Oceanography Committee

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Ref G

REPORT OF THE

WORKING GROUP ON RECRUITMENT PROCESSES

Texel, Netherlands
7–9 October 1998

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK-1261 Copenhagen K Denmark

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1 TERMS OF REFERENCE AND PARTICIPANTS

At the 1997 ICES Annual Science Conference, resolution C.Res 1997/2:54 was adopted as follows:

The Working Group on Recruitment Processes (Chair: Dr P. Pepin (Canada)) will meet in Texel, Netherlands, from 7–9 October 1998 to:

1. Collate and analyse available data on the abundances of various life history stages from a variety of stocks with a view to determining patterns in the stages at which year-class strength is fixed.

2. Define objectives and tasks required to examine the robustness of plankton survey design for the generation of distributional indices and to assess whether existing distributional data are sufficient to detect inter and intra-annual patterns.

3. Review the development of reference growth curves for early life stages of important species and contrast those with existing data on the development from both wild and laboratory studies from various species to provide a baseline for laboratory and field studies.

4. Review the development of new approaches, developments, or techniques used in the study of factors and processes which influence the development and survival of fish eggs and larvae in relation to recruitment or the formation of year-class strength. These should include, but are not restricted to, biochemical and histological measures of condition and their relation to the probability of survival, and modeling methods for the study of drift, dispersal and mortality.

5. Consider the future work programme in relation to the remit of the Oceanography Committee and the ICES 5-year Plan, including co-operation with other Working Groups.

The meeting was attended by the following:

C. Clemmesen	Germany	M. Dickey-Collas	UK
A. Folkvord	Norway	P. Fossum	Norway
M. Heath	UK	B. Klentz	Germany
P. Munk	Denmark	R. Nash	UK
C. Needle	UK	P. Pepin	Canada **(Chairman)**
P. Solemdal	Norway	H. van der Veer	Netherlands

Apologies were received from:

A. Rijnsdorp	Netherlands	C. Fox	UK
E. Houde	U.S.A.	K. Frank	Canada
J. Gagné	Canada	F. Arrhenius	Sweden
G. Marteinsdottir	Iceland	M. St. John	Denmark
C. N. Hammer	Germany	T. Linkowski	Poland

2 OVERVIEW

The Working Group (WG) was greeted by H. van der Veer. The WG was able to address the assigned Terms of Reference to varying degrees of detail. There were five main areas of work: (1) collate and analyze available data on the abundance of various life history stages from a variety of stocks; (2) define objectives and tasks required to examine the robustness of plankton survey design; (3) review the development of reference growth curves; (4) review on-going multidisciplinary research projects; (5) review the Working Group's activities in light if the ICES 5-year plan. In addition, the WG considered nomination of a Chairman.

3 REPORTS OF DISCUSSION GROUPS

3.1 Collate and Analyse Available Data on the Abundance of Various Life History Stages

ToR 1: *Collate and analyse available data on the abundance of various life history stages from a variety of stocks with a view to determining patterns in the stages at which year class strength is fixed.*

Survey data on the abundance of life history stages for a number of stocks were available to the WG (Irish Sea cod, haddock, plaice, sole, and whiting; Norwegian spring spawning herring and Northeast Arctic cod; North Sea sole, plaice and herring; Baltic Sea herring). Other stocks were identified by WG members as having similarly documented histories. However, only in the case of North Sea and Baltic Sea herring did the data cover sufficient range of early life stages and extend for an adequate time period (>10 years), to allow any assessment of when year class abundance might be established. Even in the case of North Sea herring, close analysis of the data did not support an unequivocal statement as to the timing of a critical stage in the early life history. The WG was forced to conclude that adequate data to address the term of reference could not be obtained for the stocks within the members remit.

The WG went on to consider whether general statements about when year-class strength might become fixed for different species might be of value to stock assessment. It was concluded that in fact such information was probably of rather limited use since the establishment of year-class strength probably does not occur at the same stage under all circumstances of stock abundance or environmental conditions. Nevertheless, indication of the age or stage beyond which changes in relative abundance of year classes due to factors other than fishing are relatively minor, could be of value in assessing the utility of survey indices.

Although it may not be possible to give clear guidance on the stage at which year-class strength is fixed, the WG considered the need to dis-aggregate the effects of environment on recruitment from the effects of spawning stock abundance and composition, with the aim of exposing underlying stock-recruitment relationships. It is now clear that the survivors of the recruitment process are in all probability not a random sample of the annual egg production, but a select subset by virtue of their spatial, temporal and parental origins. There is strong evidence that the age and size of spawning females confers survival differentials on the offspring. Thus, the standard practice of relating recruitment simply to spawning stock biomass does not make effective use of the extensive information on age structure and spatial distribution of the stock that exists for most assessable species.

The WG considered how spatial, temporal and parental patterns in surviving recruits might be resolved. The so called "birthdate backcalculation" method offers good prospects. In this method, the birthdate distribution of survivors is compared with the temporal distribution of egg production at the whole stock level in order to evaluate relative survivorship of different fractions of the annual production. This approach has been applied to several species (e.g. North Sea sandeels, herring and haddock, Baltic Sea cod, Norwegian Spring spawning herring, Arcto-Norwegian cod) and shown that survivors do indeed originate from distinct subsets of the temporal distribution of eggs, but not a consistent fraction from year to year. In addition to this, ongoing work on cod in Norway and Iceland, haddock in UK, and the Baltic countries has shown strong dependence of viable egg production/kg of spawning stock on the age and size structure of the population. These results indicate that there exists considerable potential to rationalise the basic data on stock and recruitment routinely used in stock assessment procedures. It was suggested that reanalysis of the stock and environment conditions associated with extreme year classes, and investigations of stocks at extremes of the geographical range of a species offered some of the best prospects of exploiting these new ideas. This overall approach seems to offer good prospects of achieving the assimilation of processes orientated information into routine stock assessment procedures, which must be the overall goal of the WG.

The WG noted the Theme Session "Cod and haddock recruitment processes - integrating stock and environmental effects" planned for the 1999 ICES Statutory Meeting. The philosophy behind this Session was very much along the lines discussed by the WG, and arose from a recently completed European Union funded project on recruitment processes. It was proposed that assembling a formal synthesis of this Theme Session would be a very valuable objective for the WG.

Recommendations:

- A synthesis of the 1999 Theme Session "Cod and haddock recruitment processes: integrating stock and environmental effects" should be prepared by M. Heath (UK), B. MacKenzie (Denmark) and G. Martiensdottir (Iceland) for presentation at the next meeting of the WG.

- The WG should sponsor a Study Group on "Incorporation of process information into stock-recruitment models" to address:

    1. Determine the potential use of environmental information in increasing our knowledge (in terms of accuracy) of the underlying stock-recruitment relationship, as they are used in population assessments;
    2. Determine how accurate knowledge of the impact of environmental variations on recruitment or survival can be used to constraint moderate terms (5-10 year) projections of stock abundance, as they are currently applied in population assessments

    (Justification: The relationship between spawning stock and recruitment is fundamental to the scientific approach to fisheries management. However, the basic analytical models which are most commonly applied (e.g. Ricker, Beverton and Holt) have evolved little in the last 30 years, even though knowledge of the physical and biological processes determining the production and survival of early life stages of fish has advanced dramatically in this time. The WG considers that it is now time to seriously consider how this large fund of knowledge can be incorporated into stock-recruitment models which will be of genuine practical value in stock assessment procedures, capitalising on the extensive world-wide investment in research on fisheries recruitment issues.)

3.2 Examine the Robustness of Plankton Survey Design

ToR 2 *Define objectives and tasks required to examine the robustness of plankton surveys design for the generation of distributional indices and to assess whether existing distributional data are sufficient to detect inter and intra-annual patterns.*

This topic was introduced by presentations by Peter Munk, Mark Dickey-Collas, Birgitt Klenz and Pierre Pepin that highlighted different aspects of plankton survey designs:

Herring and cod larvae surveys were presented as examples of problems encountered with different sampling strategies in different environments (Appendix 6.1). Survey designs were developed based on practicality and knowledge of the physical environment. He commented on the need for extensive coverage to cope with changes in distributions and a strategy to ensure that areas of varying abundance are still routinely monitored. He highlighted the problem of missing samples in regular grid surveys in the estimation of abundance. Sampling should be at a suitable scale to resolve spatial patterns, particularly with relevance to physical structures, and suit the dynamic environment of the area. In the case of cod larvae in the eastern North Sea, a fine scale sampling regime seemed appropriate due to the relatively fine scale aggregations of larvae.

Results of a cruise from a series of plankton surveys in the Irish Sea in 1995 that were carried out to investigate cod, plaice and sole egg production were presented (Appendix 6.2). It seemed likely that the variance estimates of each survey were underestimated. Methods such as GAMs (General Additive Models) were being developed to account for the spatial and temporal distribution of egg production. The same surveys are being used to estimate annual *Nephrops* larval production. Again the estimation of variance proved problematic, and bootstrapping techniques were being used to investigate the robustness of the estimates of abundance. He then went on to explore the question of between sample variance, with relevance to a time series of post-metamorphic gadoid abundance. The time series of whiting had a high level of variance that increased with mean abundance, resulting in increased coefficients of variation with the mean. Members of the group commented that high levels of variance were to be expected with organism that showed such levels of aggregation. Discussions followed on a suitable measure of central tendency for populations in which the underlying distribution is unknown.

Recent ichthyoplankton surveys in the western Baltic Sea were carried out in May-June of 1993 to 1997 to investigate biodiversity and the abundance of commercially important species (Appendix 6.3). The number of larvae caught varied throughout the time series. Major concentrations were found at single stations during some cruises. Cod larvae were less numerous than in the central Baltic Sea. It was stressed that the thickness of the reproductive layer was important to cod spawning and so the vertical environment should always be considered. Newly hatched larvae of spring spawning herring were found in 1996 and 1997. The survey could be carried out in half of the time but was extended due to multiple use of ship time. Problems were encountered with the timing of the surveys in relation to fish spawning.

In a discussion paper on statistical treatment of sampling design the variance associated with temporal sampling of spatial grids was investigated using a Fourier-based model of drift and mortality for plankton (Appendix 6.4). This highlighted the interaction of temporal and spatial scales in surveys in a physically dynamic environment. The relevance of suitable resolutions of sampling was illustrated in terms of variance in abundance estimates and resolving complex spatial patterns. An incorrect survey design could result in a greatly increased level of variance, as was highlighted by modelling surveys using two different strategies. A discussion followed as to whether most surveys are designed to reduce the level of variance and as to if these techniques could be used to determine optimum survey design.

In the discussion, a number of points, concerning surveys were raised. Many survey designs work with two dimensions i.e. double or single oblique tows to give numbers per square metre. There are a few survey designs that utilise three dimensional sampling, converting numbers per cubic metre, layer depth and topography of a statistical area to estimate abundance. Some members of the group expressed concern that the two dimensional sampling scheme with raising of abundance to a statistical area may have an unknown bias or error, particularly in areas with highly variable topography. This may need to be examined in more detail.

The group concluded that there is a necessity to look at the perennial problem of non-synoptic sampling of developing populations in a dynamic environment and ascertain ways of correcting for error or bias. There is a necessity to re-examine the spatial and temporal scales of sampling regimes from which estimates of abundance and distribution at different life stages or age are obtained. Current surveys need to be examined to assess whether they provide useful information on recruitment levels and stock / recruit relationships. The group is concerned that a full examination of survey design and the development of protocols will involve substantial additional resources, which to date has not been forthcoming.

The WG recommends that the following tasks should be addressed by the Methods Working Group:

1. Provide a quantitative framework which can be used to determine how dispersal and mortality processes may affect the underlying statistical distribution of abundance and the estimation of central tendency an variance;
2. Determine the accuracy and precision of population survival estimates from sequential plankton surveys taking into account dispersal and spatial variability in mortality rates;
3. Establish the principles of optimal strategies for plankton sampling grids in physically dynamic environments.

The Methods Working Group should take into account the report and recommendations from the Study Group on Spatial and Temporal Integration (ICES CM 1993/L:9). Possible data sets for evaluation may include the North Sea larval herring surveys and the Irish Sea egg surveys.

3.3 Review the Development of Reference Growth Curves

ToR 3: *Review the development of reference growth curves for early life stages of important species and contrast those with existing data on the development from both wild and laboratory studies from various species to provide a baseline for laboratory and field studies.*

Following three presentations (Appendices 6.5-6.7) a general discussion took place with respect to the term "reference growth curves". It was considered more suitable to explicit mention what the growth curves were supposed to reflect. We therefore propose a rephrasing of the term reference growth curves to maximum potential growth curves. The temperature optimum for maximum growth is dependent on prey availability. In poikilothermic animals as fishes several curves have to be established to encompass the entire temperature span the species can encounter. There were concerns regarding whether the curves should be based on individual values or on the mean individual growth of individuals. A possible way to resolve this would be to use the median growth of the fastest growing group at any given temperature, but the use of any given percentile (e.g. the 90th percentile) could be used instead of the mean or median. In any case the growth curves should not be based on average population size at age data since these contain potential bias due to size selective mortality. It was pointed out that the use of average size-at-age data had been used in recruitment studies since 1914 without providing the necessary information to resolve the ongoing processes determining the recruitment in fish populations. Obtaining individual growth data originating from otolith microstructure analysis was conceived as the route to proceed in this respect.

Several other issues/questions arising from the discussion on the potential and use of reference growth curves are listed below with some of the arguments that were put forward.

Question 1: *Can we establish a realistic reference growth function for any species?*

There is a possibility to develop such temperature specific relations, but special attention should be made with respect to the temperature history of the individual larvae and also the parental origin of the larval material. It was recommended that the parental fish (especially the female fish) should be representative of the adult fish population and represent a wide range of age classes. The importance and benefits of integrating such data into unified model framework based on simple mechanistic rules of uptake of use of energy of individuals was stressed. A promising approach might be the use of dynamic energy budgets.

Question 2: *Can laboratory studies realistically be contrasted with field measurements?*

There has been a transfer of knowledge in connection with the efforts on culture of marine fish that has benefited the experimental recruitment research during the last years. This has led to new laboratory rearing experiments with more consistent and predictable outcome, and very high survival rates for herring (95% after 8 weeks from hatching) have been achieved. This is a confirmation of that the environmental conditions offered to the fish larvae in these experiments are not detrimental, and the observed growth rates seem to support the quality and relevance of the laboratory rearing data. It should be noted though that although the larvae initially may perceive the rearing unit as a relatively large habitat, the rapid growth and development will eventually result in space limitation in smaller laboratory units.

Question 3: *What factors are likely to affect the mean response?*

There are a variety of factors that will affect the mean growth response in fish, e.g. temperature, food availability and light conditions. Maternal effects have also been shown to affect the initial offspring size, growth and viability. We suggest to return to the conceptual scheme proposed by Fry (1971) for considering the effects of environmental effects on the physiology of fishes: controlling, limiting, masking, lethal, and directive factors, such as temperature, oxygen content, pollution, toxic substances, and photoperiod.

Question 4: *Is the mean response (growth rate) the appropriate metric to consider?*

It was considered more appropriate to use the growth of the upper percentile (e.g. 90th) of the best growing group as the measure of maximum growth rate.

Question 5: *Should we not consider whether there is selective loss of weaker individuals?*

In the field there are several examples of selective loss of weaker and smaller individuals. With respect to the reference growth curves it was considered that these should address the individual growth trajectories. A preliminary comparison of the apparent growth rate of larval cod in a mesocosm (Parisvatnet, 1991), revealed that the estimated (population) growth rate was higher during the first feeding phase in the mesocosm than according to the model proposed on laboratory data. The subsequent growth during the latter larval stage was somewhat lower than expected, resulting in a similar age at metamorphosis (12 mm) in the mesocosm and the model.

Conclusions:

There has been a marked progress in the development of growth relations in several species reared under controlled conditions such as cod and herring, and future efforts will be made to provide a common model framework that can be used for several marine fish species.

Recommendation:

- The WG should produce a report of "reference growth curves" for a wide range of species in the ICES area.

References

Fry, F.E.J. (1971). The effects of environmental factors on the physiology of fish. In Fish physiology, vol VI (Eds W.S. Hoar and D.J. Randall). Academic Press, London, pp. 1-98.

3.4 Review of On-Going Multidisciplinary Research Projects

ToR 4 *Review the development of new approaches, developments, or techniques used in the study of factors and processes which influence the development and survival of fish eggs and larvae in relation to recruitment or the formation of year-class strength. These should include, but are not restricted to, biochemical and histological measures of condition and their relation to the probability of survival, and modeling methods for the study of drift, dispersal and mortality.*

The WG was presented with a summary of the purpose, goals, and findings from four multidisciplinary international research programs funded by the European Union (Appendices 6.8-6.11).

Results from the project on "Recruitment Processes in Cod and Haddock: Developing New Approaches"; (M. Heath, UK) dealt with exploratory studies of the paradigms that (1) spawning stock biomass was a poor index of viable egg production; and (2) that survivors were non-random subsets of egg production, influenced by maternal origins and spatial/temporal distributions. Results from one component focussed on laboratory and field studies of maternal influences on the growth and survival of fish eggs and larvae. Age, size, and condition of females was shown to influence the time, location and duration of spawning as well as the size of eggs. Studies of birthdate distributions showed that survivors were a distinct temporal subset of the spawned eggs but that this varied between years. Results from patch studies were linked with Individual Based Models (IBM) coupled with particle tracking models which predict the spatial and temporal distributions of length-at-age. Results from this study serve as the basis of a new European Union funded project ("Stock Effects on Recruitment Relationships") which will investigate the potential recruitment based on the distribution and features of the spawning stock of haddock from the west of Scotland.

The objectives and progress of the European Union funded project on "Precision and Accuracy of tools in Recruitment Studies", which started in 1997, was reviewed (C. Clemmesen, Germany). The goal of the project is to improve methods used to monitor the early life stages of fish in terms of indicators of growth, condition and origin of individuals. The work is based on a combination of laboratory and field studies that aim to inter-calibrate methods based on otolith microstructure and nucleic acid ratios (RNA/DNA). Work is being undertaken on several stocks of herring, cod and sardines to establish the general relationships for the various indices. The overall results of the project will be published in a general manual describing standardized methods for the use of otolith microstructure and nucleic acid ratios in the analysis of growth, condition, and origin of larval fish.

The objectives of a new project (to be funded by the European Union) "Environmental and Fisheries Influence of Fish Stock Recruitment in the Baltic Sea" (C. Clemmesen, Germany) aims to forecast the effects of stock structure and environmental factors on the underlying stock-recruitment relationship for cod and sprat in the Baltic Sea. The program is based on a combination of laboratory studies of parental influences on the viability of eggs and larvae and how these interact with toxic substances. The influence of dispersal is to be assessed using hydrodynamic circulation models and the impact of feeding conditions and predator impacts are to be determined from field studies. The overall objective is to develop new recruitment models for the area.

The WG recognized the importance of such projects in developing new perspectives and knowledge of recruitment processes in general. The WG concluded that review and synthesis of future developments within these and other projects should form an important part of the WG long-term activities. The WG also noted the importance of funding by the European Union in the development of research programs dealing with recruitment processes.

3.5 Review of ICES 5-Year Plan and Working Group Activities

ToR 5 *Consider the future work programme in relation to the remit of the Oceanography Committee and the ICES 5-year Plan, including co-operation with other Working Groups.*

After deliberation, and consideration of the results of the ad hoc meeting of the WG held in Lisbon, Portugal (Appendix 6.12), the working group determined that the three primary objectives for activities are:

[1] To provide a biennial overview of fisheries recruitment studies in the ICES area;

[2] To provide a synthesis of specific issues of importance to recruitment studies based principally on discussion and comparison of on-going research;

[3] To investigate the applicability and utility of biological recruitment process models and the incorporation of their results into stock assessment models for the purposes of fisheries management.

The importance of issues pertaining to the study and understanding of recruitment variability was recognized by all members present at the meetings of the WG but the activities of the WG appear not to carry through in Assessment WGs of ICES. The WG came up with the following suggestions as methods to highlight the activities and conclusions of its activities:

- The Working Group should highlight its activities through the development of Theme Sessions as part of the Annual Science Conference. The WG supported the organization of two Theme Sessions (Appendix 6.13) for the Annual Science Conferences in 1999 (Cod and Haddock Recruitment Processes – Integrating Stocks and Environmental Effects; Convenors: M. Heath (UK), B. MacKenzie (Denmark), G. Marteinsdottir (Iceland)) and 2000 (Spatial and Temporal Patterns in Recruitment Processes; Convenors: E. Houde (USA), P. Pepin (Canada), P. Munk (Denmark)).
- The development of focussed multidisciplinary workshops also represents an effective method of focussing on specific issues of importance to recruitment studies. However, there was no commitment at this time to dedicate the resources, time and effort required to co-ordinate such an activity. Many of the issues currently important to recruitment research can be dealt within the context of the WG meetings.
- The WG decided to develop a summary document outlining efforts and successes at dis-aggregating the effects of stock structure and environment on the nature of the stock-recruitment relationship (P. Pepin (Canada), M. Heath (UK), P. Solemdal (Norway), C. Needle (UK)). The document should be published in the ICES Newsletter and distributed to all Assessment Working Group Chairs.

The WG identified the following issues, which represent the long-term focus of activities:

1. Review multidisciplinary projects dealing with recruitment research, with attention to providing a synthesis of the projects and highlighting unresolved issues which deserve future consideration;

2. Synthesize on-going and past studies of the patterns of growth histories and birthdate distributions of surviving individuals;

3. Synthesize knowledge concerning the influence of spawning stock characteristics on viable egg production and subsequent larval survival and recruitment with the goal of dis-aggregating the effects of spawning stock on recruitment from the effects of the environment;

4. Review knowledge of size-dependent mortality, focusing on the modeling and description of patterns of mortality as well as efforts to understanding the possible causes;

5. Assess the possible importance of multispecies interactions (e.g., competition, predation) during the larval and juvenile stages of fish;

6. Review the development of new approaches or techniques used in the study of factors and processes that influence the development and survival of fish eggs and larvae in relation to recruitment or the formation of year-class strength.

Although the WG noted the potential for collaboration with the Working Groups on Shelf Seas Oceanography, Oceanic Hydrography, Zooplankton, and Cod and Climate Change, there were no items at this time that warranted specific recommendations for joint meetings. Future WG discussions should consider potential collaborations with other Working Groups in the hope of increasing inter-disciplinary interactions.

3.6 Review and Nomination of Chair

Review and nomination of the Chair has been discussed at the ad hoc Meeting of the Working Group on Recruitment Processes, Lisbon and again in detail at the Working Group Meeting at Texel, both in the absence of the Chair. The present Chair P. Pepin had indicated that he would be willing to co-ordinate the work of the WG for one more meeting. At both meetings the members present unanimous supported the re-nomination of the present Chair for the period which includes the next WG meeting.

Furthermore, it was concluded that it would be beneficial to the WG to prepare over the next year a short list of those members who would be willing to be nominated to chair the WG after the next meeting. The present Chair was asked to consult all members of the WG by correspondence.

4 RECOMMENDATIONS

- A synthesis of the 1999 Theme Session "Cod and haddock recruitment processes: integrating stock and environmental effects" should be prepared by M. Heath (UK), B. MacKenzie (Denmark) and G. Martiensdottir (Iceland) for presentation at the next meeting of the WG.

- The WG should sponsor a Study Group on "Incorporation of process information into stock-recruitment models" (Chairman: Dr. Carl O'Brien, UK) which will meet during the week of 22–26 November, 1999 in Lowestoft (UK) to address the following issues:

    1. Determine the potential use of environmental information in increasing our knowledge (in terms of accuracy) of the underlying stock-recruitment relationship, as they are used in population assessments;

    2. Determine how accurate knowledge of the impact of environmental variations on recruitment or survival can be used to constraint moderate terms (5-10 year) projections of stock abundance, as they are currently applied in population assessments

    (Justification: The relationship between spawning stock and recruitment is fundamental to the scientific approach to fisheries management. However, the basic analytical models which are most commonly applied (e.g. Ricker, Beverton and Holt) have evolved little in the last 30 years, even though knowledge of the physical and biological processes determining the production and survival of early life stages of fish has advanced dramatically in this time. The WG considers that it is now time to seriously consider how this large fund of knowledge can be incorporated into stock-recruitment models which will be of genuine practical value in stock assessment procedures, capitalising on the extensive world-wide investment in research on fisheries recruitment issues.)

- The WG recommends that the following tasks should be addressed by the Methods Working Group:

    1. Provide a quantitative framework which can be used to determine how dispersal and mortality processes may affect the underlying statistical distribution of abundance and the estimation of central tendency an variance;
    2. Determine the accuracy and precision of population survival estimates from sequential plankton surveys taking into account dispersal and spatial variability in mortality rates;
    3. Establish the principles of optimal strategies for plankton sampling grids in physically dynamic environments;

    The Methods Working Group should take into account the report and recommendations from the Study Group on Spatial and Temporal Integration (ICES CM 1993/L:9). Possible data sets for evaluation may include the North Sea larval herring surveys and the Irish Sea egg surveys.

(Justification: The group concluded that there is a necessity to look at the perennial problem of non-synoptic sampling of developing populations in a dynamic environment and ascertain ways of correcting for error or bias. There is a necessity to re-examine the spatial and temporal scales of sampling regimes from which estimates of abundance and distribution at different life stages or age are obtained. Current surveys need to be examined to assess whether they provide useful information on recruitment levels and stock / recruit relationships. The group is concerned that a full examination of survey design and the development of protocols will involve substantial additional resources, which to date has not been forthcoming.)

- The next meeting of the Working Group on Recruitment Processes should be held in late March of 2000 in Bergen, Norway (Chair: P. Pepin (Canada)), and include the following draft terms of reference, which may be revised in 1999:

1. Review multidisciplinary projects dealing with recruitment research, with attention to providing a synthesis of the projects and highlighting unresolved issues which deserve future consideration;

   (Justification: There currently exists a large number of on-going and planned multidisciplinary and multinational studies which are investigating some of the fundamental processes which influence recruitment patterns and stock dynamics. Since many are not supported through ICES, it is essential that the WG keep abreast of developments, results and conclusions of such projects in order to inform ICES of the applicability and utility of these findings and identify potential avenues of research which should be pursued.)

2. Synthesize on-going and past studies of the patterns of growth histories and birthdate distributions of surviving individuals;

   (Justification: There is a growing body of knowledge concerning the patterns of survival of individual recruits which clearly indicate that events and selection patterns are non-random. It is essential that the WG identify possible generalities which are apparent among various studies in order to determine whether certain management practices might be beneficial in ensuring the greatest potential viable production of recruits from spawning stocks.)

3. Synthesize knowledge concerning the influence of spawning stock characteristics on viable egg production and subsequent larval survival and recruitment with the goal of dis-aggregating the effects of spawning stock on recruitment from the effects of the environment;

   (Justification: Variability about the stock-recruitment relationship has often been assigned to environmental variability. However, there is considerable evidence that indicates that characteristics of the spawning adults (e.g., condition, age, size, spawning history) influences the potential viability of eggs and larvae. To provide ICES with up-to-date information about the potential effects of altering stock structure, the WG must provide a consensus synthesis of existing information.)

4. Review knowledge of size-dependent mortality, focusing on the modeling and description of patterns of mortality as well as efforts to understanding the possible causes. Efforts should address how widely current knowledge can be applied in the estimation of Spawning Stock Abundance and in the understanding of recruitment variability;

   (Justification: Patterns of size-dependent mortality are considered to be widespread among fishes. However, there needs to be a complete assessment of the general patterns of size-dependent mortality in order to provide reliable tools for the study of recruitment variability as well as in the back-calculation of spawning stock abundance based on egg and larval abundance data. Members of the WG are very active in this area of research and can provide fundamental insight into which models and methods are most appropriate to estimate mortality rates of egg and larval stages.)

5. Assess the possible importance of multispecies interactions (e.g., competition, predation) during the larval and juvenile stages of fish;

   (Justification: Most ichthyoplankton studies treat individual species as an island, which is not influenced by other species with which it co-occurs. Because many commercial species represent only a minor component of the overall community, the WG has determined there needs to be an evaluation of the potential for competitive or predator-prey interactions among larval and juvenile stages of marine fish in a diversity of environments.)

6. The WG should produce a report of "reference growth curves" for a wide range of species in the ICES area.

(Justification: The interpretation of variations in patterns of growth requires that an underlying perspective of growth potential be established. There must be development of an understanding of the fundamental processes which govern growth dynamics in larval and early juvenile fish.)

7. Review the development of new approaches, developments, or techniques used in the study of factors and processes that influence the development and survival of fish eggs and larvae in relation to recruitment or the formation of year-class strength.

   (Justification: The dynamic nature of research on recruitment processes requires that ICES be kept informed of new developments in approaches used in the study of various elements used in the study of recruitment dynamics. Careful appraisal of new methods, approaches, and techniques will provide the ICES community with the combined expertise of WG members.)

8. To Review progress of the of the Study Group on "Incorporation of process information into stock-recruitment models" (Chairman: Dr. Carl O'Brien, UK).

5 TIMETABLE OF WORKING GROUP ON RECRUITMENT PROCESSES

Wednesday 7 October

9:00-10:40	Introductory remarks, terms of reference and adoption of agenda ICES 5 Year Plan - defining the role and activities of the WG
11:00-12:30	ToR 1 -- Determining when year-class strength is fixed. Evaluation of data needs and analytical approaches
13:30-17:00	ToR 2 -- Spatial and temporal patterns in the distribution of fish eggs and larvae Presentations (limited to 15-20 min): Munk, Dickey-Collas, Klentz, Pepin Discussion and plan of action

Thursday 8 October

9:00-10:40	Tor 3 Review the development of reference growth curves Presentations : Folkvord, Solemdal, Pepin
11:00-12:30	Summary of on-going (or planned) collaborative projects. Issues arising.
13:30-15:00	Round table discussion of 5 Year Plan.
15:30-17:00	Break off into small groups to summarize discussion, draft report. Outline recommendations
17:00-17:30	Review and nomination of Chair (H. van der Veer)

Friday, 9 October

9:00-12:00	Presentation and discussion of draft report.

6 APPENDICES

6.1 The herring data from the North Sea and examples of survey designs. (Peter Munk, Danish Institute for Fisheries Research, Denmark)

Summary:

The extensive data set on herring in the North Sea is presented. This data set includes time-series of overall abundance of herring at 4 life stages. All abundance estimates are available for the period 1976 to 1994, when dramatic changes in abundance of herring were observed. Comparison between abundance of given year-classes measured at different life stages could be used in the evaluation of recruitment patterns.

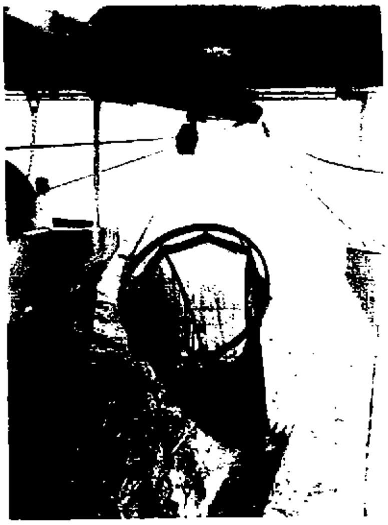
The estimate of North Sea herring at the late larval stage, is carried out as a separate survey programme during a standard trawl survey programme (International Bottom Trawl Surveys). The larval sampling programme and survey results are briefly presented. The production of distributional indices and the robustness of the programme is discussed, and compared to a survey programme on larval North Sea cod. The comparison illustrates the importance of developing the survey programmes with proper consideration of the practical possibilities (sampling intensity, gear catchability etc.) and the physical/biological variability.

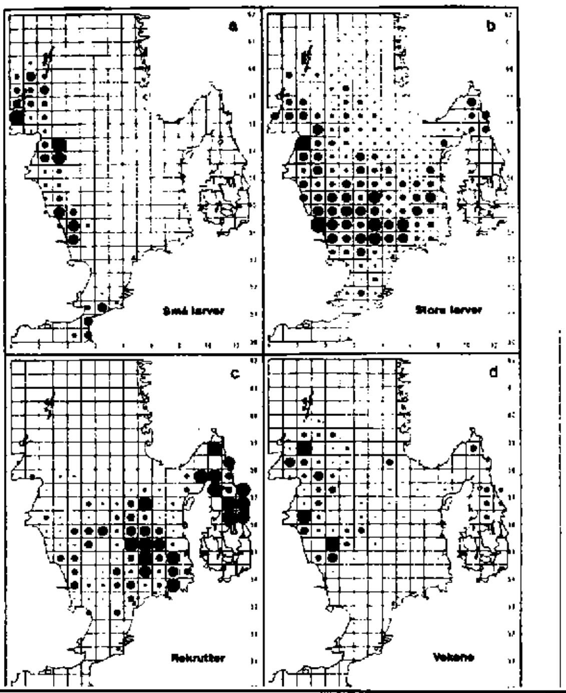
I) The sampling scheme and the data on different life stages of North Sea herring, illustrated as data series of possible interest in relation to ToR 1.

Available data series on North Sea herring

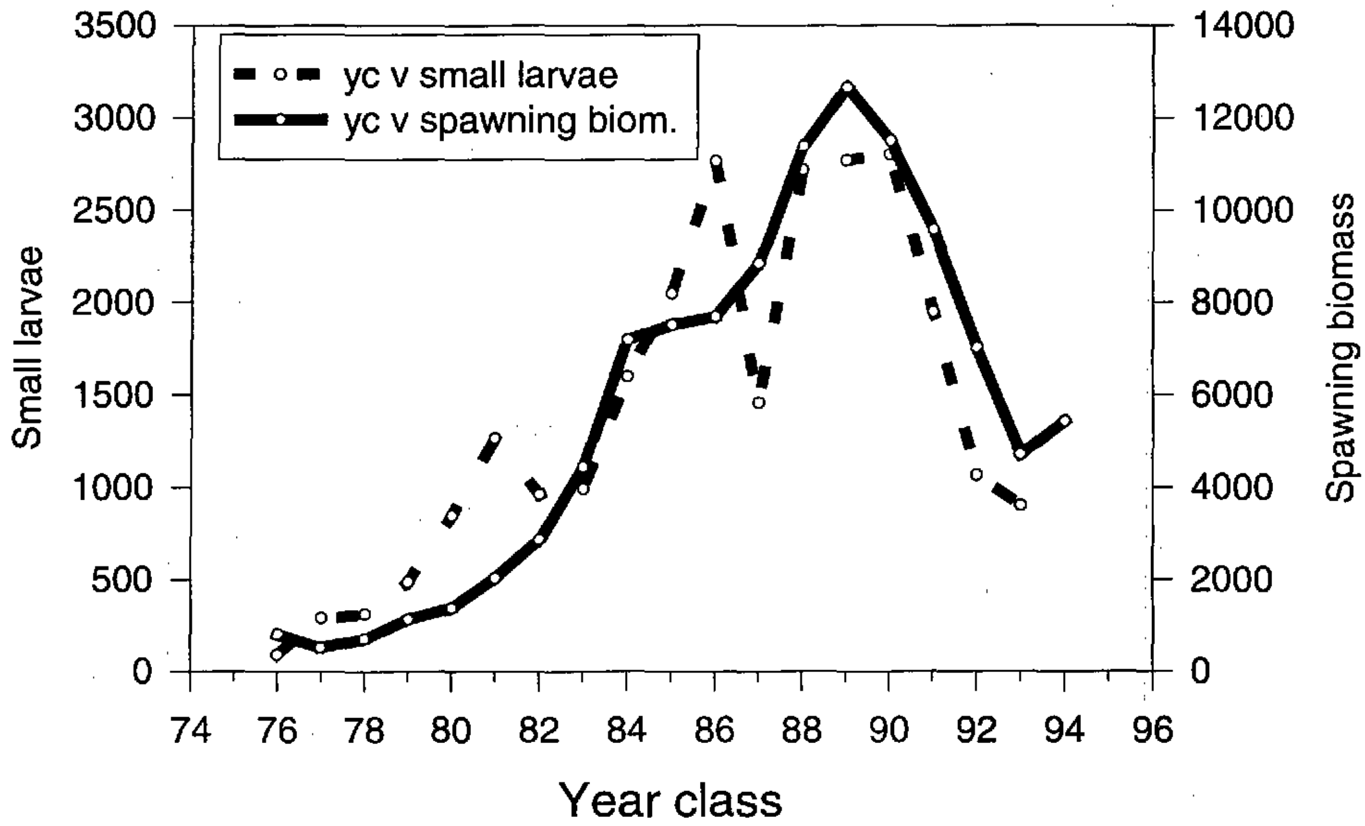
Stage	Sampling	Time-series
LARVAL 1-3 weeks of age	Larval Surveys (IHLS) 24 h with high speed sampler	1972-93(present)
LARVAL 5 months of age (0-ringers)	Bottom Trawl Surveys (IBTS) Night time with ring net	1977-present
JUVENILE 17 months (1-ringers)	Bottom Trawl Surveys (IBTS) Daytime with bottom trawl	1979-present
ADULT Spawning stock	VPA (tuned 1977-present)	1947-present

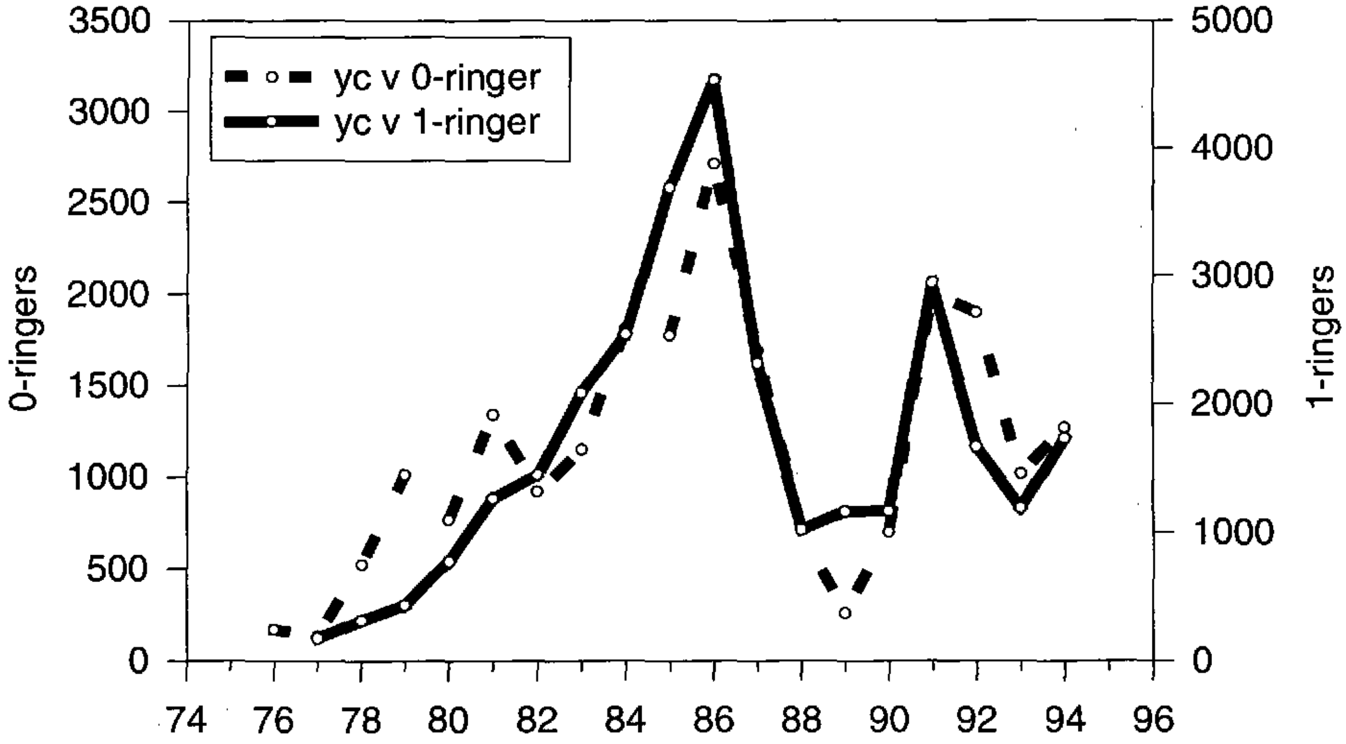
To the left: The gear used for the sampling of large larvae (a 2 meter ring net, with 1.5 mm mesh of black netting). To the right: An example of the major distributions of the different life stages of North Sea herring (data for the 1984 year class). a) small larvae in September, b) large larvae in February, c) juveniles in February, d) adult herring in February





Indices of North Sea herring abundance





Two plankton surveys are illustrated, and used as examples for the discussion of distributional indices and robustness of survey design: (Terms of Reference 2)

[a] The large herring larvae

- participating countries
- At night
- 2-meter ring net
- Oblique, column integrating hauls
- Two hauls at random in 30x30 minutes (lat/long) rectangles
- Approx. 300 hauls covering the entire North Sea/Skagerrak/Kattegat

<u>Questions about robustness of survey design</u>

Constant catchability ?	Indication of approximately 100% catchability: Low avoidance at night-time, gear of fixed large opening, small meshed net, used at relatively high speed (3 knots).
Full coverage of potential area of distribution ?	Yes, sampling covers entire North Sea, Skagerrak and Kattegat. However, a specific stock is not included (larvae too small).
Are significant concentrations always sampled ?	Yes, concentrations appear much larger than the resolution of the sampling grid. *However, bad weather might lead to large unsampled areas*
Is sampling grid appropriate?	Yes, the sampling is reasonably 'dispersed'. It is flexible, which is needed when combining larval sampling with the daytime trawling. *However, the sampling is not completely random, it might be biased*
Are differences between areas detectable ?	Yes, significant differences among areas
Are differences between years detectable ?	Yes, significant differences among years

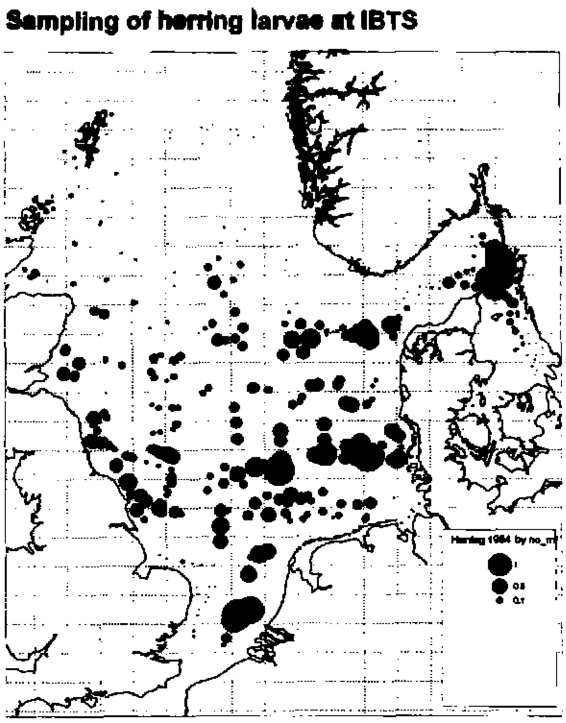
[b] The cod larvae

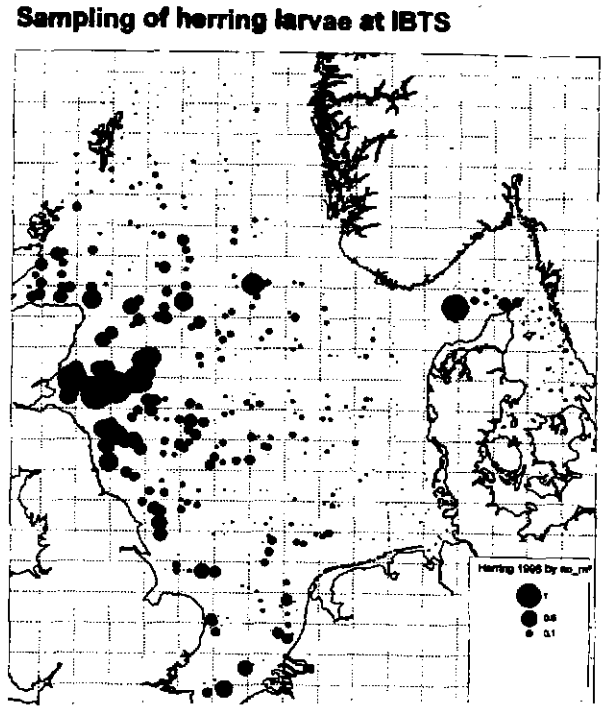
- 2-3 participating countries
- At night and day
- 2-meter ring net
- Oblique, column integrating hauls
- Transsect based sampling
- Approx. 100 hauls covering Northern North Sea and Skagerrak

Questions about robustness of survey design

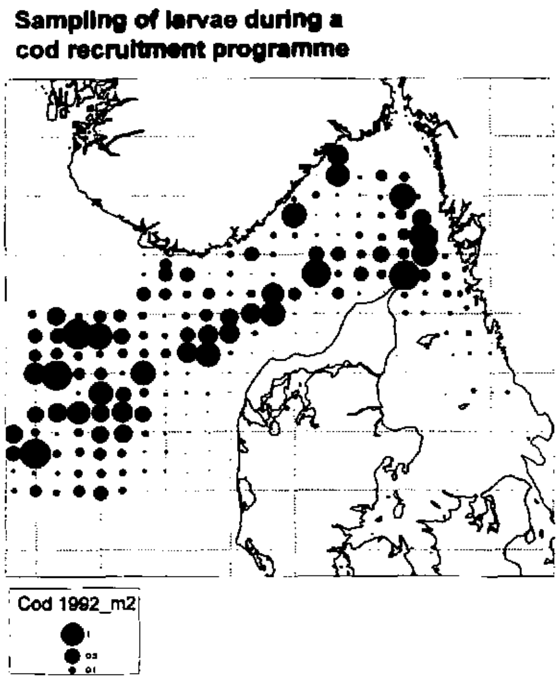
Constant catchability ?	High catchability even at daytime. Gear of fixed large opening, small meshed, 3 knots. *However, day- and night-time catchability differs, and when using both periods the daytime catches need to be calibrated.*
Full coverage of potential area of distribution ?	*No, not including entire stock*
Are significant concentrations always covered?	Yes, significant stratification/frontal activity in May results in patchy distribution of larvae, but transect sampling ensures that major concentrations will be identified
Is sampling grid appropriate?	Appropriate for investigation of processes. *However, for standard distributional indices, a finer sampling net across the narrow bands of concentration, and more closely spaced transects will be necessary.*
Are differences between areas detectable ?	Significant differences among areas
Are differences between years detectable ?	Significant differences among years

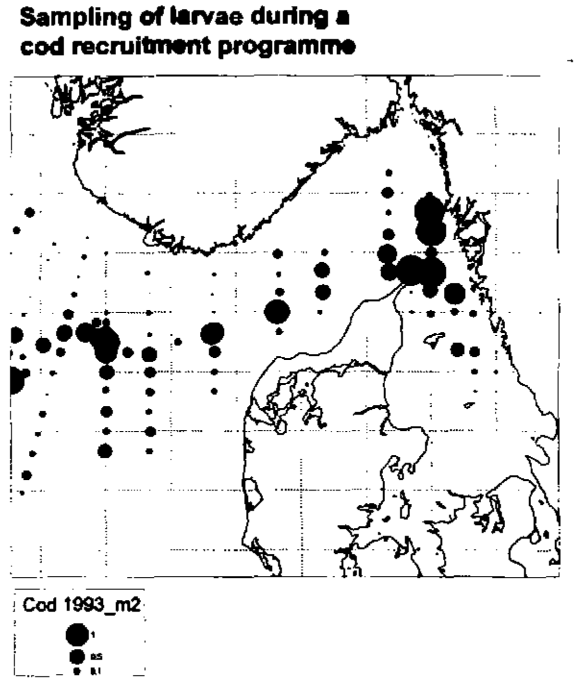
a) The herring larvae sampling programme (examples of survey results 1984 (left) and 1998 (right))





b) The cod larvae sampling programme (examples of survey results 1992(left) and 1993(right))





6.2 Spatial and temporal patterns in fish eggs and larvae in the Irish Sea. (Mark Dickey-Collas, AESD, Department of Agriculture for Northern Ireland, Belfast)

Various plankton surveys are carried out by the Department of Agriculture for Northern Ireland. Their main purpose is to provide fishery independent abundance data for stock assessment, as either time series indices or as investigations of absolute abundance by egg or larval production methods. The target species are cod, haddock, whiting, herring, plaice, sole and *Nephrops*.

The annual egg production method has been successfully used for Irish Sea cod in 1995 (Figure 6.2.1). A series of cruises enabled an egg production curve to be estimated (Figure 6.2.2). These data were analysed by investigating the mean abundance and variance in predetermined sampling strata. However the temporal element of the surveys caused problems in estimating total production so now General Additive Models are being developed to cope with the spatial and temporal differences within and well as between sampling cruises.

Similar annual production methods have also been used for sole, plaice and *Nephrops* egg or larval production. However due to the problems associated with spatial and temporal edges, these methods have not proved so robust, primarily because surveys have failed to sample the entire production period. Methods to investigate the variance in the estimation of *Nephrops* annual larval production (Figure 6.2.3), are being attempted using bootstrap techniques. However yet again these are proving heavily dependent on the assumptions made about the underlying distribution of the data. Additional problems are being encountered in the estimation of the production at time zero due to poor estimation of the variance of mortality in stage 1 of the *Nephrops* larvae. Monte Carlo techniques are being investigated to address this problem.

Annual surveys of the western Irish Sea are being made to investigate the variation in abundance of pelagic juvenile gadoids between years (Table 6.2.1). There appear to be problems with the survey design. The gadoids appear to be very highly aggregated whether their abundances are high or low. So mean abundance from each survey do reflect changes between years but the overall variance increases so greatly in years of high abundance that the CV increases with the mean (Figure 6.2.4). Further field sampling and analysis is required to address this problem.

Table 6.2.1. The mean abundance (numbers per m²) and spatial variation in abundance estimated of the pelagic juveniles for 3 gadoid species in the western Irish Sea from 1994-1998.

	cod		**haddock**		**whiting**	
year	mean	standard error	mean	standard error	mean	standard error
1994	0.057	0.0179	0.047	0.0155	0.778	0.2988
1995	0.007	0.0043	0.002	0.0016	0.225	0.0623
1996	0.066	0.0266	0.048	0.0146	0.397	0.1085
1997	0.002	0.0021	0.015	0.0086	0.205	0.1165
1998	0.000	0.0000	0.000	0.0000	0.059	0.0316

Figure 6.2.1. Stage 1 egg abundance in the Irish Sea on 15-22 March 1995.

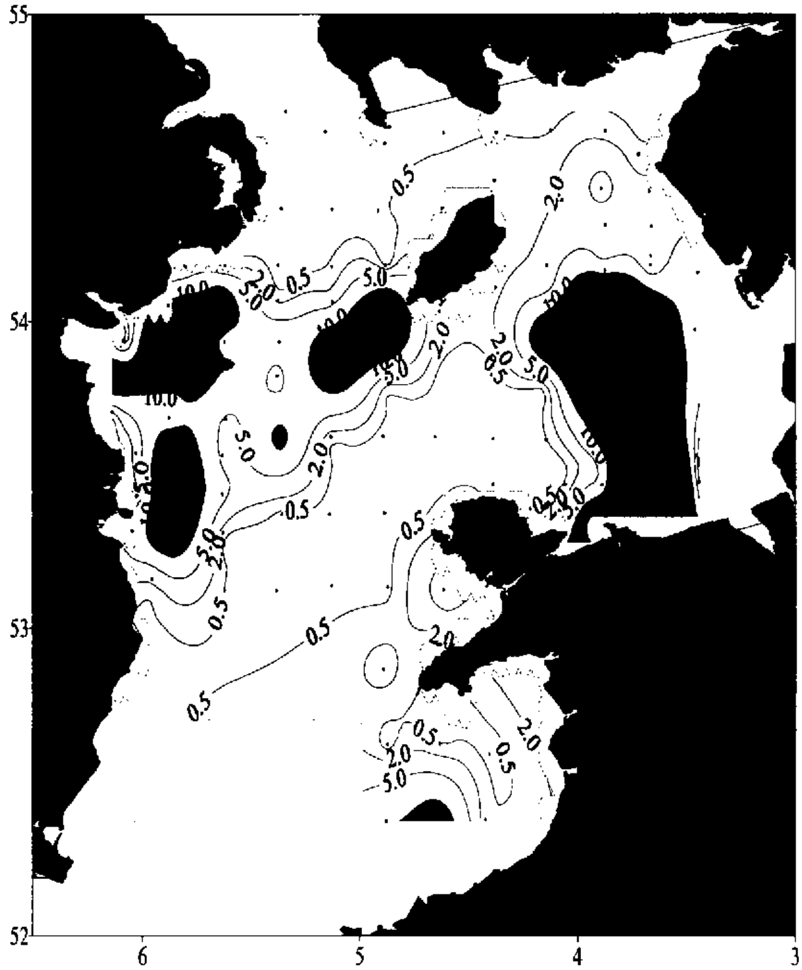


Figure 6.2.2. The production of cod eggs in the Irish Sea in 1995.

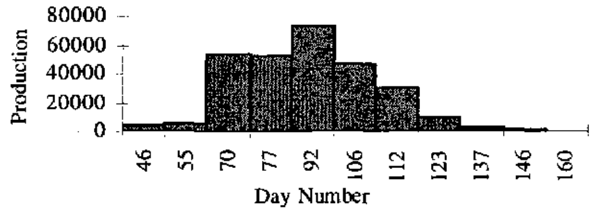


Figure 6.2.3. Production of *Nephrops* larvae in the western Irish Sea in 1995.

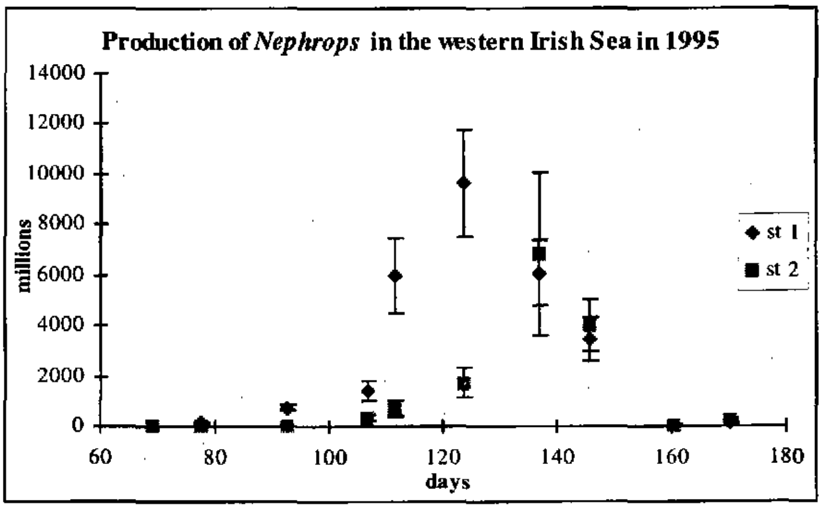
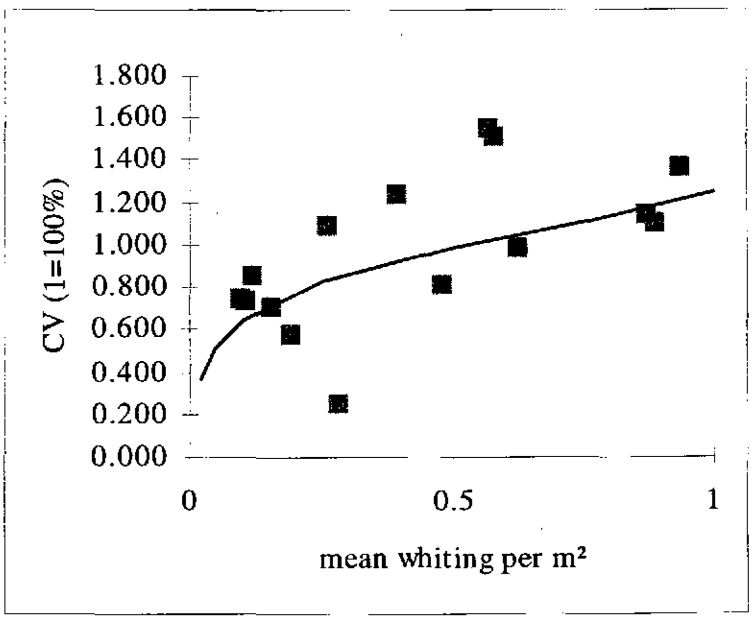


Figure 6.2.4. The coefficient of variation over mean abundance estimate of whiting from each survey strata (1994-1998), in the western Irish Sea.



6.3 Abundance and distribution of larvae of commercially important western Baltic fish species in the period 1993 - 1997. (Birgitt Klenz, Institute for Baltic Sea Fishery, Rostock, Germany)

The results of this working paper were based on four ichthyoplankton surveys carried out on a standard station grid in the Belt Sea and Arkona Sea (ICES Subdivisions 22 and 24) in May or June. Samples taken by means of Bongo - Nets (0.5 mm and 0.335 mm mesh size) were considered in these studies. The paper gave an account of the sampled larvae and juveniles of herring, sprat, cod, dab, european plaice and flounder. They are species with a high fecundity and a long developmental phase in the plankton communities. Their reproduction success is determined very essentially by the environmental conditions in this phase.

In the working paper there were selected some of the results of the German ichthyoplankton studies in the western Baltic Sea. They dealt with the abundances of larvae and juveniles of western Baltic cod stock and the environmental effects on the development of early life stages of cod. In the plankton samples from this area of investigation cod larvae have never been numerous. The level of their mean abundances was below the mean densities of larvae of the eastern Baltic cod stock in the Bornholm Basin. For 1994 a better reproduction potential as numbers of produced ripe cod eggs within the western Baltic Sea as one of the biological bases for the year - class strength had been announced by Oeberst & Bleil (1996). But an important factor for the normal development of cod eggs is the thickness of the reproduction layer with favourable environmental conditions. During the ichthyoplankton survey in June 1994 bottom water temperatures were observed that were at the upper limit for the normal development of cod eggs. In spite of an good egg production announced an unexpectedly low hatching success in the spawning area was confirmed caused by high mortality rates and developmental defects (Anon. 1994, Bleil 1994, Klenz 1998).

Additionally the paper dealt with the discrepancy between low numbers of cod larvae sampled and strong cod year - classes estimated on the basis of young fish surveys (ICES 1998). In ICES SD 22 the spawning process began in February, in SD 24 in March (Bleil & Oeberst 1997). The larvae hatching was observed ten to fourteen days after spawning (pers. comm. Bleil 1998). So one of the conclusions of the paper was:
Till 1998 the research vessel time in May or June was used for multiple objectives. But the ichthyoplankton surveys in ICES SD 22 and 24 as part of these cruises were too late in time. Ship time for sampling cod larvae after the peak spawning in the western Baltic Sea must be in April.

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6.4 Partitioning the influence of physical processes on the estimation of ichthyoplankton mortality rates: theory and application to simulated and field data. (P. Pepin, Department of Fisheries and Oceans, St. John's, Newfoundland, Canada)

We examined the effects of natural spatial-temporal variability in ichthyoplankton concentration and in currents on the estimation of mortality rates. We derive expressions for the biases and variances of mortality estimates computed from the change in plankton concentration between successive surveys as well as estimates of the corrections due to the advection of plankton. We demonstrate that estimate bias depends primarily on how well the mean current and mean ichthyoplankton fields are sampled, whereas the variance depends on the variability about the mean in currents and plankton concentration and on the time and length scales on which this variability occurs. Simplified versions of the theoretical expressions provide an easily implemented framework for evaluating the quality of field sampling plans. The theory was verified through a series of numerical simulations and by comparing predicted variances in estimated fluxes with those observed in an earlier field study. In the simulations, errors in estimated mortality rates were clearly dominated by errors in estimated fluxes due to transport, and estimates of variance and bias were all in good agreement with theoretical predictions. For the field data, the theory predicted a distribution of values slightly lower than that observed, but of the correct order. That the model performed well for both simulated and field data suggests it can be applied in practice with reasonable confidence. We also briefly explore the role of the model in survey design and analysis for ichthyoplankton studies in which transport might be important.

6.5 Progress made on the construction of reference growth curves. (Arild Folkvord, Department of Fisheries and Marine Biology, University of Bergen)

The work on establishing temperature dependent growth relations in cod (*Gadus morhua*) and herring (*Clupea harengus*) has continued since last Working Group meeting in Halifax. The results from two manuscripts were presented (Fiksen & Folkvord, in prep.; Otterlei et al. subm.).

Larval and juvenile growth was clearly temperature and size dependent in larval Norwegian coastal cod (NC) and Northeast Arctic cod (NA) (*Gadus morhua* L.) fed in excess on live zooplankton (Figure 6.5.1). Growth in length and weight increased successively with increasing temperature from 4 to 14°C with a corresponding reduced larval stage duration (*D*). Maximum growth rate occurred at a larval size of 0.1-1.0 mg dry weight, followed by a declining trend during the juvenile stage. Temperature optimum (T_{opt}) of larval cod is indicated to be in the range of 14 to 16°C with a maximum weight specific growth potential (G_{max}) exceeding 25% day^{-1}. For both stocks, temperature specific growth curves of dry weight at age are well described by a generalised Gompertz model (Figures 6.5.2 & 6.5.3). A stock specific difference in mean dry weight at age was observed, with NC growing better than NA. The length-weight relationships of cod indicate a positive allometric growth in both the larval (b_{larv}=4.0 to 4.1) and juvenile (b_{juv}=3.7) stages. A stock specific difference in weight at length was observed for early juveniles, with NC being heavier than the NA. Overall, a positive correlation between temperature and condition level were found. No distinct temperature or stock specific differences in survival were observed.

A preliminary comparison of the predicted temperature dependent growth of larval cod with observed data from a mesocosm study indicated that the predicted size-at-age was lower than the observed size-at-age during the first two weeks after first feeding, but that this difference gradually disappeared towards metamorphosis. Further investigations relating to the possible size selective mortality during first feeding in the mesocosm will be carried out, as well as further evaluation of the generalised Gompertz model.

In herring larvae reared in excess on natural zooplankton the growth rate was also strongly temperature dependent, but no marked size dependencies were evident during the larval stage. A simplified linear model for absolute length increase (corresponding to a constant weight growth rate) was therefore suggested. A basic individual based model describing herring larvae ingestion and growth based on first principles is being developed, and the results of this model is initialised and compared with existing laboratory growth data on herring. Some examples of model runs with varying feeding and environmental regimes were presented.

References

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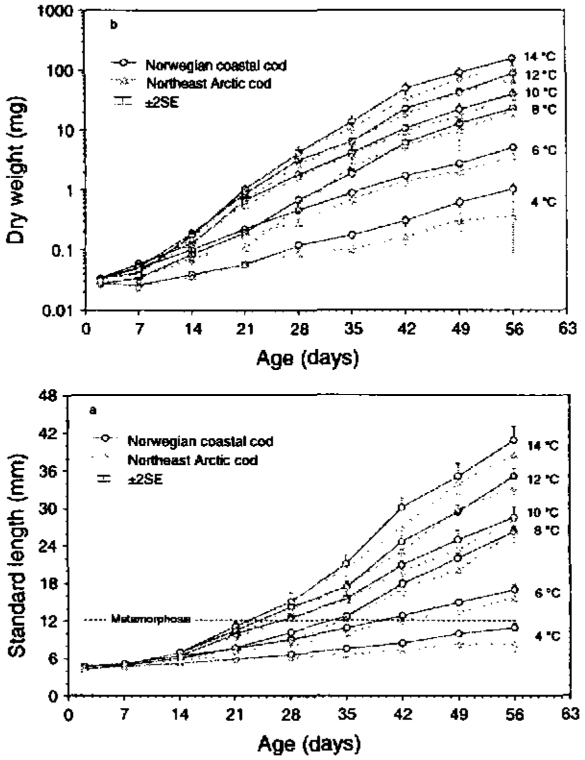

Figure 6.5.1. Mean dry weight (mg) and length-at-age (mm) of Norwegian coastal cod and Northeast Arctic cod reared at 6 different temperatures(Data from Otterlei et al. Submitted).

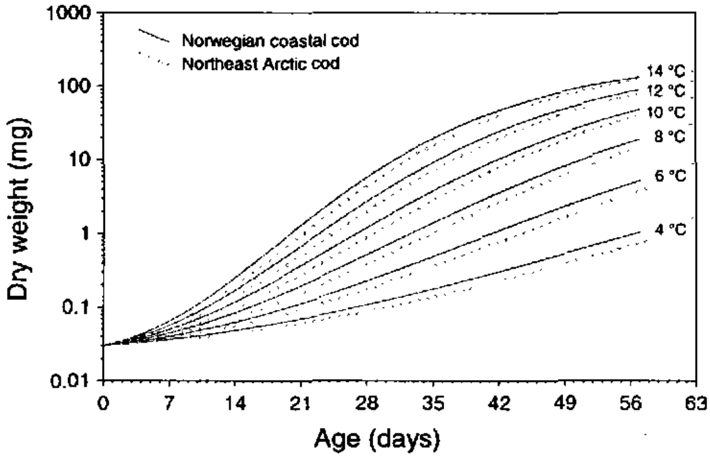

Figure 6.5.2. Modified Gompertz growth curves of ln dry weight-at-age for Norwegian coastal cod and Northeast Arctic cod larvae and juveniles reared at 6 constant temperatures from 4 to 14°C(Data from Otterlei et al. Submitted).

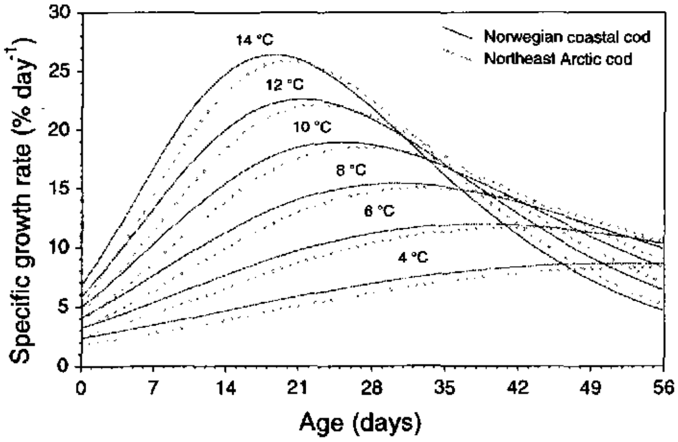

Figure 6.5.3. Estimated weight specific growth rate at age for Norwegian coastal cod and Northeast Arctic cod larvae and juveniles reared at 6 constant temperatures from 4 to 14°C. Values for growth rate are estimated from the derivative of a modified Gompertz equation (Data from Otterlei et al. Submitted).

6.6 Long-term studies on spawning in Norwegian coastal cod and Arcto-Norwegian cod - mortality patterns in eggs and early larvae from first and multiple spawners. Per Solemdal, Olav Sigurd Kjesbu (Institute of Marine Research, Norway), Valeri Makhotin (Institute of Ichthyology, Moscow State University, Russia) and Merete Fonn (Institute of Marine Research, Norway).

Total egg production to characterize the reproductive potential of the spawning population of Arcto-Norwegian cod instead of traditional spawning stock biomass estimates was introduced by Marshall et al. (1998). However, this does not only involve calculations based on size-dependent fecundity data, (Kjesbu et al. 1998), and number of spawners of different size. Refining the estimates of the reproductive potential also includes the inclusion of some phenomena which have yet to be taken into account. The main factors are atresia, (Kjesbu et al.1991.), and the varying frequency of different types of malformations and mortality occurring during embryonic development related to age/size and condition of the females, called the maternal effect (Nikolski 1962). To investigate the significance of this effect in first and multiple spawners cod from two tribes (Arcto-Norwegian and Coastal) were kept for several years in captivity and the patterns of egg production and quality were monitored for several individuals. For detailed information on methodology see Solemdal et al. (1995), Kjesbu et al. (1996) and Solemdal et al. (1998).

Care was taken to ensure the well-being of the cod in these long-term experiments, and the following variables were recorded regularly to monitor that fish health was within the desired limits: growth, maturity stage, condition, fecundity, spawning rhythm and frequency of irregular egg production. On the basis of this information 6 out of 10 of the Norwegian coastal cod and 3 out of 8 of the Arcto-Norwegian cod had to be excluded from the egg mortality analysis.

Figure 6.6.1 shows the egg mortality pattern during development in the four Norwegian coastal cod as first and multiple spawners. All experiments of the four coastal cod females are pooled and show a steady reduction in egg mortality from first to third time spawner. The difference in egg mortality levels is caused by a variable mortality at the blastula stage, when the maternal genetics is still the ruling factor in development. The mortality patterns from the four individual Norwegian coastal cod show the same tendency towards a reduced egg mortality with age (Figure 6.6.2). In Figure 6.6.3 the data for the four coastal cod are pooled with average egg diameter given at the top of the histograms. This indicates that the maternal effect is partly the result of changes in egg size during growth of the individual.

Identical experiments were carried out for Arcto-Norwegian cod. In addition, an inspection of the newly spawned eggs were performed. A part of these results are shown in Figure 6.6.4. The frequency of "good eggs" (normally developing eggs) shows an increase from first to second spawning for 5 of the 8 cod females. Cod females 5,7 and 8 are shown to be «unhappy» according to the criteria given above. Egg mortality in Arcto-Norwegian cod in first and second spawners, 1997 and 1998, is shown in Figure 6.6.5 (parallel to Figure 6.6.2 for coastal cod). The same irregularities are traced in cod females 5, 7 and 8 which provides reasons to exclude them from our analysis. However, when the results from all the cod females are included in the analysis, we found a statistically different pattern, at the 5% level, between first and second time spawners, based on a Wilcoxon non-parametric test. The experiments clearly demonstrated that the mortality patterns were the result of developmental malformations at different critical stages during development. The time from which the malformation occurred until death depended on type of malformation. Often, the malformed embryo survived until hatching but died a few days after. The proportion between mortality occurring during the egg and early larval stages seem to be fixed from year to year (Figure 6.6.6)

Main conclusions:

1. There is a general tendency of a reduced egg mortality and increased egg size in second-time spawners compared to first-time spawners in both Norwegian coastal cod and Arcto-Norwegian cod. This mechanism is mostly related to developmental problems during the blastula stage.

2. The reduced egg mortality is somewhat larger in Norwegian coastal cod . The reason for this difference probably relates to the fact that the two tribes mature at very different sizes, Arcto-Norwegian cod being the larger.

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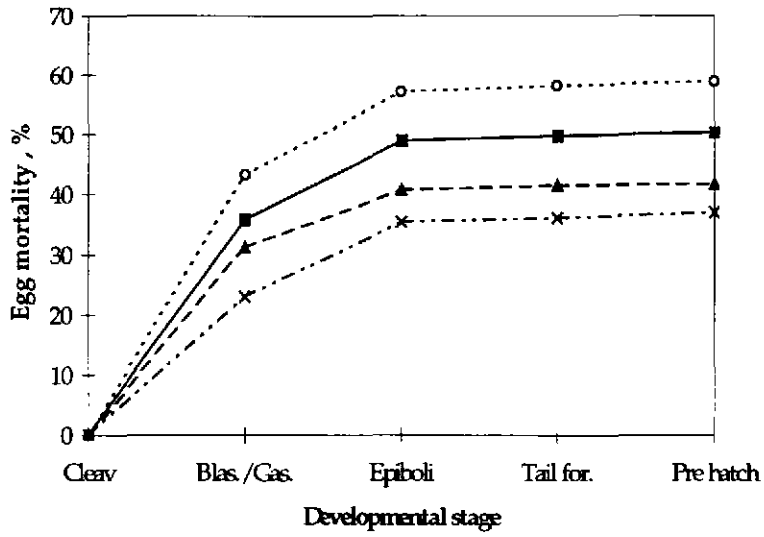

Figure 6.6.1 Cumulative egg mortality curves from captive Norwegian coastal cod

—■— All egg mortality experiments, cod females 1,4,5 and 6.
- - o - - First time spawners, 1,4,5 and 6.
– ▲ – Second time spawners, 1,4,5 and 6.
– × – Third time spawners, 1,4,5 and 6.

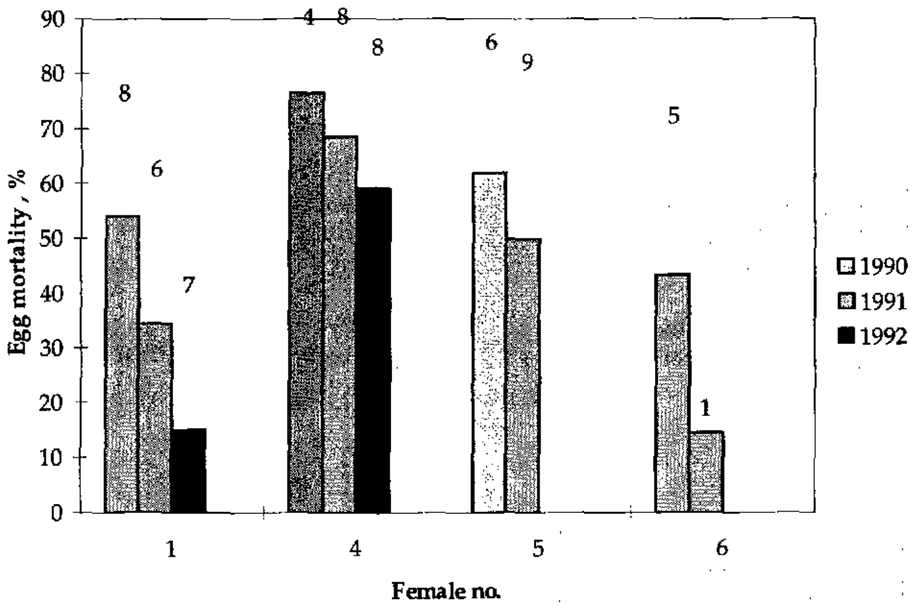

Figure 6.6.2. Average egg mortality from Norwegian coastal cod nos 1,4,5 and 6 as first (1990), second (1991) and third (1992) time spawners. Numbers of experiments are indicated at the top of the histograms.

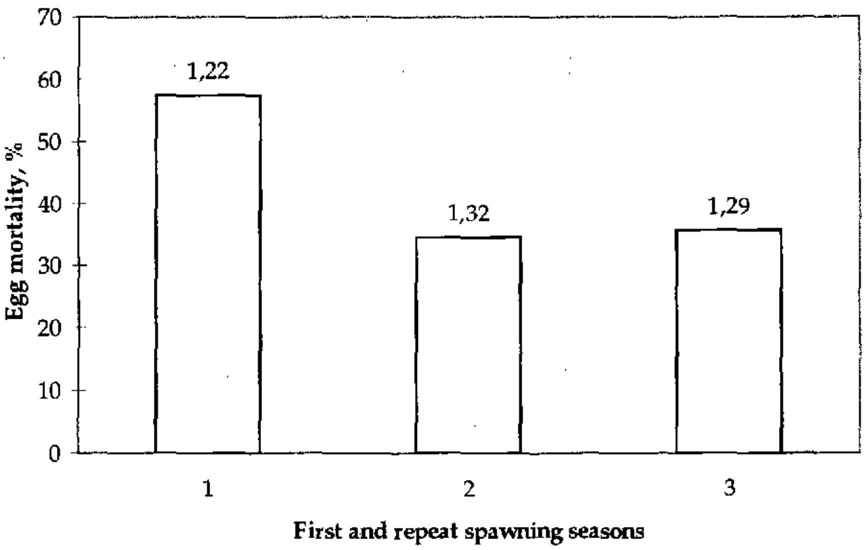

Figure 6.6.3. Total egg mortality, in percent, weighted from Norwegian coastal cod nos 1,4,5 and 6 based on 65 egg mortality egg experiments. Mean diameter of the eggs is shown at the top of the histograms.

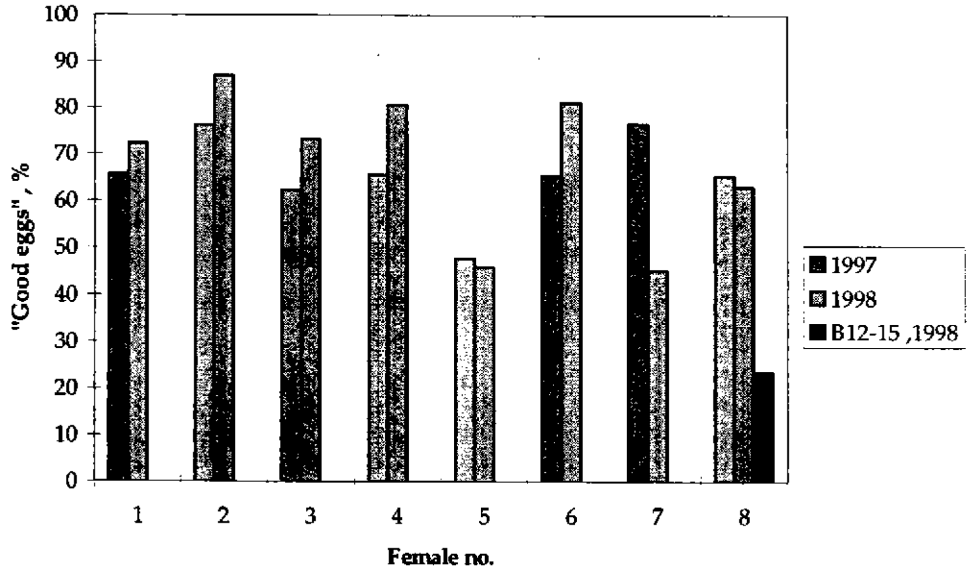

Figure 6.6.4. Percentage of "good eggs", at the time of collection, from Arcto-Norwegian cod, during the 1997 and 1998 spawning seasons. Egg batches 12-15 from female eight are given seperately.

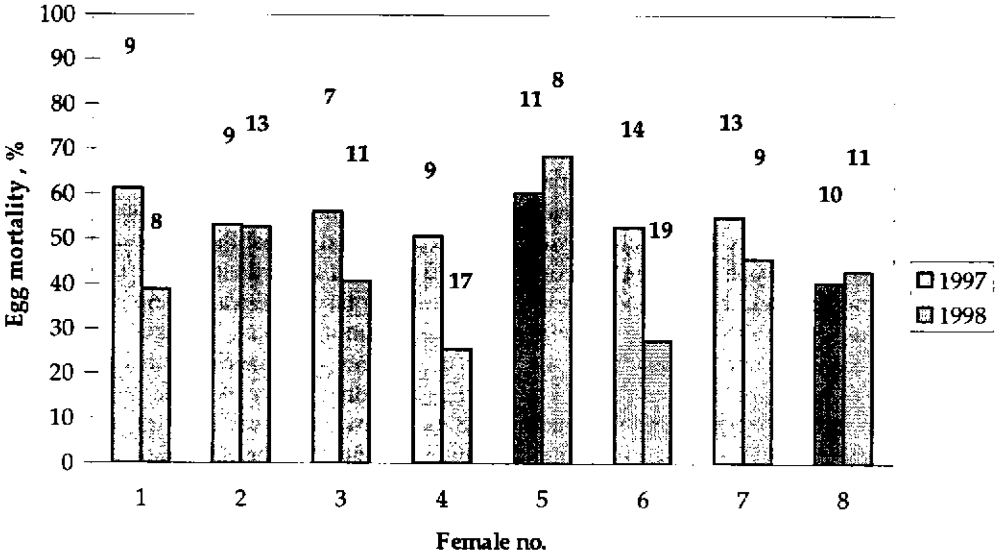

Figure 6.6.5. Average egg and early larval mortality from eight Arcto-Norwegian cod females, during the 1997 and 1998 spawning seasons, using the NUNC-tray method. Numbers of experiments are indicated at the top of the histograms.

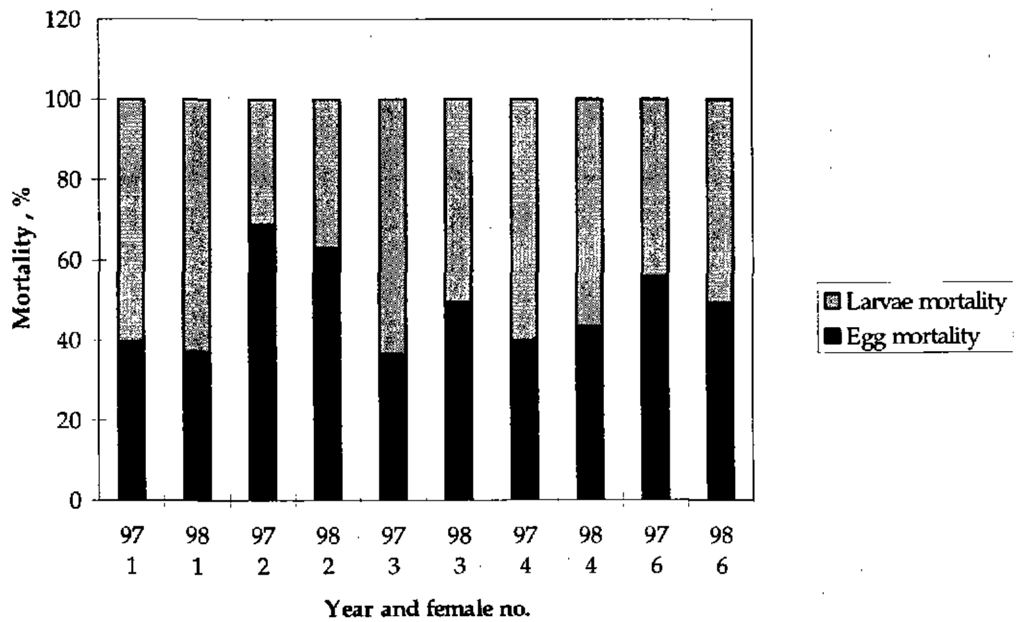

Figure 6.6.6. The individual proportion of mortality during the egg stage and early larval stage (before starvation). The relation is given separately for 1997 and 1998. Data from female 1,2,3,4 and 6.

6.7 Patterns of RNA/DNA ratios in larval fish and their relationship to survival in the field. (P. Pepin, G.T. Evans, T.H. Shears, Department of Fisheries and Oceans, St. John's, Newfoundland, Canada)

A fish larva that survives until metamorphosis has been unusually lucky. This might be the result of unrelated events in successive time intervals, or perhaps some of its luck consisted of attaining a superior condition that gave it a better chance of survival for many days in succession. Is persistent good condition important for determining larval survival? Is survival like winning a lottery or a scholarship? How could we tell? The first requirement would be to measure some condition factor that might plausibly be associated with increased survival probability. If poor-condition individuals are more likely to die, the probability distribution for condition will contract towards its upper tail as time goes by. In this study, we have chosen nucleic acid ratio to indicate the condition of a larva. we want to be able to track changes in the whole distribution so that we can see what is happening in the important upper tail. We have no prior theory for how the distribution ought to look or change, and we shall therefore use the non-parametric methods for estimating the whole probability distribution of condition and how it depends on age (or some proxy like size). The methods are applied to nucleic acid ratio data collected as part of population studies of several larval fish species from Conception Bay, Newfoundland. Our ultimate goal is to establish whether general changes in the distribution of condition measured as nucleic acid ratio reflect the survival probability when compared among species. Analyses and parameter estimates are based on collections from several surveys and years and thus represent general life history features of the species rather than cohort-specific tracks.

The results show that the upper limit in condition appears to be relatively constant and independent of total DNA: maximum production, and consequently the rate of protein synthesis, is constant within a species. The smallest individuals have a condition distribution with low scatter and relatively close to maximum values. The scatter in condition increases to a maximum at an intermediate level of total DNA, and decreases at higher levels. Maximal scatter occurs at total DNA levels found in larvae which have recently exhausted their endogenous energy reserves. The overall pattern of variation is roughly similar among all species studied. The broadest range covers about 1.5 orders of magnitude in condition levels. The rate of selection against weaker individuals was measured as the average rate of change of scatter with respect to length. Decrease in scatter, interpreted as selective mortality, is correlated with total mortality.

6.8 Summary of final report: *Recruitment Processes in Cod and Haddock: Developing New Approaches.* EU Contract Number: FAIR-CT95-0084: 1 January 1996 - 31 December 1997

Coordinators: Dr M.R.Heath, Dr P.Wright (Fisheries Research Services, The Marine Laboratory, PO Box 101, Victoria Road, Aberdeen, AB11 9DB, Scotland).
Partners: Dr O.Kjesbu, Dr S.Sundby, Dr T. van der Meeren (Institute of Marine Research, PO Box 1870 – Nordnes, N-5024 Bergen, Norway); Dr G.Marteinsdottir (Marine Research Institute, Skulagata 4, PO Box 1390, 121 Reykjavik, Iceland); Dr B.MacKenzie, Dr M.St John (Danish Institute for Fisheries and Marine Research, Charlottenlund Castle, DK-2920 Charlottenlund, Denmark).

Objectives of the Project

The overall objective of the project was to evaluate methodologies for partitioning sources of variability in gadoid recruitment between effects due to spawning stock structure (*i.e.* age composition, spatial distribution) and those due to the environment. This represents a significant advance on earlier approaches which have focussed on single classes of processes. The approach to this problem was twofold:

- Develop an environmental survival index, based on sound understanding of processes, so that a more realistic specification of the statistical error distribution about stock recruitment relationships can be provided.
- Establish the importance of the structure of the spawning stock, by accounting for the non-linearity between stock biomass and viable egg production, thereby allowing an examination of the potential value of manipulating stock-structure to reduce the probability of low recruitment.

To achieve this the project has developed a conceptual framework within which the following specific objectives are addressed through a combination of field measurements, studies in mesocosms and the laboratory, and modelling:

- Determine the relationship between spawning stock structure and the timing, duration and amplitude of egg production,
- Determine the relationship between female age, size and condition and the viability of eggs and larvae,
- Determine the relative contribution of the various components of the annual egg production to the surviving population of pelagic juveniles,
- Determine the relationship between larval growth rate and survival,
- Determine the environmental factors which influence individual growth rate and derive a suite of environmental parameters which could provide an index of their contribution to year-class survival,
- Evaluate methodologies for coupling environmental indices of survival to data derived on the effects of stock structure, so that their relative importance can be evaluated.

Introduction and Rationale

Gadoid fish produce very large numbers of eggs per individual, and only a small proportion survive to recruit to the adult stock. In the case of most NE Atlantic gadoid stocks the relationship between the abundance of the spawning stock and subsequent annual recruitment is generally obscured by a combination of factors. These include environmental effects on the survival of eggs and larvae and the use, for lack of alternative information, of spawning stock biomass as an index of the reproductive output of the adult population. Environmental factors exert strong control over the mortality rates of eggs and larvae, possibly through starvation but also through the dynamics of predator populations. At the same time, the survival of larval fish is linked to their growth rate. In general, the survival of fast growing individuals over a growth interval, will be higher than that of slow growing individuals. With regard to the reproductive output from the spawning population, egg production per unit biomass varies with the size, age and condition of the females, and so changes in the population structure associated with exploitation and annual differences in year-class strength are likely to have a major effect on population fecundity. These effects are not taken into account by conventional analyses of stock-recruitment relationships.

The aim of the project has been to establish the priorities and develop methods for investigating recruitment mechanisms in gadoid species, focussing on Icelandic and Norwegian cod stocks and North Sea haddock. The eventual aim is to be able to disaggregate the effects of changes in spawning stock structure on stock-recruitment relationships, from effects due to the environment. This is an important goal because it has the potential to significantly reduce the uncertainty in the models currently used to assess the sustainability of fisheries.

The key findings of the project are:

- The timing and distribution of spawning activity in both cod and haddock populations studied is strongly related to the age and size composition of the adult stock,

- The size and viability of larvae is strongly related to the size of eggs, which is in turn related to batch number, size and spawning history of the adult females,
- For North Sea haddock, the juvenile fish surviving to the demersal phase in August were not drawn at random from the annual egg production by the adult stock. In 1996, spawnings in early April contributed a disproportionate number of recruits,
- A patch tracking study of larval haddock growth and survival showed that hatch date, rather than short term variations in environmental conditions contributed most to the variability in individual growth rates, and hence to survival. The fastest growing individuals in the study were from spawnings in early April,
- Laboratory experiments showed that signatures of diet composition and feeding rate of reared cod and haddock larvae can be detected in the biochemical composition of individuals. However, there was little relationship between these indices and temporal variations in environmental conditions during the patch tracking study in the North Sea. Larvae appeared to be feeding maximally under the range of conditions encountered during the study,
- Turbulence regimes, representative of those encountered in the field can be generated artifically in mesocosms. Protocols for conducting experiments on the effects of turbulence on larval fish feeding and growth have been developed. However, simulation modelling indicates that current theory is not sufficiently robust to predict the consequences of such experiments,
- Strategic modelling of the interaction of growth and mortality rates for the composition of larval fish populations shows that short-term variability in growth rates can significantly modify, and in some cases mask, the outcome. These results were partly confirmed by rearing experiments in mesocosms. No relationship between growth and mortality rates could be detected in the results from the patch tracking study on larval haddock,
- Modelling predictions of the most favourable hatch-sites for subsequent growth of larval cod and haddock in the North Sea matched closely with the observed distributions of eggs of the two species,
- The project has deveoped a strategy for integrating models of egg production by cod and haddock spawning stocks with bio-physical models of egg and larval dispersal and survival, to produce a system capable of evaluating the relative contributions of stock structure and environmental effects on recruitment.

<u>Summary of results</u>

Maternal effects and egg production

Samples of cod were obtained from four areas in Icelandic waters (2 offshore and 2 inshore) and of haddock from two areas in the North Sea. Potential fecundity and the incidence of pre-ovulatory atresia were measured by a variety of methods. Data on atresia allow estimation of the proportion of potential egg production which is resorbed by the ovaries rather than being shed.

This study provides the first estimates of potential fecundity in Icelandic cod since 1967. The new estimates are significantly higher than those from the earlier period for fish of equivalent size and age, possibly reflecting unfavorable environmental conditions and presumably low food levels during the late 1960's. This is especially true for the older fish in the population. Relative fecundity was shown to increase with age and size of cod and to be influcence by liver condition. This study has also been the first to estimate the realised fecundity of haddock, *ie*. the number of eggs that are actually spawned as opposed to the number of oocytes present in the ovaries of the female stock. Age, size and spatial differences were demonstrated for the North Sea populations.

The study indicates that size and age-specific differences in reproductive development are important for protracted spawning. Results from the comparison of size and age of mature females suggested that in both cod and haddock the largest females begin spawning first. In haddock, but not in cod, the age of females also seems to be related to the onset of spawning, the older females tending to begin spawning earlier than young ones. The duration of spawning also appears to be related to size and age. In Iceland, the size of eggs produced by the spawning population decreased as the season progressed. This effect was most pronounced in the larger females in the population. In addition, female body size and egg diameter were directly related.

Detailed laboratory and mesocosm studies on the characteristics of eggs and larvae in relation to female attributes found initial batches of eggs from repeat spawners were larger than those from recruit spawners, but eggs in the final batches were the same size. The dry weight of larvae decreased with batch number, and was independent of previous spawning experience. Viability and swimming activity of larvae decreased with batch number for recruit spawners but not for repeat spawners, but feeding incidence and growth rates of larvae were not related to batch number.

Field and laboratory studies of larval growth and survival

The range of birth dates estimated by back calculation from otolith ring counts of both pelagic and demersal juvenile haddock sampled in the North Sea showed temporal differences in survivorship with most of the surviving demersal juveniles in August originating from spawning in early April. The environmental basis for variability in the survival rate of gadoid larvae was investigated during a drift tracking study of a patch of larval North Sea haddock to the east of the Shetland Islands during May 1996. The patch of larvae was tracked for around 10 days during which sampling was carried out on a 6h schedule. A wide range of meteorological conditions were encountered during the study, which coincided with the onset of the spring phytoplankton bloom. Analysis of the microstructure of otoliths removed from larvae failed to show a consistent relationship between individual daily growth rates and short term (day-to-day) variability in environmental factors such as food concentration and turbulence. However, there was strong relationship between individual growth rate and birthdate, with later spawned individuals in the tracked patch having higher growth rates. Time series data on the vertical distribution of haddock larvae showed a strong tendency for the larvae to aggregate in mid-water (25-50m depth). During daylight there was a slight movement of the population towards the surface, whilst the population was distributed deeper in the water column at night. For the largest size groups of larvae, this behaviour was modified by wind induced turbulence. During calm periods the larvae ascended closer to the surface during daylight than during windy periods.

A range of individual-based biochemical parameters were measured on haddock larvae collected during the drift study, and laboratory calibrations of these parameters were carried out on reared cod and haddock larvae. The laboratory studies showed that differences in food abundance have a significant effect on lipid-based condition indices in early larval haddock. However, free fatty acid levels in larval cod were found to be insensitive to short-term variations in food abundance, rendering them unsuitable for application as short-term indicators of food consumption. Tryptic enzyme activities and gut fullness indices for haddock larvae captured during the field programme showed that feeding incidence was generally high but varied strongly according to a diel cycle. Day-to-day variations in tryptic enzyme activity were only weakly related to prey concentration and turbulent dissipation rates. Similarly, RNA/DNA ratios suggested that growth rates were generally not, or only weakly, related to either food concentration or turbulence during the 48 h prior to capture. However there were large variations in RNA, protein and lipid content between individual haddock larvae of the same length, indicating wide variability within the population in growth, condition and the ability to survive stressful conditions (*eg.* low food abundance, attack by predators). Some of this variability can be attributed to the diet composition of the larvae since those individuals having a high proportion of lipids characteristic of diatom dominated food chains were in better condition (more lipid per body mass) than those with a high proportion of dinoflagellate tracer lipids. Overall, it seems that the growth of the haddock larvae in the patch was in general not limited by food, which was available in excess in the water column. Thus, short-term variations in turbulence and plankton concentration were not strongly reflected in otolith growth or the biochemical indices of growth.

Modelling

The modelling aspects of the project have been on two levels. Firstly, strategic individual based modelling was used to explore the interaction between growth-dependent mortality and short term variability in the growth rate of larvae, and the effects of turbulence on prey capture. Secondly, a spatially resolved individual based model of the dispersal and growth of cod and haddock larvae was developed for the North Sea.

The strategic modelling of growth-dependent mortality showed that linkage between growth rate and mortality rate has the power to substantially affect the composition of the surviving population. However, some conditions of fluctuating environmental conditions, leading to fluctuating growth rates, could mask these effects. Data to test the conclusions were obtained during mesocosm experiments on cod larvae carried out in Norway. Replicate mesocosms were maintained under different feeding regimes and the otolith microstructure of the surviving populations analysed at various stages. The results show that under high ration regimes the survivors in the population are drawn from the fastest growing components of the initial population. However, under low ration conditions the surviving population appeared to be drawn at random (with respect to daily growth rate) from the initial population.

The prey capture modelling showed that whilst turbulence in the water column can enhance the rate of encounter between larvae and their prey, the same factor can have a detrimental effect on the success of capture. Conclusions as to the response of larvae to turbulence are critically dependent on assumptions about the prey capture process, and to the representaion of turbulent velocity structure in the model. The latter aspect was investigated during a series of mesocosm experiments during the project, in which the statistical structure of turbulence generated in enclosed systems was measured by various instruments.

The spatially resolved modelling concentrated on the population dynamics of cod and haddock larvae in the North Sea. A particle tracking scheme, with water flow and temperature inputs from a hydrodynamic model of the NE Atlantic, was coupled to a simple representation of individual growth in the larvae. The objective was to determine the hatching origin of larvae with the highest probability of survival under climatological mean conditions. The results showed that haddock larvae hatched on the outer continental shelf early in the season (late March) had a higher probability of survival than those hatched in the North Sea. However, as the season progressed through to May, the distribution of favourable hatch sites moved into the North Sea. A similar seasonal shift in the distribution of most favourable spawning areas occurred for cod. Comparison of the modelled distributions of favourable hatch sites showed a strong correlation with both the spatial and temporal distributions of spawning activity by haddock and cod stocks.

Overall conclusions

At the simplest level, the project has exposed the complexity underlying the relationship between spawning stock biomass and recruitment. This has long been recognised, but uniquely, this project has simultaneously addressed the problem both from the perspective of the adult stock and the survival of larvae. Usually, such projects focus only on environmental considerations. The scope for recruitment variability due to the age and size composition and condition of the maternal stock seems greater than has previously been appreciated.

The integration of observational, experimental and modelling skills in the project has been particularly fruitful. An important development has been a framework for modelling the annual egg production by a fish stock, from routine assessment data supplemented with measurements of key biological parameters. The rationale for this model effectively synthesises the understanding of cod and haddock reproductive biology accumulated during the project. However, the key development has been the realisation that the surviving juvenile population at recruitment is not drawn at random from the initial egg stock. This has been clearly demonstated by the field programme on North Sea haddock, where the survivors originated mainly from a resticted temporal component of the annual egg production. It is clear from this work, and from the modelling studies, that spatial, temporal and maternal factors can all confer enhanced survival probability on eggs and larvae. As a result, the surviving juveniles can potentially originate from distinct subsets of the spawning distribution under given climatic and stock composition scenarios. This conclusion has major implications for the way in which the sustainability of fisheries is evaluated, and for the implementation of conservation measures. The developments produced by the project should provide a platform for incorporating these concepts into future fisheries management.

6.9 Executive Summary of "Stock Effects on Recruitment Relationships"

Administrative Coordinator: Dr. S. Mellergaard (Danish Institute for Fisheries and Marine Research, Denmark)
Scientific Coordinator: Dr. M. R. Heath (Fisheries Research Services, The Marine Laboratory, Scotland)
Partners: Prof. J. Backhaus (Institut fur Meereskunde, Germany), Dr A.Gallego (University of Aberdeen, Scotland), Dr O.Kjesbu (Institute of Marine Research, Norway), Dr G.Marteinsdottir (Marine Research Institute, Iceland), Dr B.MacKenzie (Danish Institute for Fisheries and Marine Research, Denmark), Dr E.Mckenzie (University of Strathclyde, UK)

Summary

The overall objective of the project is to improve the methodology for determining limit reference points for the biomass of exploited fish stocks. Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits, and are integral components of the decision making process in fisheries management. In most cases limits are currently estimated from historical time series data on spawning biomass and recruitment. However, the underlying stock-recruitment relationship is often poorly defined by such data and hence there is considerable uncertainty around many reference limits. This project will produce an operational scheme for refining stock-recruitment data by incorporating biological, spatial and temporal information on the stock structure, with the aim of reducing the uncertainty associated with the derived limits. The methodolgy will be developed for cod and haddock stocks around Iceland, Norway and in the North Sea as case studies.

The approach will be to develop a series of interconnected models mapping the development of individual fish from the point of spawning, through the egg and larval phase, to settlement out of the pelagic phase. The individual based nature of the models is the key element that will confer the ability to achieve the desired aims. In essence, it is recognised that each individual in the population has a unique parental origin and experience of the environment which confers a particular survival probability. Variability between individuals is especially high during the early life stages and capturing this feature is the key to successful modelling.

Demonstration and testing of the the operational system will be accomplished by hindcasting the histories of effective reproductive output for cod and/or haddock stocks in the northern North Sea and at Iceland. These derived data will be used as substitutes for the spawning biomass term in stock-recruitment relationships. Confidence intervals around reference limits based on the new relationships will be then be compared with those based on the conventional analysis of stock-recruitment data.

Work Content

The objective is to build a system that will predict the probability of contributions by different spatial, temporal and parental components of the spawning stock of a species to the juvenile pre-recruit population some months after spawning. The system must be formulated in such a way as to address the following strategic questions for a given stock:

1. *What are the relative contributions of different age and size components of the spawning stock to the surviving juvenile population of a year class?*
2. *What are the relative contributions of different spatial and temporal components of the annual egg production to the surviving juvenile population of a year class?*
3. *What is the sensitivity of 1) and 2) to exploitation strategies?*
4. *What is the sensitivity of 1) and 2) to spawning stock size?*
5. *What is the sensitivity of 1) and 2) to climatic scenario?*

The system will be developed for application to cod and haddock stocks, but must in principle be sufficiently generic to permit tailoring to other species.

The structure of the system will comprise a series of interconnected models mapping the development of individual fish from the point of spawning, through the egg and larval phase, to settlement out of the pelagic phase. The individual based nature of the system is the key element that will confer the ability to achieve the desired aims. In essence, it is recognised that each individual in the population has a unique origin and experience of the environment which confers a particular survival probability. Variability between individuals is especially high during the early life stages and capturing this feature is the key to successful modelling.

The project is divided into 7 tasks which fall under four categories of activity:

- model development
- supporting initiatives to improve the representation of processes in the models
- data assimilation
- regional implementation

Model development will involve the coding and testing of four modules, followed by their coupling together to form an integrated system. The modules will be:

- A conventional Virtual Population Analysis (VPA) based model to predict the whole-stock age composition and abundance of fish under different exploitation strategies, linked to routines for estimating the spatial probability distribution of fish based on statistical analyses of historical data and allowing for different scenarios of spatial distribution in fishing mortality. The module will draw heavily on the catch statistics assembled by annual ICES Assessment working Groups and the outputs will be spatially resolved data on the abundance of fish age classes.
- An egg production module. This will predict the spatial and temporal distribution of eggs by the spawning stock, and the distribution of egg quality. The basis of the module will be that fish of different size, age and spawning experience have different reproductive outputs.
- An egg and larval dispersal, growth and survival module. This will simulate the dispersal through space and time of a population of individuals, starting life as eggs and developing into larvae and pelagic juveniles. The growth and development of each individual in the model will be simulated from the estimated exposure to key environmental conditions along the dispersal trajectory, and survival probaility will be coupled to individual growth rates and at appropraite stages, to the concentration of individuals to mimic density dependence. The output of the module will be the spatial and temporal distribution of individuals by age, size, and cumulative survival probability.
- A pelagic juvenile settlement module. This will determine which of the individual larvae surviving to a particular size and/or age may join the demersal juvenile population. Settlement success will be on the basis of spatial criteria parameteriesed from observational data, and temporal criteria based on the cumulative number of individuals already settled in a particular area. The total number of successfully settled individuals, and their distribution, will be the final output from the system as a whole.

Supporting initiatives will be essential to the optimum formulation and parameterisation of the modules. These must include investigations of:

- The relationships between fish age, size and condition, and the timing, duration, quantity and quality of reproductive output.
- Characterisation of the vertical distributions of eggs and larvae and functional relationships describing spatial and temporal variability in growth and survival.

Where necessary, the supporting initiatives will depend on the collection and analysis of new field observations and experimentation, but maximum usage will be made of existing data and resources.

Data assimilation will be a significant task in the project. Oceanographic and hydrodynamic data will be required to configure the modules to particular regions, especially the egg and larval module. Historical trawl survey data will be required to configure the settlement success module. Analysis of historical survey data will be necessary to provide the parameters for simulating adult stock distributions, and to provide testing data against which some of the results can be evaluated.

Regional implementations will be the vehicle for demonstrating and testing the operational system. The aim will be to hindcast the histories of effective reproductive output for cod and/or haddock stocks in the northern North Sea and at Iceland, as substitutes for the spawning biomass term in stock-recruitment relationships. Fitted relationships between observed recruitment and effective reproductive output will be compared with the conventional spawning biomass-recruitment models to assess the improvement in resolution achieved.

6.10 Executive Summary of EU-Project PARS: "Precision and Accuracy of Tools in Recruitment Studies", (1997-1999)

Coordinator: E. Moksness (Institute of Marine Research, Flodevigen, Norway)
Partners: A. Folkvord, A. Johannessen (Department of Fisheries and Marine Biology, Bergen, Norway); A. Geffen (University of Liverpool, Port Erin Marine Laboratory, U.K.); A. Garcia (Instituto Espanol (IOE), Malaga, Spain); C. Clemmesen, D. Schnack (Institut fuer Meereskunde, Universitaet Kiel, Germany); H. de Pontual (IFREMER, LASAA, Brest, France).

This project is concerned with improving the methodologies used in investigations and monitoring of the early life stages of fish larvae. These are important in both stock assessments and underpinning strategic research intended to improve predictive capability. The proposal deals with precision and accuracy issues in two categories of measurements which together encompass most of the data which are routinely required from samples of early life stages of fish:

- The growth and condition of individuals (TASK 1)
- The origin of individuals (TASK 2)

Task 1: Growth and condition:

The aim of this part of the study is to investigate the physiology of growth and development in larvae by a series of controlled laboratory and mesocosm studies,as well as field sampling on herring and sardine larvae in order to improve the understanding of the growth processes and increase the accuracy of condition and survival predictions from biochemical and otolith microstructure measurements. Growth and condition are of paramount importance in recruitment research related studies. Early life history survival and the environmental mechanisms influencing them constitute an essential task in recruitment processes oriented research. Two principal tools are applied to investigate growth and condition:

A) Otolith Microstructure

To determine precision and accuracy of otolith microstructure otoliths from laboratory and mesocosm rearing experiments will be given to the partners for comparative readings. Compare error estimates from intercalibration exercises and apportion ageing errors amoung sources: preparation, reading, biological (growth/stock/season) will be determined. Results have to be evaluated to make recommedations on the limitations or appropriate application of microstructure tools .

B) RNA/DNA

The aim of this study is to evaluate growth rates based on nucleic acid determinations and to determine correlations. Intercalibrate existing RNA/DNA techniques to reconcile the results obtained using different standard buffers and extraction techniques. Compare results on nucleic acid content determined in different laboratories using unified standard techniques. Increase the knowledge of the latency, dynamics and sensitivity of RNA/DNA ratios depending on food availability, size and temperature to increase the accuracy and precicion of RNA/DNA ratios as a tool for recruitment studies.

Linking larval growth and condition

Determine whether growth estimates and larval condition are coupled. Analyse whether otolith growth reflects somatic growth determined by protein metabolism. Determine whether compensatory growth processes are operating. By coupling RNA/DNA ratio determinations and otolith increment structure analysis on the same larva the response time to changes in the feeding environment can be comparatively studied and the decision whether the larva's condition is improving or deteriorating can be analysed.

Task 2: Stock origin and otolith composition

The objective of this task is to examine the effects of environmental parameters (temperature, water composition) on otolith microchemistry, to examine the temporal level of resolution for determination of otolith microchemistry, to identify the benefits and disadvantages of the different analytical tools available for measuring otolith microchemistry, and to test the precision of otolith microchemistry determinations by means of intercalibration excercises between the different laboratories. Evaluate the analytical results to make recommendations on the limitations or appropriate application of microchemistry tools. With multi-variate techniques, test the addition to precision and accuracy of stock determination and temperature record resulting from microchemisty analysis.

TASK 3: Synthesis

Partners will synthesize and evaluate the analysed data, determine precision and accuracy of the techniques and combine illustrations and text for guidelines presented in form of a manual.

Further information is available on the web homepage: http://www.efan.no/pars

6.11 Executive Summary of EU- Project STORE: *Environmental and fisheries influences on fish stock recruitment in the Baltic Sea,* 1999-2001.

Coordinator: Institute of Marine Science, Kiel, Germany

Partners: Danish Institute of Fisheries Research, Charlottenlund (DIFRES), Denmark; Finnish Game and Fisheries Research Institute, Helsinki, Finland; Department of Systems Ecology, University of Stockholm, Sweden; Baltic Sea Research Institute Warnemuende (IOW), Germany; Federal research Center for Fisheries, Institute for Baltic Sea Fisheries, Rostock, Germany.

Subcontractors: Sea Fisheries Institute, Gdynia (MIR), Poland; Atlantic Scientific Research Institute of Marine Fisheries and Oceanography Kaliningrad, Russia; Institute for Hydrobiology and Fisheries research, University of Hamburg, Germany; Water Quality Institute, Horsholm, Denmark; Finnish Institute of Marine Research, Helsinki, Finland; Estonian Marine Institute, Tallinn, Estonia; Latvian Fisheries Research Institute, Riga, Latvia.

Objectives

Understanding the stock-recruitment relationship of fish stocks is crucial for generating biologically sound advice for the balanced, sustainable exploitation of fisheries resources. At present the ICES Advisory Committee on Fisheries Management uses the concept of safe biological limits (SBL) as a criterion to define exploitation and stock levels. This concept is based mainly on the assumption that below a certain spawning stock size, recruitment is negatively affected as a result of low egg production. When a stock is consired to be inside SBL, recruitment variability is expected not to depend on parental stock size, but rather be related to environmental and ecological factors influencing the survival of the early life history stages. So far, however stock recruitment relationships and critical stock levels identifying recruitment- limiting stock sizes are poorly defined for cod and sprat in the Baltic. The sensitivity of SBL's and reference points to environmental conditions, species interactions and parental stock structures for these stocks are uncertain and need clarification. The objectives of the research programme are to

- Determine stock-recruitment relationships for Baltic cod and sprat in relation to key environmental factors influencing the production of viable spawn and the survival of early life history stages.
- Improve short-term predictions of stock development by integrating recruitment estimates based on the present status of the stock and its biotic and abiotic environment.
- Develop predictive recruitment models for medium- to long-term forecasts of stock development under different environmental and fishery scenarios.
- Estimate biological management reference points, critical stock limits and target spawning stock sizes based on stock recruitment relationships and stock development simulation models, and considering the precautionary approach for fisheries management.

Key questions to be answered

How do environmental factors influence the stock-recruitment relationship for cod and sprat stocks in the Baltic and what are the implications of variations in these factors for the use of biological reference points and critical stock limits in the management of the fisheries.

List of major tasks

- Viable egg production for Baltic cod and sprat.
- Hydrographic factors influencing the developmental success of cod and sprat eggs and early larvae.
- Identification of abiotic and biotic processes influencing the feeding environment, growth, distribution and survival of larval/juvenile cod and sprat.

- Modelling the influences of hydrographic/biological processes on the survival, distribution and growth of fish early life history stages
- Prey/predator interactions and their impact on the dynamics of cod and sprat populations.
- Model the combined effects of environmental variability and fisheries on cod and sprat recruitment and evaluate the sensitivity and applicability of critical stock limits and biological reference points for fisheries management.

6.12 Summary of the ad hoc Meeting of the Working Group on Recruitment Processes, Lisbon, Portugal

On the 19th of September, 1998, a sub-group of the WGRP held an ad hoc meeting to discuss the development of the 5 Year Plan, as requested by ICES, with a particular focus on increasing participation in the WG's meetings. Members present were B. MacKenzie (Denmark), K. Frank (Canada), G. Marteinsdottir (Iceland), E. Houde (USA), J. Anderson (Canada), T. Linkowski (Poland), H. van der Veer (Netherlands) and P. Pepin (Chair, Canada). In addition, the Chair invited the participation of K. Brander (ICES/GLOBEC Coordinator). With the exception of the Chair and H. van der Veer, none of the members were planning on participating in the meeting of 7-9 October, 1998, in Texel, Netherlands.

The Chair outlined two issues that needed to be discussed:

[1] Address issues pertaining to the long-term objectives of the WG and our relationship with other Working Groups within ICES or the Oceanography Committee;

[2] Review/nomination of Chair (chaired by H. Veer).

<u>Long Term Objectives</u>

The importance of issues that pertain to the study and understanding of recruitment variability was recognized by all members present but their importance appears not to carry through in WG aspects of ICES. To remedy the situation, many proposed that meetings of the WGRP should be made more issue specific, making use of a workshop format, when appropriate, as a method of increasing not only participation but also cross-fertilization with other disciplines. This format has been successful for the WG on Cod and Climate Change, where many former members of the WGRP appear to be active. The proposal is that a workshop could be held immediately before a meeting of the WGRP where more broad ranging discussions would take place (in planning subsequent issues to be addressed).

Potential workshop topics discussed during the meeting were:

[1] The relationship between the development of Marine Protected Areas and how these relate to recruitment processes. The issues that could be addressed include: the timing and location of spawning in a variety of species; how these relate to the potential dispersal/retention of eggs and larvae in the region (bringing in the participation of physical oceanographers); what benefits (if any) could be achieve by protecting spawners rather than juveniles. This would provide a means to provide a direct link with stock management schemes by suggesting alternative tools or issues (e.g., time/space closures) (bringing in resource managers).

[2] Trying to focus on developing a better understanding of the relationship between spawners and egg production. Under this topic, one could try to gather data on egg size/weight, fecundity, maturity, etc., as they relate to a number of stocks of a species.

By addressing such specific issues from a general perspective rather than dealing with a single stock or a restricted area, the WG would therefore provide ICES with an informed perspective to be applied across Working Groups and Committees.

Potential long term issues which WG meetings could focus on developing include:

[1] Developing a broad ranging summary of early life history characteristics for diverse species/stocks of importance to ICES;

[2] Provide a synthesis of multidisciplinary studies (or projects) with the objective of pointing the way to unresolved issues;

[3] Produce opinion papers on specific issues or methods which have broad ranging applications in recruitment studies, using comparative studies as a valuable means of approaching the issues.

Throughout the discussion, members stressed the importance of establishing links with other Working Groups and Committees. To this end, we proposed sponsoring a theme session during the ASC in 2000 titled "Spatial and Temporal

Patterns in Recruitment Processes" which was submitted to both the Living Resources and Oceanography Committees, under the convenors E. Houde (USA) P. Pepin (Canada), and P. Munk (Denmark). The rationale for the sessions is:

> The processes leading to recruitment of fish and shellfish are temporally and spatially variable. Hydrography, trophic relationships, and reduced stock abundance (due to fishing) all act and interact to determine recruitment abundances, distributions, and trends therein, in time and space. Our understanding of these processes is limited, but critical to evaluate dynamics of stocks and their management. The theme session will seek contributions to address issues of patterns, trends and scale in recruitment with respect to hydrography, predator-prey and stock abundance as well as other climatic or environmental factors. New methodological approaches used to study of spatial-temporal variability (e.g., remote-sensing, spatial statistics, data visualization methods) are among the topics for inclusion. The relationships between settlement, recruitment, and habitat suitability are also subjects to be addressed under this theme.

In addition, we agreed to support the bid for a theme session in 1999 dealing with "Cod and haddock recruitment processes – Integrating stock and environmental effects", convenors M. Heath (UK), B. MacKenzie (Denmark), G. Marteinsdottir (Iceland).

Finally, the Chair approached C. Bannister, Chair of the Living Resources Committee, to ensure that questions pertaining to recruitment processes would be directed to the WGRP as required.

Review of Chair

Under ICES regulations, a chair should serve only for a three year period, unless re-nominated by the members for a second term. P. Pepin indicated that he would be willing to work to coordinate the WG for one more meeting (1999 or 2000) but also suggested that a new perspective would be beneficial to the WG during this period of transition. H. van der Veer (Netherlands) chaired the subsequent discussion, in the absence of the Chair, and will report at the WG meeting in Texel.

6.13 Theme Sessions Supported by the WG

Theme Session Proposal: Year 1999

Cod and Haddock Recruitment Processes – Integrating Stocks and Environmental Effects

Convenors: M. Heath (UK), B. MacKenzie (Denmark), G. Marteinsdottir (Iceland)

Description: Attempts to partition the variation in recruitment into components influence by the properties of the spawning stock and/or by the environment are likely to advance our understanding of the recruitment process. Several recent studies have shown that age, size and condition of spawners may affect the reproductive capacity of spawning stocks, thereby obscuring the ability to resolve environmental effects on recruitment. In addition, the environment (e.g. temperatures, circulation/advection, prey and predator abundances) to which offspring become exposed depends on size- and age-related differences in spawner behaviour (e.g., timing/place of spawning) . Studies in which interactions between spawner biology (e.g., size, age, spawning history, etc.) and environmental processes are investigated in an integrative approach have the potential to contribute important advances in the relative roles of stock-related and environmental effects on recruitment.

Theme Session Proposal: Year 2000

Spatial and Temporal Patterns in Recruitment Processes

Convenors: E. Houde (USA), P. Pepin (Canada), P. Munk (Denmark)

Description: The processes leading to recruitment of fish and shellfish are temporally and spatially variable. Hydrography, trophic relationships, and reduced stock abundance (due to fishing) all act and interact to determine recruitment abundances, distributions, and trends therein, in time and space. Our understanding of these processes is limited, but critical to evaluate dynamics of stocks and their management. The theme session will seek contributions to address issues of patterns, trends and scale in recruitment with respect to hydrography, predator-prey and stock abundance as well as other climatic or environmental factors. The development of new methodological approaches to the study of spatial-temporal variability (e.g., remote-sensing, spatial statistics, data visualization methods) are among the topics for inclusion. The relationships between settlement, recruitment, and habitat suitability are also subjects to be addressed under this theme.