives

The goal of the programme is ultimately to develop a model of the transport and survival of larvae which has some prognostic capability. The fundamental hypothesis is that 'adverse' transport - ie. advection to some area other than the ideal nursery site - may in the final analysis be regarded as the main origin of mortality, irrespective of whether the cause is starvation or predation. The principle should be to introduce larvae into a suitable hydrodynamic model of the North Sea and shelf waters, as particulate tracers in the spawning regions, and determine the proportion that will not reach the nursery areas in time for metamorphosis.

In common with most shelf sea areas, the North Sea contains regions of high vertical shear and consequently a 3-dimensional (3D) hydrodynamic model will be necessary to determine the flow fields from hydrographic and meteorological inputs. In addition, herring larvae are not uniformly distributed through the water column. Thus, their location in the vertical plane may have significance for their advection.

Various hydrodynamic models of the North Sea already exist and the physical part of the ACE program will provide the inputs necessary to calculate the flow fields. The major part of the biological program is to generate the data needed to develop and test an interface model describing the larvae as vertically active tracer particles in a hydrodynamic model, and to provide the distribution data necessary to evaluate the success of the models in accounting for the transport of larvae.

Specific Objectives

The specific objectives of the investigations in the autumn/winter of 1987/88 will be as follows:

a. Investigate the short term (ie. cruise duration) dispersal of larvae, and in particular to examine the extent to which wind induced dispersion may override containment by hydrographic features.

b. Study the vertical distribution of overwintering larvae and evaluate the consequence for their feeding and geographical distribution.

c. Evaluate the dependence of larvae on variation in primary and secondary production and plankton biomass distribution, for growth and survival during the winter.

Principle of the field investigations

The patch study method was a successful technique in the earlier investigations because herring spawning grounds are characteristically discrete entities. This feature results in the production of distinct patches of larvae that, during the first weeks of life, are relatively easily distinguished from each other.

However, after a few weeks these patches become diffuse and intermixed. Thus, the concept of a 'patch study' loses much of its meaning by late autumn. During the winter period, a more satisfactory approach may be to consider all of the larvae in the North Sea as one group. If we assume that:

- the successful transport of larvae from spawning grounds to nursery grounds is a prerequisite for survival
- that transport is dependent upon the circulation patterns in the North Sea

then the initial starting point of an individual larva is not so important to our considerations. This approach does not, of course, preclude the study of differences in larvae ecology in different areas but it does simplify the sampling strategy.

Line-surveys

Instead of trying to define the limits of individual patches through extensive grid surveys, we propose that a series of survey lines through the North Sea be repetitively sampled (see Fig. 1). The portions of the lines where larvae are present should be surveyed on as many cruises as possible during 1987-1988. The minimum data required from these surveys are numbers of larvae per square meter and surface temperature and salinity. If possible, the following data should also be collected on all or part of the lines:

- surface to bottom temperature and salinity profiles (salinity to ±0.05 per mille)
- vertical distribution of larvae
- phytoplankton/zooplankton biomass and/or productivity

If the data for these surveys are to be used as 'sea-truth' for verifying a circulation model then we regard it as essential that experienced modellers should have the opportunity to advise and comment on the frequency and locations of sampling positions.

Other laboratories should also be encouraged to sample on these same or similar survey lines - especially in the Southern North Sea. In this respect, a recent offer by the Institute of Marine Environmental Research (IMER) to deploy hydrographic data loggers and possibly an Undulating Oceanographic Recorder (UOR) during ACE, in conjunction with the Continuous Plankton Recorder (CPR) surveys carried out monthly on certain North Sea ferry routes, could make a very significant contribution to the programme.

Vertical Distribution Studies

Using the sampling strategy described above, a Eulerian approach to studying processes affecting the vertical distribution of larvae and their prey is more appropriate than a Lagrangian method - in other words, investigations should be carried out at fixed geographical points rather than at drifting positions.

Studies of the vertical distribution of larvae should be carried out on all cruises in order to develop a picture of the vertical distribution patterns of different sizes of larvae. During the autumn, when the mjority of larvae are smaller than approximately 15mm, vertical sampling can be carried out using the DAFS High Speed Multi-depth GULF Sampler. During the winter cruises, (Dec-Feb) vertical studies can be carried out using the Method-Isaacs-Kidd Trawl (MIKT) towed at different depths over the same ground, or an opening/closing version of this being developed in Aberdeen.

The water column should be sampled in at least 3 equal depth layers. Theoretically, a larger number of sampling strata would give better resolution, but it is important that all depths at a given station be sampled within ca. 1 hour if the subsequent analysis is to resolve any variations in distribution correlated with tidal current shear (cycle frequency 6h). Wind (direction and speed) and light (incident upon the surface and vertical attenuation) should be measured at all stations. In addition, vertical distribution studies should, as far as is possible, be carried out adjacent to a current meter mooring or with concurrent measurements using a profiling current meter. The Acoustic Doppler Current Profiler (ADCP) is ideal for this purpose since continuous measurements of the current profile are recorded even while the vessel is under-way. As a last resort, an estimate of tidal current velocity could be obtained by tracking a drifting buoy, if this can be achieved without compromising the vertical distribution sampling, but this will not provide data on vertical shear.

Timetable of biological field studies

Field investigations will cover the period September-February:

September: The ICES coordinated International Herring Larvae Surveys take place during September, and these will provide a valuable 'base-line' survey for the intensive biological studies to follow, in addition to generating the data required for stock assessment purposes. In 1987, as in previous years, Scotland will cover the entire northwestern North Sea and the west coast of Scotland, and Denmark will be working in the Buchan area. The preliminary data on distribution of larvae will therefore be available in Aberdeen before the biological studies.

In addition, some biological studies (primary production, chlorophyll distribution, and vertical distribution studies of larvae) will be carried out on 'Dana'. The possibility of using the DAFS multi-net Gulf sampler from the Dana is being discussed. This would involve loading/offloading the gear and an operator at a Scottish port during the cruise. Both Scotland and Denmark will deploy current meter rigs during September (see Fig 2 for positions).

Apart from the vessels engaged in the ICES Survey, a Norwegian vessel will be carrying out hydrographic investigations at this time. It may be possible for some sampling of herring larvae to be carried out from this ship, in areas at the fringes of the geographic distribution in September which are not covered by the ICES Survey.

October: Eulerian studies of the vertical distribution of herring larvae will be carried out from FRV Scotia at sites adjacent to current meter moorings to the northwest and southeast of the Orkney Isles. Measurements of primary production, copepod egg production, illumination attenuation and vertical distribution of larvae will be carried out over 3 day periods at each position. In addition, these measurements will be made along the standard survey lines in the northern North Sea, and along lines of stations positioned perpendicular to the drift trajectories of satellite tracked drifting buoys which will be deployed at the start of the cruise.

November/December:

RV Dana will operate in the northwestern and southern North Sea, carrying out studies of advection and dispersion of larvae. Drifting buoys deployed by Scotia in October could be used as reference markers during the Dana cruise. Two of the survey lines identified in Figure 1 will be covered during this cruise. In addition, vertical distribution studies of larvae will be carried out at the current meter positions off the eastern Scottish Coast and possibly near the DAFS moorings off Peterhead. Biological measurements (chlorophyll distributions, primary production, and zooplankton biomass) will also be

carried out. The Danish moorings will be retrieved during this cruise.

January: RV Challenger will complete all of the standard survey lines in the northern North Sea (north of 57,00N) during the cruise. Vertical distribution studies will be carried out along one of the lines, each study lasting 2-3 days, the positions being determined with reference to the drift trajectories of buoys released in October. It is intended to use an ADCP to obtain current profiles during these investigations, thus avoiding the need to carry out the work adjacent to a current meter mooring. In addition to recording the distribution of larvae, the concentration and size distribution of zooplankton will be investigated and compared with the size distribution of prey items in the stomachs of the larvae.

February: The International Young Fish Survey carried out in February each year includes an extensive survey of the distribution of herring larvae and basic hydrographic parameters. It may not be possible to conduct more detailed investigations during this survey, but RV Dana and Scotia will also be operating at this time, and certain biological rate measurements are planned by the Danish scientists.

REQUIREMENTS FOR ADDITIONAL SUPPORT AND EQUIPMENT

1. Hydrodynamic modelling.

The use of a 3D hydrodynamic model of the North Sea and shelf waters is essential if the programme is to achieve its long-term goal. Models exist in Germany (Hamburg) and UK (Bidston).The support of one of these modelling groups is regarded as being of the highest priority.

2. Line survey sampling.

The line surveys are an important part of the programme, both for documenting the eastward advection of larvae and for providing sea-truth data for verifying circulation models. Assistance from other Institutes with the collection of these data would be of great value. In this respect, the IMER proposal to record hydrographic data during selected monthly CPR deployments for the benefit of ACE participants is most welcome.

3. Multiple opening and closing plankton sampling gear.

The DAFS multi-depth Gulf sampler is suitable for quantitative sampling of young larvae (smaller than approximately 15mm) in depth discrete layers in the water column. However, determining the vertical distribution of larger larvae during the winter presents particular problems on account of the ability of these larvae to avoid the mouth opening of conventional gears. We therefore regard the development of an opening and closing mid-water frame trawl (along the lines of the Method-Isaacs-Kidd trawl) as being of prime importance. This work is underway in Aberdeen.

4. Current measurements.

a. Verification of physical models.

The current meter and mooring deployment capabilities of Denmark, Norway and Scotland are insufficient to provide full coverage of the area of interest, and in the original outline of the physical aspects of ACE a large area of the central-northern North Sea is devoid of moorings. We have been able to provide some coverage of this region by the use of hired current meters supplied by Denmark, and two moorings supplied by Aberdeen. However, three additional deployments would be desirable.

b. Data requirements for larval vertical distribution studies.

An important aspect of the programme of experiments on the vertical distribution of larvae is the effect of vertical shear in tidal currents. This requires that measurements of the vertical profiles of current velocity be carried out concurrently with the measurements of larval distribution. The ideal system for achieving this is the acoustic doppler current profiler (ADCP). The next best solutions are either regular (1 hour frequency) deployments of a profiling current meter from the survey vessel, or a single string mooring equipped with three standard meters that could be deployed for the duration of each experiment (2-3 days) and then recovered.

Neither 'Scotia' or 'Dana' are fitted with an ADCP. However, as described above moorings and/or current meters are in short supply. If the equipment cannot be obtained then the experiments may have to be carried out

adjacent to one of the existing moorings which reduces flexibility in the field. RV 'Challenger' is fitted with an ADCP and this will be available for use in January 1988.

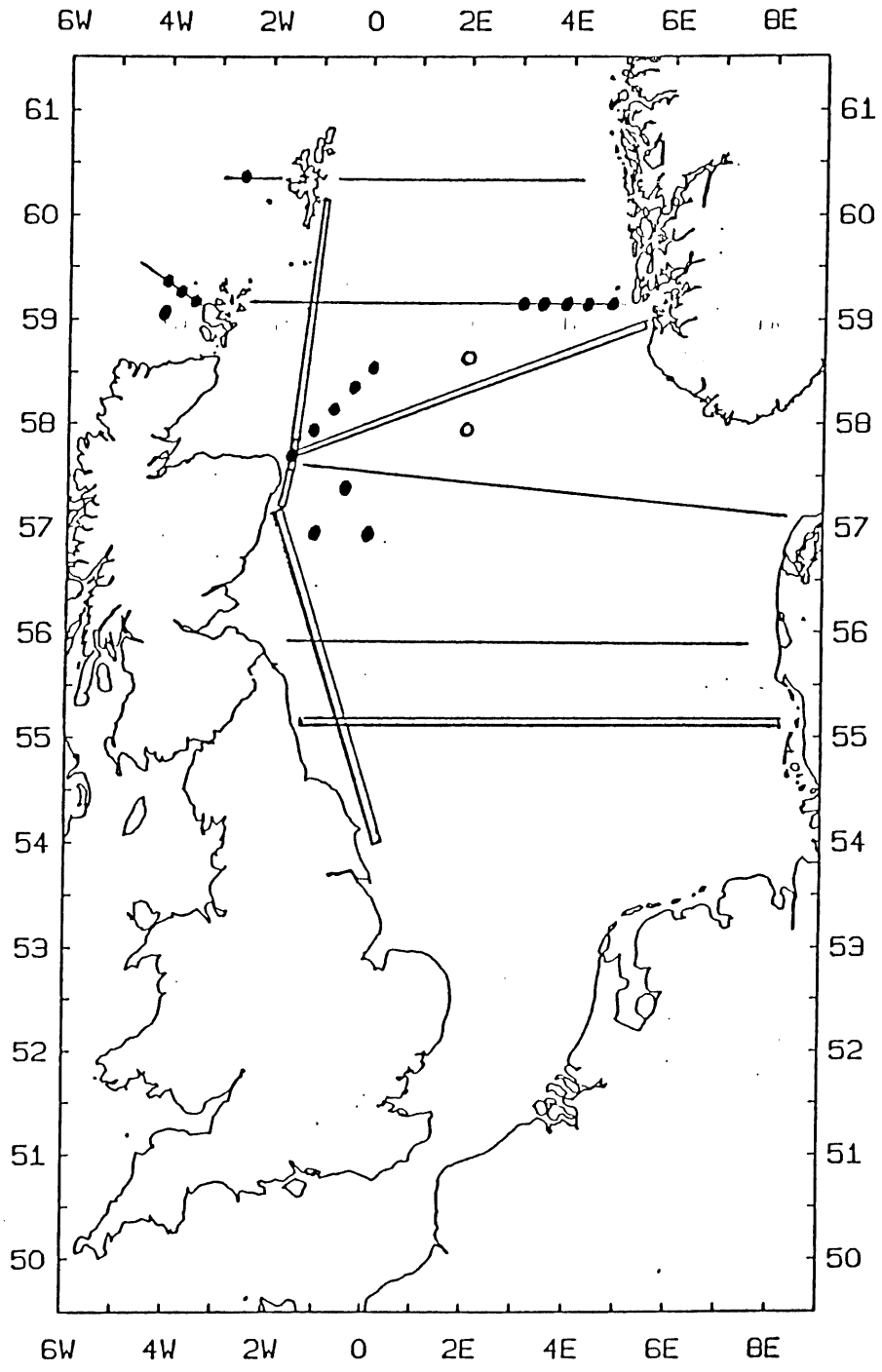
5. Light measurements.

Light intensity is implicated as a major determinant of the vertical distribution of herring larvae. Reliable measurements of low intensity illumination and attenuation underwater are extremely hard to make, and we can identify a role for a person with experience in the field of optical oceanography to collect this data.

6. Space/time resolution of hydrographic sampling.

The requirement to achieve high frequency (1-2h) sampling of the vertical distribution of larvae is not consistent with the requirement to also perform concurrent hydrographic sampling using existing technology (ie. CTD/water bottles). We can therefore identify an important requirement for reliable data logging units which can be mounted on the plankton sampler and record the vertical profiles of temperature, conductivity (as the minimum parameters) and fluorescence during the tow. Since this data is not necessary for decision making during the tow then an internal logging rather than a data telemetry system would seem most appropriate. Logging units of this type would also allow very much more efficient use of ship time during line-surveys.

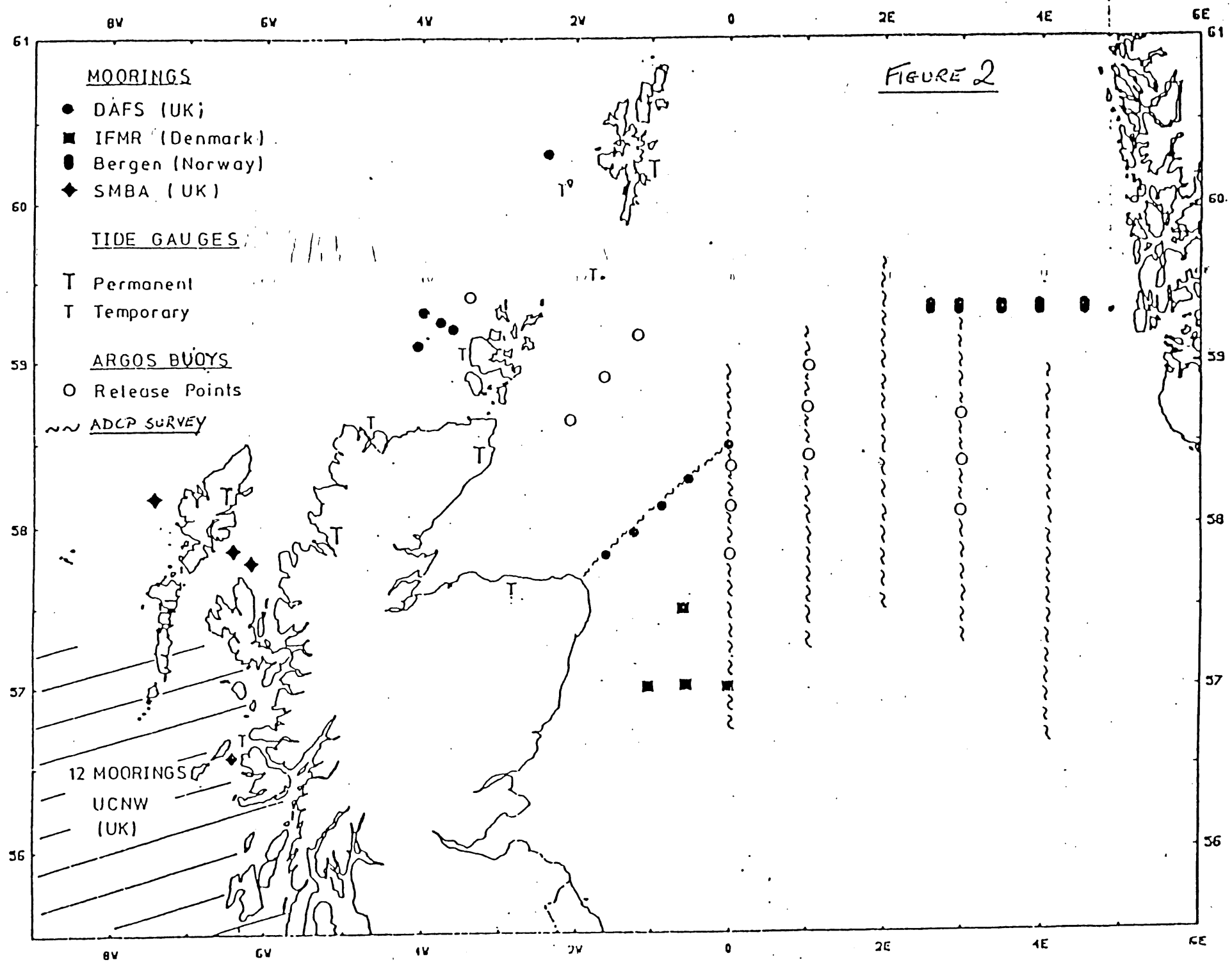
FIGURE 1



- Planned current meter mooring positions.
- Possible positions of additional moorings.
- CPR routes of interest to ACE.
- Proposed line survey routes.

SUMMARY OF INSTRUMENT DEPLOYMENTS - PROJECT ACE

FIGURE 2



PROPOSED STRATEGIES FOR RECRUITMENT RESEARCH ON HADDOCK AND COD WITHIN THE NORTHEAST CONTINENTAL SHELF ECOSYSTEM

by

G. C. Laurence
National Marine Fisheries Service
Northeast Fisheries Center
Narragansett Laboratory
Narragansett, RI 02882-1199

and

E. Cohen, M. Grosslein, and R. G. Lough
National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole Laboratory
Woods Hole, MA 02549

Narragansett Lab. Ref. No. 87-02
MARMAP Contribution FED/NEFC 87-03

The conservation of living or renewable resources from the sea for the benefit of society requires knowledge of the workings of long and short-term variability of these resources. In fisheries this variability is usually measured as the biomass that passes from the unexploited to the exploited segment. It is given the term "recruitment" which includes not only the measurement of variable biomass but also the determination of the mechanistic physical and biological functions as well. From a scientific standpoint, the recruitment problem is one of the most important in the ecological sciences.

The Northeast Fisheries Center has been studying the recruitment problem for Northwest Atlantic fishery stocks from a functional basis for approximately the last 15 years. The overall philosophy of the Center's research has been to view the problem within whole marine ecosystem studies with a goal of satisfying the need for multispecies fisheries management. A 3-tiered approach has been used incorporating mesoscale time series surveys, process-oriented field studies, and laboratory research activities revolving around early stages in the first year of life. The chronology of this strategy had its inception with broadscale annual survey cruises for early life history stages under the MARMAP Program. Concurrent with the MARMAP surveys were experimental laboratory studies to establish the critical quantitative and functional parameters of developmental physiology and trophodynamics of eggs and larvae. Process-oriented field research was carried out in the ICNAF larval herring program.

In 1980 these three research approaches were brought together in a

coordinated effort to study cod and haddock larval survival and growth on Georges Bank. The results of previous laboratory work, field work, and literature surveys were used to formulate hypotheses about larval starvation and prey requirements for successful growth and survival. Modelling was used as a tool to synthesize the results of this research. In 1982 ancillary field research was conducted to determine the effects of advection of water off the continental shelf by warm core rings on survival of early life stage fishes. The scientific information gained from these studies was considerable, however, it did not reveal a single dominating factor controlling variable survival during the egg or larval stages.

The lack of a consistent critical mortality mechanism in the egg and larval stages coupled with some modelling efforts and estimation of field mortality rates pointed towards the possibility of predation controlled mortality of gadids during the juvenile stage. Thus, in 1984 the emphasis of recruitment research was shifted to sampling juveniles in the field and determining their predators and predation rates. To date a great deal about the biology of juveniles and their distribution on Georges Bank has been learned, but significant predation has not been demonstrated. Hypothesis testing at sea within a recruitment framework has proven to be especially difficult. The formulation of provable or falsifiable hypotheses in an inferential manner, which is an accepted scientific methodology in particularly complicated research situations, has thus far not proven to be possible. This has been due mainly to the overwhelming logistics of sampling at sea, the lack of control of variables in field experiments, and the synergistic complexity of the recruitment problem. Consequently, we collectively feel that we need to change the research strategy to a broader evaluation of the problem de-emphasizing the mechanistic approach for the time

being and move toward providing information on mortality rates within a life table context before we can resume specific hypothesis testing.

Recent Recruitment Research

Studies conducted to date have been in three general research areas--larval starvation, advection of eggs and larvae, and juvenile predation.

Ten years of empirical laboratory studies formed the framework within which at sea-testing of hypotheses concerning starvation and prey requirements of larval gadids for successful growth and survival was conducted. An overall synthesis of these field and laboratory results indicated that starvation mortality in the larval stage is one of the largest components of total mortality and is most prominent in the first weeks after hatching. However, its magnitude is such that it does not appear to be population limiting under most conditions observed in the field. There is normally enough food in the sea to allow an ecologically significant portion of larval populations to grow and survive.

Research on advective processes has neither confirmed nor rejected their potential impact. Samples taken in an entrainment feature associated with a warm core ring were examined in 1982 for larval fish. Coastal zooplankton species were present, but coastal larval fish species were not. Furthermore, no evidence of significant loss of haddock eggs or larvae across the shelf break off the northeast U.S. coast potentially attributable to advective processes was noted for the period 1977-82. A lack of correlations between physical processes and larval mortality and subsequent year-class strength for Georges Bank haddock and silver hake was also noted. Relationships between warm core ring entrainment, Ekman transport and position of the shelf slope front with egg, larval and post-larval mortality, and subsequent year-class

strength in silver hake and haddock were examined for 1975 to 1981. This time series is short, but there was no conclusive evidence that physical processes set year-class strength every year on the northeastern shelf. Physical processes may, however, plan an important role in particularly good or bad years. For example, 1982 was a year when virtually no gadoid larvae were found on the bank. Physical transport of eggs and larvae off the bank caused by either a warm core ring or major storm event may have been responsible for their absence.

Recent research emphasis on predation as a factor in early life stages mortality has likewise shown tentative results. Preliminary comparisons of the relative magnitude of mortality in larval vs juvenile stages indicated that on the average juvenile mortality is responsible for the major part of the variability in recruitment. Further support came from multispecies food habits and energy budget studies which indicated that major fish predators consume most of the growth production of pre-recruit fish in aggregate. However, the results of stomach analyses on research cruises conducted since 1984 have not identified any significant predators of juvenile gadids. Identification of major predators and direct estimation of predation on larval and juvenile fishes may be an intractable problem within current field research capabilities.

The results of these specific functional studies have shown that the inter-annual variability of cod and haddock recruitment in the northwestern Atlantic may be dominated by local effects. These may include predation, anomolous temperatures or advective loss due to storms or warm core rings. These processes vary in importance from year to year. Consequently, year-class strength may be set at different stages during the first year of life.

A New Direction

It now is quite clear that, due to the mixed results of prior studies, we need field research detailing the timing and magnitude of mortality in the early first year life stages. Accumulating evidence points to greater importance of the late-larval phase and the probable key role of predation. However, we do not yet have a sufficient series of the timing and relative magnitude of mortality rates at the various developmental stages of gadids during their first year to represent an adequate test of the hypothesis regarding timing, let alone sort out the causes of mortality. In particular we have a significant gap in quantitative information on the abundance of postlarvae while they are still in the water column, and during their first month or so as juveniles on the bottom at a time when their average weight appears significantly less than the average size of fish prey observed in the major fish predators sampled to date. Furthermore, there is evidence that in some years year-class size is determined by factors operating on the egg and early larval stages during which time physical environmental factors (temperature, advection) are much more likely to be operable.

Experiments in the last two years suggest that with the large MOCNESS we can extend our quantitative sampling to include postlarval gadids in midwater through June which is about the end of the pelagic stage for haddock at age 3-4 months. We need a longer and more precise time series of quantitative estimates of eggs, larvae and including postlarvae (midwater phase) in order to adequately document the timing and magnitude of mortality within the pelagic stage. This time-series is needed both for empirical description of the timing aspect, but also to help sort out the probable mortality mechanisms and their relative importance. Concurrent information on the spawning process itself (condition and structure of spawning stock, fecundity, and egg

viability) should be obtained as well as continued coverage of the 0-group demersal stages. It is also important to collect a good concurrent series of measurements on growth and physiological characteristics of the cohort populations in addition to environmental factors including food, temperature and advection indices at the same time we measure within-season mortality variations.

Essentially, a life table is needed for each cohort including abundance and distribution of egg/larval/midwater post-larval/and demersal juvenile stages along with measures of their condition and age/growth at each stage. These data together with the environmental data noted above and potential, as well as, documented predator fields will be necessary inputs for testing the robustness and consistency of hypotheses about both the timing and mechanisms of mortality.

Sampling Strategy

Current time-series sampling strategy for the early life stages is conducted so that 6 to 7 broad-scale ichthyoplankton surveys are completed each year with Georges Bank gadids sampled 2 or 3 times at best. On Georges Bank, typically 35 to 50 stations are sampled each survey. The egg and larval data are then used to back-calculate spawning stock biomass after making various assumptions. The results of a recent simulation model to evaluate spawning stock size estimates derived from larval abundance indicate the broadscale survey coverage only appears to be minimally adequate for haddock. Although some estimate of growth and mortality of the larvae can be made, the current sampling intensity falls short of the minimum coverage needed to provide a more definitive ecological assessment of the population.

The best evidence from the available data bases indicates that the size

of a recruited year-class may be determined by the end of the pelagic phase in late June, prior to their assuming a demersal life style as juveniles. Significant losses can occur at any time during their pelagic life, and these losses can be the result of various biological and/or physical events or processes as noted above. We need to develop more definitive and resolvable hypotheses to identify and clarify these important processes even though we are faced with the difficulty of not being able to control the natural variables at sea. In short, we have to make the best experiment that nature affords us. To do this we need to increase the survey coverage during the pelagic period of cod and haddock (March-June), as well as the sampling frequency, in order to derive reliable abundance at age data for all life stages: eggs, larvae through early juveniles. We propose to do this for three years commencing in calendar year 1988.

Field Program

The proposed field sampling program (Table 1) consists of five pelagic surveys between late March and mid-June. A related bottom trawl survey of Georges Bank is needed by early March in order to derive an approximate variance estimate of the haddock spawning biomass, or at least an index of the mature biomass potential. Similarly, a bottom trawl survey in early autumn will be used to provide an index of the size of the recruited year-class. The five pelagic surveys are spaced in time to collect abundance data on all the life stages from egg through early juveniles, but closer together in May-June when critical mortality events may occur. Standard MARMAP bongo net gear will be used to collect the eggs and early larvae up to mid-May (Ca. 12mm SL), but for larger larvae and early juveniles that have greater ability to avoid nets, the MOCNESS-10m will to be used to fully sample the complete size frequency in

May, when considerably larger volume of water has to be filtered as the population decreases in numbers.

On each pelagic survey the number of stations sampled should approach 100, in contrast to the MARMAP station plans of 50, to increase the probability of the percent standard deviations of the mean abundance falling to less than 50% rather than Ca. 70%. The stations will extend across Georges Bank from the Northeast Channel to the Great South Channel encompassing the 200-m isobath. The station density will nominally be 10-20 miles apart, but in high concentrations of eggs and larvae the station density will be increased to one every 5-10 miles. Stratified sampling will be used as much as possible on the surveys while maintaining minimum sampling coverage of the entire Bank. Temperature and salinity profiles will be made on all stations along with other parameters if they can be readily obtained. Remote sensing of thermal structure of surface waters will be made prior to or during each survey to extend sampling coverage as time permits.

Related Studies----Subsamples of the eggs, larvae, and juveniles from each survey will be staged and aged so that a representative age distribution can be determined. Ultimately, from the composition of surviving recruits, we want to know their time and place of spawning, and the environmental events that promoted their survival, or circumstances that led to the loss of the rest of the population. Otolith increment ageing technique permits us to accurately age the larvae and juveniles providing sufficient specimens are processed. It is even feasible to link growth and mortality rates to nutritional and environmental occurrences by the microstructure and chemical analyses of their otoliths. Given sufficient resources to collect and process samples, other new techniques can be used to interpret the survey data. Recent growth and nutritional state can be assessed by RNA-DNA ratio

analysis. And, it is now possible to distinguish between cod and haddock eggs at all stages by principal component analysis of their fatty acid patterns.

Summary and Expectations

The results of our recruitment research to date, although positive in many aspects, have led us to a critical juncture as far as strategy is concerned. The complexities involved in devising truly testable hypotheses of a mechanistic nature necessitate that we collect more information in a broader context before resuming testing. Understanding recruitment really involves knowledge of all the stages in the life history of fish species. Once this knowledge is available hypothesis formulation becomes easier because of the capability of integrating information from a matrix of data---the life table.

We advocate the initiation of research surveys and the incorporation of information from ongoing surveys to establish an intensive three year time-series of abundance and distribution of all life stages of Georges Bank cod and haddock within a life table context to permit the calculation of mortality rates. Once the mortality rates are established we should be able to construct verifiable hypotheses in a hierarchical series focusing on particular factors affecting the life stage(s) where mortality is shown to be critical or on more random factors in the event that no life stage shows a critical mortality rate. Additionally, the data from these studies will be used to validate and further develop existing models of the first year of life. In any event, we should be in a better position to ultimately understand the functional basis for recruitment variability.

Table 1. Proposed field sampling program for pelagic eggs, larvae, and early juveniles of haddock on Georges Bank.[1]

Date	Survey Type	Stage Sampled
15 Feb-20 Feb	Bottom trawl	Adult maturity index
1 Mar-18 Mar	Bottom trawl	Egg
21 Mar-1 Apr	Bottom trawl	Egg
21 Apr-15 Apr	Bongo	Egg & recently hatched larvae
18-28 Apr	Bongo	Egg & recently-hatched larvae
2-13 May	Bongo	Early larva
16-27 May	Bongo & MOCNESS-10 m	Late larva & postlarva
6-17 June	MOCNESS-10 m	Postlarva & early juvenile
15-30 July	Bottom trawl (IYGPT)	Demersal juveniles
25 Jul-5 Aug	Bottom trawl	Demersal juveniles
25 July-10 Aug	Submersible observations[2]	Demersal juveniles
12-30 Sep	Bottom trawl	Demersal juveniles

[1]Personnel costs per pelagic survey would be approximately $5K. This is based on 6 people per cruise at an average grade of GS-9.

[2]Contingent on NOAA funding for proposed submersible studies.