International Council for
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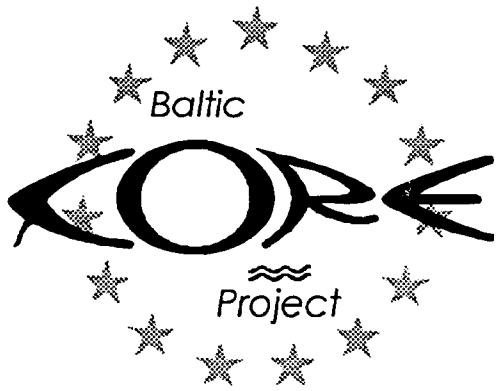
Baltic COd REcruitment Project



by

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Abstract

This paper outlines the goals, the objectives and the Work Programme of an internationally coordinated EU project (AIR2-94-1226): "**Mechanisms influencing long term trends in reproductive success and recruitment of Baltic cod: implications for fisheries management**".
An overview is given on the first period of field sampling in 1994/95, summarizing the preliminary results of which some will be presented in more detail in individual papers presented at this conference.

Organisations involved

Institute of Marine Sciences, Kiel (Coordinator)
Danish Institute for Fisheries Research, Charlottenlund & Hirtshals
Institute of Biological Sciences, University Aarhus
Institute for Baltic Sea Research, Warnemünde
Institute for Baltic Sea Fisheries, Rostock
Institute of Marine Research, Lysekil
Dept. Systems Ecology, Stockholm University
Finnish Game and Fisheries Research Institute, Helsinki
Finnish Institute of Marine Research, Helsinki
Estonian Marine Institute, Tallinn
Sea Fisheries Institute, Gdynia
Latvian Fisheries Research Institute, Riga

Introduction

The cod stock in the Central Baltic is a major component of the ecosystem and has a large social and economic importance in the countries bordering the Baltic Sea. After an intermediate increase in stock size and landings in the beginning of the 80's, the stock was on its lowest level on record in 1992, slowly recovering afterwards. The drastic decline appears to be caused by a substantial reduction in reproductive success during the last decade, while high fishing pressure was continued. As cod is the main predator in the system, the reduction in stock size influences also the lower trophic levels in the food web and it has economic implications on fisheries of herring and sprat in terms of increasing potential landings but decreasing product quality. In order to investigate the abiotic and biotic processes influencing cod recruitment and thereby aid not only assessing and managing the stock but understanding the impact of cod stocks on the Baltic ecosystem this multinational European Union funded research programme was developed.

Objectives of the research project

The primary goals of the present research programme are to:

a) identify and describe the dominant biotic and abiotic processes affecting the maturation of cod and the developmental success of the early life stages of cod in the Central Baltic;
b) incorporate these key processes into recruitment models to enhance prediction of future stock fluctuations due to the state of the spawning stock, environmental perturbations, species interactions and fisheries management directives as a prerequisite for an integrated fish stock assessment in the Central Baltic;
c) assess the biological basis and evaluate the feasibility and possible effects of cod stock enhancement programmes in the Baltic.

Work Programme

The work programme is seperated into four major components with further subdivisions as given below:

1 Trend analysis

This component examines how key aspects of cod biology and environmental variables interact to cause long-term trends in the reproductive success of Baltic cod. The following three hypotheses being addressed:

- reduced oxygen concentrations in the deep basins of the Baltic (caused by low intrusion rates of Kattegat water and eutrophication) have produced conditions which are detrimental for reproductive success and thus recruitment,

- physical oceanographic and food web processes influencing the abundance of prey and predators of larval and juvenile cod show long-term trends and affect substantially growth and survival of the early life stages,
- abiotic factors (e.g. temperature, salinity) directly affect survival of cod eggs and larvae in situ.

Existing long-term data bases are utilized to analyse associations between biological and climate/physical oceanographic parameters. Mechanisms that can potentially be used to construct new cod recruitment models will be identified and additional hypotheses will be generated that can be examined in process-oriented field studies.

2 Process analysis

Biotic and abiotic processes and interactions are analysed with respect to impacts on sexual and gonadal maturation and fecundity of cod, on quality, viability and developmental rates of eggs, on distribution, drift and mortality of early life stages. Depending on the results of the trend analysis, following subjects are considered:

2.1 Fecundity and quality of spawning products

The fecundity is linked to the individual fish size, but also to the feeding and possibly to the health condition during maturation. Consequently, the total saisonal egg production of the stock is dependent on the size structure of the spawning stock, the size at first maturation and on the condition of the spawners which may be influenced by factors like stock density, abundance of suitable food, deseases, timing of spawning and/or abiotic environmental factors including pollutants. The quality of the spawn which is relevant for the viability of the fertilized eggs may be influenced by the same factors and can be characterized for example by the lipid content of the oocytes and the contamination with toxic substances. Specific tasks to be covered within this subtopic:

- describe sexual maturation of juvenile cod at different stock densities and set up of sex specific maturity ogives,
- determine timing of spawning in relation to the sex/age structure of the stock, hydrographic conditions and spatial distribution of the spawning stock,
- analyse fecundity in relation to size/age and condition of individual females,
- resolve contamination level of sex products by toxic substances,
- ascertain relation between egg quality, contamination level, fertilization rate, egg development and hatching success.

2.2 Physical and chemical factors acting directly on the developmental rate, mortality and small scale distribution of eggs and larvae

Hydrographic variables like temperature, salinity, oxygen concentration and turbulence are governing the development, mortality and small-scale distribution patterns of eggs and larvae. In the spawning areas of the Baltic Sea, temperature is an important factor controlling the rate of egg development, but has less direct influence on the egg mortality. Salinity effects the fertilization rate and the vertical distribution of eggs, but only to a lesser extent the distribution of larvae. The oxygen concentration has severe influence on the development and mortality rates of eggs. Behavioural responses of larvae to different salinity and oxygen levels are not well described. Small-scale turbulence can increase encounter rates between planktonic predators and prey, while simultaneously dispersing existing aggregations of larval prey. Turbulence may therefore have either a net beneficial or detrimental effect on larval and juvenile cod feeding rates. Specific tasks to be covered within this subtopic:

- determine the distribution patterns and hydrographic environments conducive for survival of cod eggs and larvae,

- conduct experiments on the influence of temperature, salinity and oxygen concentration on fertilization success, egg development and mortality as well as on viability and behaviour of larvae,
- resolve the small-scale distribution of larvae and their prey in relation to hydrographic processes acting on the same scale by utilizing in-situ particle counters and video-systems.

2.3 Meso-scale distribution and drift of pelagic early life stages and densities of 0-group cod

Due to the buoyancy of cod eggs, their meso-scale horizontal distribution is limited to the deep basins in the Central Baltic, where they occur from the pronounced halocline down to the bottom layer. The horizontal distribution of larvae and pelagic 0-group cod is influenced by the drift of surface water masses forced by wind stress. The net effect of this drift is substantially depending on the diurnal migration of larvae and pelagic 0-group cod. Specific tasks to be considered:

- conduct ichthyoplankton surveys to map the horizontal distribution of eggs and larvae and describe the diurnal migration of larvae,
- conduct surveys to investigate the horizontal distribution and abundance of both pelagic and demersal 0-group cod and describe the diurnal migration of the pelagic stage,
- tests of robustness and predictability of the drift model implemented by comparing distribution patterns obtained from available data bases and survey results with the model output.

2.4 Predation on early life stages

Only scarce information is available that can be used to assess the importance of predation on the developmental success of early life stages of cod in the Baltic Sea. Among all possible predators, the two commercially utilized pelagic species, herring and sprat, appear to have the highest potential as predators of cod eggs and larvae in the Central Baltic. This is of particular interest in view of decreasing stock sizes of the predatory cod resulting in increased stocks of herring and sprat. However, other potential predators, e.g. scyphomedusae, may influence the mortality rates of early life stages significantly. Actions to be conducted:

- identify potential predators by a literature review and evaluate all available data bases on stomach contents,
- design of a stomach sampling and analysis scheme to fill gaps in the knowledge of the feeding strategies of identified predators,
- conduct experiments to estimate evacuation and consumption rates of predators,
- describe the time and spatial overlap between predators and early life stages of cod and the prey selection process by comparing results from hydroacoustic, trawl and plankton surveys.

2.5 Influence of prey availabiliy on growth, condition and survival of early life stages

Fronts and pycnoclines are sites where planktonic and nektonic organisms aggregate either passively or actively resulting in increased density of potential prey organisms. Utilization of these aggregations has been observed for both larval and juvenile fishes and can result in increased feeding success and nutritional condition. These sites, however, may be locations where also predators of larval and juvenile fish aggregate due to the relative high densities of their prey. Therefore, it is possible that the utilization of these physical phenomena may change during development, depending partly on the relation between size and abundance of predators and the size of the early life stages. These hypotheses are examined by the following specific actions:

- review existing hydrographic data to identify features existing in the Baltic which may result in enhanced feeding potential,
- conduct field studies on the distribution of larval and juvenile cod as well as their prey items and potential predators in different hydrographic regimes,
- observe the feeding and swimming behaviour of larval and 0-group cod,

- determine and compare larval and 0-group diets within various hydrographic and turbulent regimes,
- examine triacylglycerol and cholesterol ratios in larvae and juveniles as a long-term averaging indicator of the nutritional condition integrating over weeks in different hydrographic regions,
- determine RNA/DNA ratios in larvae as a short-term averaging indicator (days to weeks) of growth and conditions in different physical environments.

3 Modelling

3.1 Modelling cod recruitment

Results from the first two components will be used for the modelling of cod recruitment processes. This work includes:

- developing biological/physical models to predict the effects of long-term (decadal) and short-term (days/weeks) environmental variability on the biology of early life stages of cod,
- implementing a multi-layer flow model for the Central Baltic to estimate drift patterns of larvae and 0-group cod,
- describing feeding success of larval and 0-group cod in relation to small- and meso-scale hydrographic processes and related prey densities,
- testing hypotheses of size selective mortality using characteristics (e.g. growth rates, birthdates, size at metamorphosis) of individual larval and juvenile cod,
- predicting mortality rates of eggs and larvae caused by predators,

These recruitment process models will be analysed in respect to their robustness and sensitivity and will subsequently be used to enhance the recruitment estimates required for medium-term (1-3 years) fish stock and catch projections taking into account environmental perturbations and multispecies interactions.

3.2 Incorporation of recruitment processes into stock assessment models

This section will examine the necessity and feasibility of an incorporation of biotic and abiotic factors relevant for the recruitment success into presently used stock assessment models. 0-group cod as prey has already been incorporated into the MSVPA and the MSFORECAST model for the Central Baltic (Anon. 1994). The mortalities of 0- and 1 group cod caused by cannibalism were estimated to be rather high during the the last decade, when the adult cod stock was on a high level. However, the results appear to be sensitive to the data available and compilation procedure adopted for converting stomach content by weight to numbers. Therefore following tasks are considered:

- sensitivity analysis by reviewing the compilation procedure for stomach contents adopted by Jensen & Sparholt (1992),
- updating the existing data base and perform MSVPA runs to calculate updated predation mortalities of juvenile cod and recruitment estimates.

Results will be used in the section on modelling cod recruitment, i.e. 0-group abundances derived by the MSVPA will serve as an independent estimate to be related to predicted values. Furthermore, reliable predation mortalities are a prerequisite for performing medium and long-term MSFOR runs assuming different recruitment scenarios and fisheries management objectives.
The results obtained from the process analysis and the subsequent modelling section will provide the basis for assessing the necessity and feasibility of an incorporation of recruitment models (e.g. stock recruitment relationships) and predation on early lifes stages (cannibalism by cod and by herring and sprat) into present stock assessment models.

4 Evaluation of the stock enhancement programmes

The drastic decline in recruitment of several stocks stimulated the initiation of large scale rearing programmes for cod enhancement. The success of a stock enhancement programme is critically dependent on sufficiently inexpensive mass rearing of fry and on the survival and growth during the first months after release. Time and location of the release as well as the size of the released fish are probably important determinants for the survival; but processes controlling survival and growth of the metamorphosed juveniles are poorly known. Drift and migration may be further relevant process parameters. Therefore understanding of important biological/physical processes regulating survival and growth has to be improved to estimate the potential benefit and feasibility of enhancement programs to the adult stock. Actions to be conducted:

- examine the success in artificial fertilization of eggs and captured brood stock and study the developmental success and survival of the early life stages in relation to the characteristics of methods used for fry production, in connection to sections 2.1, 2.2 and 2.5,
- carry out tagging and recapturing experiments with artificial reared larvae on natural spawning areas to describe the dispersal of released larvae and estimate growth and survival rates, in connection to section 2.3,
- analysis of the obtained estimates of growth and survival rates in respect to time, size and place of release for comparing the artificial reared and the natural population.

Interdependence of different tasks

The interdependence between different tasks are given for each year of the project separately in following figures:

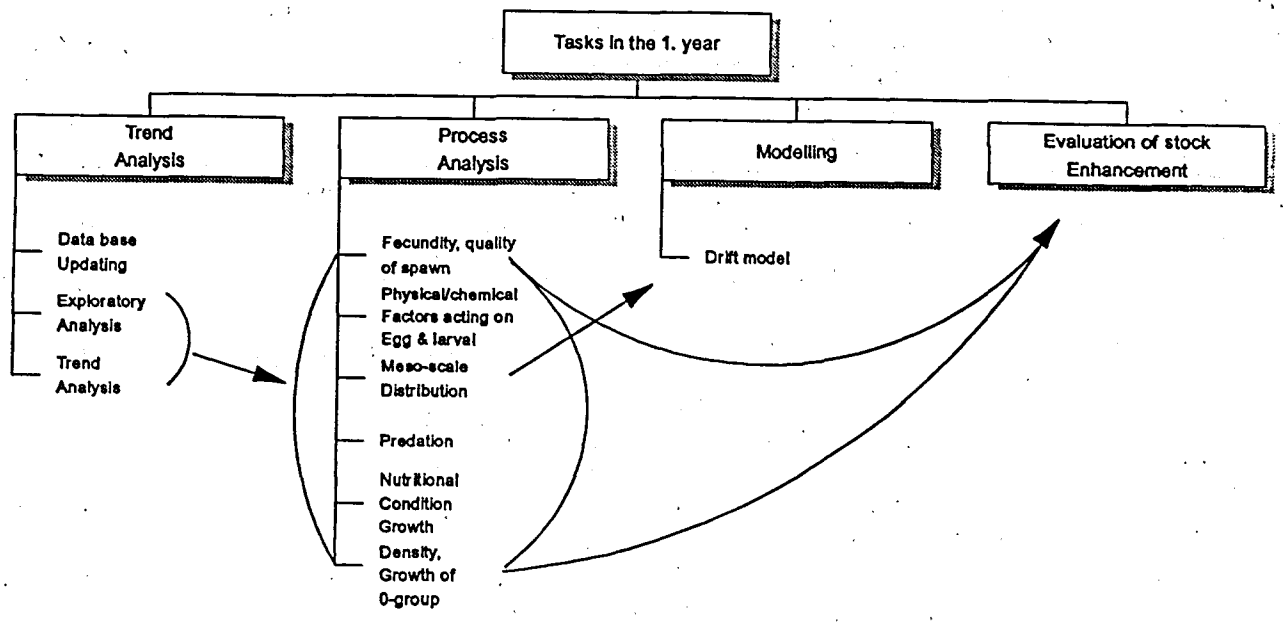

Figure 1: Interdependence between tasks in the first year of the project

Interdependence between different tasks, continued:

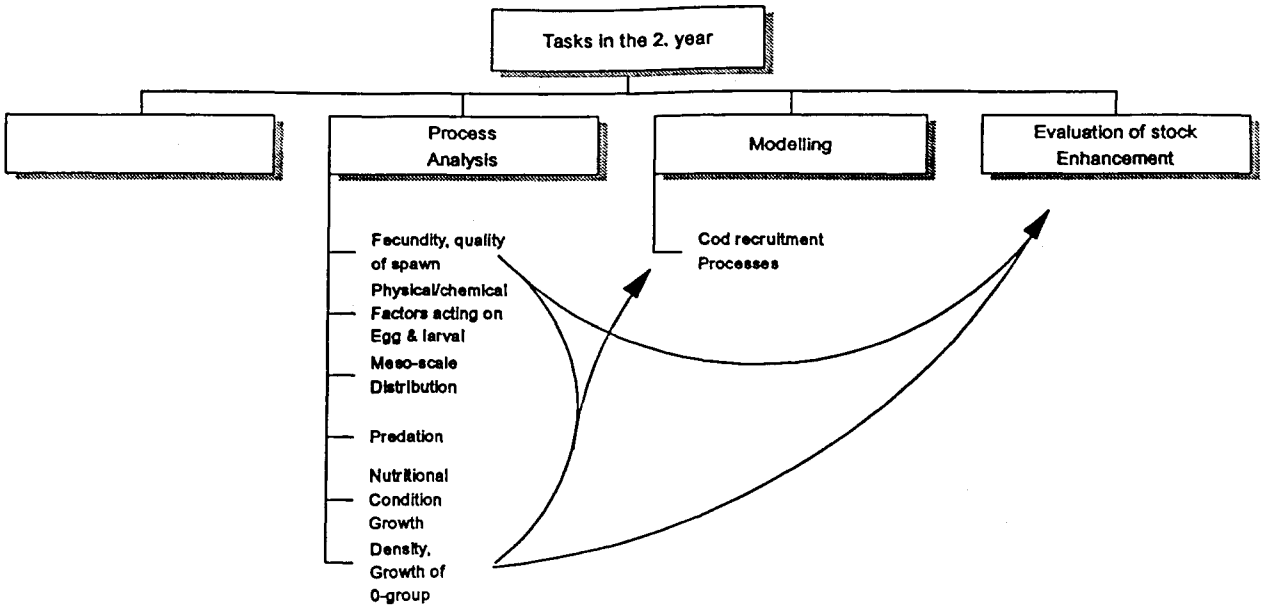

Figure 2: Interdependence between tasks in the second year of the project

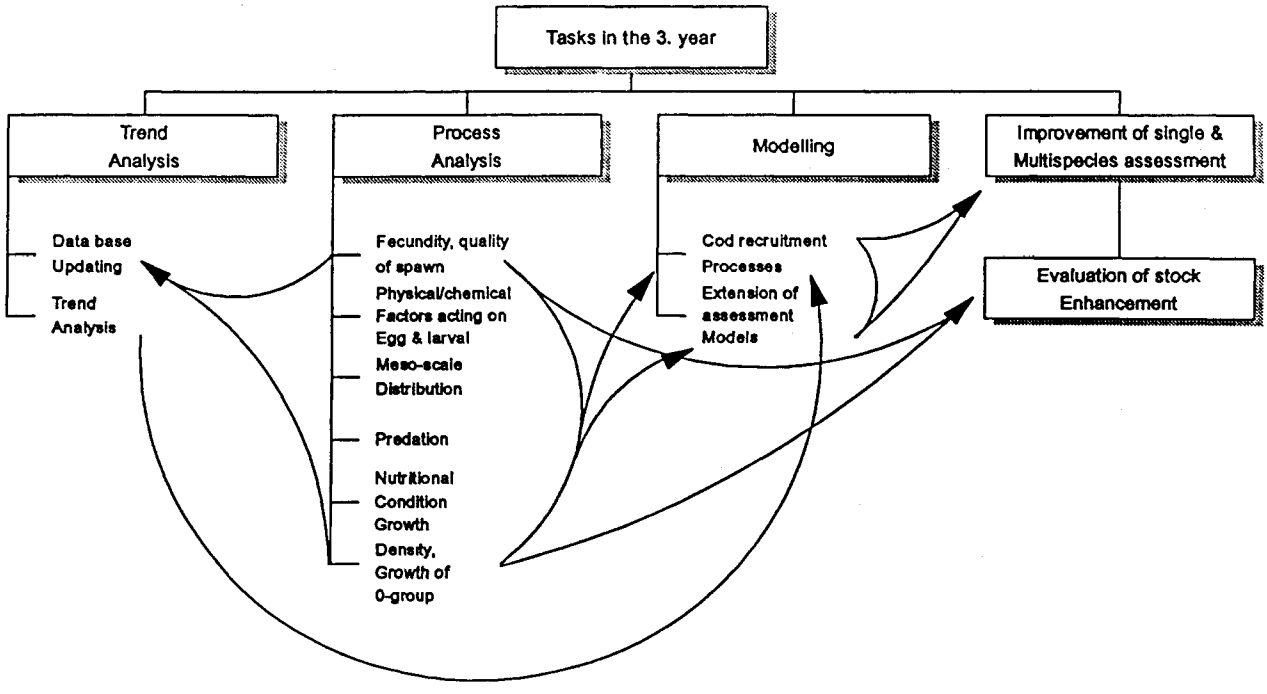

Figure 3: Interdependence between tasks in the third year of the project

Definition of task groups

The contribution of the different laboratories to the tasks are summarized in the following table
(o = organizing participant)
(+ = contributing participant)

	Participants							
Component related tasks	IFM	DIFRES	IOW	IOR	IOM	FIGFR	MIR	LATFRI
1. Trend analysis	+	o	+					+
2. Process analysis								
2.1 fecundity & quality of spawn	+	+	+	+	o		+	+
2.2 physical/chemical factors on egg & larval development	o	+			+		+	+
2.3 meso-scale distribution & drift of early life stages, densities of 0-group	o	o		+	+	+	+	+
2.4 predation on early life stages	o	+	o		+		+	+
2.5 nutritional condition & growth	+	o		+			+	+
3. Modelling								
3.1 modelling cod recruitment processes	o	o				o		+
3.2 extension of stock assessment models	o	o			+	+		
4. Evaluation of stock enhancement programmes	+	+		+	o	+		

IFM: Institute of Marine Sciences, Kiel
DIFRES: Danish Institute for Fisheries Research, Charlottenlund & Hirtshals
Institute of Biological Sciences, University Aarhus
IOW: Institute for Baltic Sea Research, Wanrnemünde
IOR: Institute for Baltic Sea Fisheries, Rostock
IOM: Institute of Marine Research, Lysekil
Dept. Systems Ecology, Stockholm University
FIGFR: Finnish Game and Fisheries Research Institute, Helsinki
Finnish Institute of Marine Research, Helsinki
Estonian Marine Institute, Tallinn
MIR: Sea Fisheries Institute, Gdynia
LATFRI: Latvian Fisheries Research Institute, Riga

Preliminary results and discussion

1 Trend analysis

Data sets containing time series of hydrographic conditions for successful egg development, and of egg and larval abundances have been assembled from international data bases, published and grey literature, and original cruise journals. Analyses of these data have identified important gaps in the understanding of cod reproductive biology (e.g. spawning time variability, annual egg production rate) as well as of physical oceanography (e.g. oxygen, temperature and salinity conditions in deep water) and biological oceanography (e.g. zooplankton abundances and distributions) that need further study in other subsequent sections of the Work Programme (MacKenzie et al. 1995, this conference). Work activities in the next year will involve further calibration and updating of data sets, and analyses of statistical relationships among variables within the assembled data sets. A further improvement in the results of this section could be achieved through increased involvement of colleagues from Latvia, Poland and Estonia. Scientists from these countries have interacted unofficially with the project but will require funding in order to continue participation thereby expanding not only the data sets but the scope of the project.

2. Process analysis

2.1 Fecundity and quality of spawning products

A shift in the annual sexual maturation to smaller individuals in a period of declining stock size as well as sex specific differences in the timing of sexual maturation have been identified. Consequently, new sex specific maturity ogives were established for the cod stocks in the Western and Central Baltic and presented to the Working Group on the Assessment of Demersal and Pelagic Stocks in the Baltic (Anon. 1995). A shift in spawning time to a later period of the year previously observed in ichthyoplankton surveys (Bagge et al. 1994, Wieland 1995) has been confirmed by data on the gonadal maturation. The shift can be related to a simultaneous change in the age structure of the stock towards younger fish. To estimate the total egg production of the stock in the Bornholm Basin, which appears to be the only important spawning area in the Baltic at present, data on abundance, structure and sex ratio of the spawning stock were sampled over the extended spawning season (e.g. Tomkiewicz & Degnbol 1995).

Fecundity data, however, are still insufficient for reliable egg production estimates. High variabilities in fecundity were encountered among areas, time periods and individual fish of similar size. This variability cannot be explained by the methodology applied and was not related to the condition of the fish. Consequently, considerable effort has been directed to further sampling and analyses of ovaries for fecundity (for outline of methodology see Bleil & Oeberst 1993). The presently utilized procedure has proven to be quite time consuming, thus newly developed automatic counting devices are presently tested. Remaining technical problems are to be solved within the 2 nd year of the project.

For resolving the contamination level of sex products by toxic substances, chlorobiphenyl congener and pesticide concentrations in cod tissues are investigated in relation to their lipid class composition (Petersen et al. 1995, this conference). First results indicate negative correlations between the hatching success of fertilized cod eggs and their contamination with chlorobiphenyl congeners as well as DDE. These preliminary results have to be confirmed with more experimental data.

Preliminary results from experiments directed to egg quality and viability of the offspring indicate on average a lower survival of cod eggs and yolk-sac larvae from the Central Baltic as compared to those from the Skagerrak area. First time spawners seem to produce smaller eggs, resulting in smaller larvae which suffer higher mortality rates. A decrease in egg size and subsequent lower survival of larvae has also been observed for the last batches spawned in the season.

2.2 Physical and chemical factors acting directly on the developmental rate, mortality and small-scale distribution of eggs and larvae

In order to identify and examine hydrographic factors influencing the development and survival of Baltic cod eggs and larvae, a close linkage between field and laboratory studies has been established. Field studies have identified the natural range of variations in the hydrological conditions, i.e. temperature, salinity and oxygen concentration, to which Baltic cod eggs are exposed (Wieland et al. 1994, Horbowa & Wlodarczyk 1995, this conference). The most prominent feature was a considerable shift in the ambient salinity levels experienced by the eggs towards higher values in the recent years (Wieland 1995). The increased salinity was related to several small to moderate inflow envents observed since 1990, which have resulted in the presence of high saline water and tolerable oxygen conditions for the adults in the bottom layer at least during the pre-spawning season in the Bornholm Basin.

Methods for experimental studies on egg viability were standardized and activities on this topic were coordinated according to the facilities of the different laboratories. Incubation experiments with cod eggs were successful for the estimation of egg developmental rates, hatching success, viability of hatch and mortality rates of larvae in relation to size/age, condition and contamination of parental fish. First results indicate a significant relation between egg size and growth as well as survival of cod larvae during the yolk-sac period, possibly correlated to female size/age. A number of experiments examined the effects of oxygen concentration and starvation on larval behaviour. Larvae initially were relatively inactive for the first two days. Swimming activity increased after this period for the next two days thereafter displaying a reduced swimming activity until death. Experiments examining the effects of reduced oxygen concentration revealed that the average activity level of the larvae was reduced but no apparent influence on larval swimming speed was observed.

The food environment of larvae was examined by towed optical particle counters and underwater video systems deployed during field studies. Research has focussed on the small-scale distribution of plankton suitable as prey for cod larvae in relation to physical processes (e.g. turbulence intensity and circulation features). These analyses have demonstrated that the variability in abundance of food particles was much more intense at small scales (<10-20 m) than at larger scales. The patchiness of abiotic variables (temperature and salinity) often was independent of zooplankton patchiness and occurred at small/intermediate scales (500-800 m), particularly under conditions of low turbulence. These results suggest that the behaviour of planktonic organisms strongly influences the food environment of larvae during periods of low turbulent mixing (MacKenzie & St. John 1995, this conference). The effects of turbulent mixing processes on the aggregation and dispersal of prey items of Baltic cod is at present unclear and requires further theoretical and empirical studies planned during future laboratory and field activities in this programme.

2.3 Meso-scale distribution and drift of pelagic early life stages and densities of 0-group cod

A large coordinated cruise programme has been developed and started, to examine the temporal and spatial distribution of cod eggs and larvae in the Baltic. Very positive interactions among participants has allowed the successful integration of standard egg and larvae surveys into the multidisciplinary EU research project. The Bornholm Basin, presently being the only important spawning ground in the Baltic, has been covered regularly at monthly intervals from March to September 1994 and 1995. However, an expansion of the geographical area of the surveys to include the Gotland Basin and the Gdansk Deep as historically important spawning grounds of Baltic cod should be considered. Comparative historical information is available in the Latvian Fisheries Research Institute (e.g. Plikshs et al. 1993) and the Sea Fisheries Institute, Gdynia (e.g. Herra 1988) and should be compiled for the extension of the data base for trend analysis. At present, the Latvian Fisheries Research Institute conducts 2 to 3 ichthyoplankton surveys per spawning season in the Gotland Basin with a limited station grid. An extension of the field sampling, especially to the Gdansk Deep, would be highly desireable. In this context, intercalibration work has to be continued on sampling methods used in the past and at present by the different institutes. In addition to the activities concentrating on the Central Baltic, information on the distribution and

abundance of early life stages of cod in the Western Baltic were obtained by complementary ichthyoplankton surveys (Klenz 1994).

The Baltic Sea model (Lehmann 1994) and the Lagrangian tracking technique (see section 3.1 on page 14 for further explanation) has proven to be suitable to simulate the drift of larval cod (Hinrichsen et al. 1995, this conference). However, further comparisons of the model output and survey results are required, preferably in situations with higher larval abundance than in the recent studies. The distribution of demersal 0-group cod in shallow waters has to be carefully examined in the future to verify model predictions concerning settling sites of Baltic cod.

The success in sampling pelagic 0-group cod was extremely low in spite of intensive trawling during all cruises carried out in the Bornholm Basin (e.g. Lehmann & Nielsen 1995, this conference). The transition from the pelagic to the demersal habitat appears to occur over an extended period of time, suggesting only a slow gradual change in the orientation of the juveniles to the demersal environment (Hüssy & Tomkiewicz 1995, Mosegaard et al. 1995, both this conference). Preliminary observations from hydroacoustic surveys indicate that this technique may prove valuable for determining the horizontal and vertical distributions of 0-group cod, but further effort is required to ground truth this technique before realistic estimates of biomass and distribution patterns can be established (Lehmann & Nielsen 1995, this conference).

Information on the distribution of demersal 0- and 1-group cod has been obtained from the ICES Baltic Sea Young Fish Data Base. The data available for 0-group cod abundance in the Western and Eastern Baltic are insufficient for any useful examination of the meso-scale distribution pattern. For 1-group there are more possibilties to estimate detailed distribution patterns between and within years. However, detailed information on historic trawl locations is partly missing in the data already compiled. The data base has to be completed accordingly including also new data obtained from young fish surveys conducted within the project.

2.4 Predation on early life stages

For identification of predators on early life stages of cod, a literature review has been performed, available data bases evaluated and specific stomach content analyses carried out. It appears that in cod spawning areas of the Central Baltic the predator field is rather restricted.

Predation on cod eggs by herring and especially sprat (Köster & Schnack 1994), and cannibalism on 0-group cod (Anon. 1994, Sparholt 1994, Uzars 1995) were identified as most important processes. In contrast to the Bornholm Basin, in eastern spawning areas predation on eggs by herring and sprat appears to be less important. This might be explained by a limited vertical overlap of prey and predator, a hypothesis which has to be verified during the next period of field sampling. Scyphomedusae (*Aurelia aurita* and *Cyanea capillata*) were identified as being potentially important predators (Margonski & Horbowa 1994, Margonski & Horbowa in press).
Preliminary estimates of daily consumption rates of cod eggs and larvae by herring and sprat in the Bornholm Basin were derived on the basis of daily rations ingested and population sizes estimated. Compared to the standing stock of cod eggs, the estimated predation was rather high, especially by sprat at the beginning of the spawning season (Köster & Schnack 1994). Based on updated catch statistics and results of hydroacoustic surveys conducted during cod spawning time, new population estimates of herring and sprat in the Bornholm Basin will be derived. Together with updated consumption rates, the daily egg consumption by the populations will be recalculated and compared to corresponding new estimates of the daily egg production.

Contrasting the results on eggs, fish larvae were only rarely found in stomachs of herring and sprat. This may be explained by a difference in the vertical distribution of predator and prey. The estimated consumption of cod larvae by the herring and sprat populations in the Bornholm Basin is sensitive to the assumed average digestion time of fish larvae (Köster 1994). Therefore, additional effort has to be

allocated to determine this parameter more precisely and subsequently to revise the daily rations and the total daily consumption by the populations accordingly.

2.5 Influence of prey availabiliy on growth, condition and survival of early life stages

Field conditions

The food supply for larval cod in the Bornholm Basin and Gdansk Basin has been investigated (e.g. Krajewska-Soltys & Linkowski 1994) and the available information has been reviewed (MacKenzie et al. 1995, this conference). Nauplii from all copepod species are most abundant from April to June showing a distinct seasonality. The timing of cod spawning usually coincides with peak prey abundances on average and thus the food supply should be sufficient. However, throughout recent years a shift in the occurrence of peak larval abundance has been observed towards later months (Grønkjaer et al. 1995a, this conference). This may result in a mismatch of larvae and food production, a process to be investigated in the present project. Processes influencing the plankton distribution and production in the Bornholm Basin during a typical summer situation (August) have been described in relation hydrographic features encountered (St. John et al. 1995, this conference), thus identifying key variables influencing the larval food availability at late hatching dates.

Preliminary results on the diets of 0-group cod in the Baltic indicate that the benthic orientation of cod starts at a length of 40 mm; the majority has reached this stage at 60 mm (Hüssy & Tomkiewicz 1995, this conference). The otolith microstructure patterns found in a number of 0-group cod suggest that settling juveniles may test various sites. Before the final settling, otolith ring structures indicate that diel vertical migration is interrupted several times (Mosegaard et al. 1995, this conference). The nearshore habitats appear to be the most important ones for the development of juvenile Baltic cod. Mysiids, amphipods and small fishes, the prefered prey of benthic juvenile cod (Kowalewska-Pahlke 1994), are found in high abundances in shallow areas of less than 40 m depth, where they are relatively unaffected by oxygen deficiency.

The methods proposed to evaluate the influence of prey availability on growth and condition of early life stages of cod have been applied to laboratory and field samples. Due to the low numbers of larvae encountered in-situ, the results from field samples are yet restricted. However, the importance of the first-feeding migration inferred from the obtained data is obvious (Grønkjaer et al. 1995a, this conference). Baltic cod larvae are visual predators and hatch at a depth where light is weak and not above the threshold required for feeding. Furthermore the abundance of suitable prey in the Bornholm Basin, especially copepod nauplii, has shown to be higher above the halocline than in the deep water (Dahmen 1995, Krajewska-Soltys & Linkowski 1994). This makes migration towards the surface a prerequisite for successful feeding. Nevertheless, intermediate sized larvae are still encountered in the deep water (Grønkjaer et al. 1995a, this conference). This fraction might contain individuals not able to ascend to upper water layers. Hence they should be faced with sub-optimal feeding conditions and be subject to an increased mortality. The buoyancy of cod larvae is dependent on ambient salinity during egg development and initial egg buoyancy (Nissling & Vallin 1994). A low sinking rate of newly hatched larvae implies that the frequency of swimming phases can be kept low and still allow the larvae to rise to the surface (Waller & Rosenthal 1995, this conference). It is unlikely that cod larvae maintain their normal activity pattern at low oxygen levels and are able to approach the feeding areas within the yolk-sac stage (Nissling 1994). Future experimental and field studies will focus on this aspect in order to allow a more conclusive interpretation of vertical distribution patterns, and to elucidate the migratiory behaviour and the energetics of early life stages of cod.

Laboratory experiments

Laboratory experiments performed to date during this programme have examined the effects of food availability on growth and condition through utilization of measurements of nucleic acid and group

lipid content (Clemmesen & Doan 1995, Grønkjaer et al. 1995b, both this conference). DNA, dry weight and protein content are commonly utilized as an estimate of structural size. When related to RNA content, indicative of protein synthesis, this provides an indication of larval growth, while the content of triacylglycerol (TAG, storage lipids) related to structural components generally gives an indication of larval energy reserves. Preliminary laboratory experiments suggest that the utilization of these indices of growth and condition are not always appropriate dependent upon ages/developmental stages. The comparison of nucleic acid content and dry weight performed on starved and feeding larvae indicates that this measure of feeding success is suitable for differentiating between individual starving and well fed cod larvae 11 days after hatching. Analysis of storage lipid content (TAG) on pooled samples suggest that this technique is not appropriate for the early larval stages but may provide a useful indicator of larval condition at later stages when individuals are incorporating energy reserves (St. John & Lund in press). The need for further research in these areas is clearly indicated with a more detailed intercalibration of these two techniques coupled with an examination of changes in larval morphology planned for 1996.

Otolith studies

Otolith analysis has been included in this context primarily as a tool for the back calculation of hatch date distribution (Linkowski & Kowalewska-Pahlke 1993). To date, only the samples from benthic juveniles can be taken as representative for a year-class. Aging of these stages should be continued in order to obtain an extensive data set for further calibration of the age prediction model. In laboratory rearing experiments the age reading technique was validated by comparing otolith increment numbers with known age from observed hatching as well as from Alizarin-marking dates (Clemmesen & Doan 1995, this conference). Comparison of the left and the right otolith clearly showed that care has to be taken when measuring the total size (radius) of the otolith. Obvious differences in total sizes were not related to the differences in the width of daily increments, but to the size of the primordium, the core of the otolith at the time of hatching. Factors influencing the formation of the primordium should be further analysed. In addition to the validation of age readings, the individual ring increments have been studied in more detail on otoliths from larvae reared at different food supplies. The width of the increments was effected by the availability of external food sources. Differences between feeding and starving larvae became apparent starting on day 7 after hatching.
Both the nucleic acid technique and the otolith structure analysis could be successfully applied to the laboratory reared cod larvae. The coupling of biochemical analysis and otolith microstructure analysis has shown a new potential for the use in recruitment research. RNA/DNA ratios are commonly used to back- and forecast the potential growth and survival for larvae. The validity of the RNA/DNA ratio can be improved by incorporating daily otolith increment studies to derive information on the growth history of the larvae as well as the condition at the time of sampling.

Larval feeding behaviour

Effort was allocated towards developing models of prey encounter rate for two different types of larval fish predators. Experiments conducted showed that cod larvae are pause-travel predators (search for prey while stopped) and that herring larvae are cruise predators (search for prey while swimming). These two types of search behaviour suggest that the sensitivity of encounter rate for these two predators will be quite different in response to turbulent water motion. A model of prey encounter rate was developed for the pause-travel predator and compared with that for the traditional cruise predator (MacKenzie & Kiørboe in press).

3 Modelling

According to the time schedule of the project, activities in the modelling section concentrated mainly on the implementation of a multi-layer flow model in order to investigate the effects of circulation patterns in the Bornholm Basin on the advection of cod early life stages.

3.1 Modelling cod recruitment

In order to elucidate the drift of larval cod from the centre of the spawning ground in the Bornholm Basin, a three-dimensional eddy resolving baroclinic model of the Baltic Sea (Lehmann 1994 and in press) coupled with hydrographic and ichthyoplankton measurements has been used (Hinrichsen et al. 1995, this conference). Larval drift was simulated by incorporating individual cod larvae as passive tracers into the model and determining Lagrangian drift trajectories. Initial fields of temperature and salinity within and around the area of investigation were constructed by objective analysis using hydrographic observations from the Arkona and Bornholm Basin and from the Stolpe Trench. The baroclinic model was forced by realistic wind data taken from meteorological observations. For verification the simulation results were compared with ADCP-measurements and hydrographic observations during subsequent surveys (Hinrichsen et al., submitted). The modelled hydrographic properties appeared to be coherent with observed features, indicating that predictions of larval distribution should be possible with a high degree of confidence. Further improvements of the model are expected from the planned implementation of vertical migratory behaviour of the larvae.
The aquatic ecosystem model FINEST, based on size-dependent food web conception and mass-dependent biochemical reactions parametrisation (Tamsalu & Myrberg in press) has so far been applied to the Gulf of Finland (Tamsalu & Ennet in press). It will further be developed and implemented for the Baltic Proper including the Kattegat, Belt Sea and Sound by a joint bilateral effort of the FINnish and ESTonian scientists involved in the project.

3.2 Incorporation of recruitment processes into stock assessment models

Within the frame of the ICES Working Group on Multispecies Assessment of Baltic Fish in June 1995, updated MSVPA runs were conducted by using a new programme package (4M) developed by the Danish Institute for Fisheries Research within the frame of another EU-project. The updated runs resulted in new recruitment figures of Central Baltic 0-group cod to be used in the trend analysis and modelling section as independent estimates and updated predation mortalities to be used in planned stock projections. Actions required to test the reliability of these predation mortalities have been identified and will be taken up during 1996. The Working Group also discussed whether an integration of stock recruitment relationships (e.g. Sparholt 1995) and predation on early life stages might be required and whether the inclusion appears to be feasible. A final conclusion has not yet been achieved.

4 Evaluation of stock enhancement programmes

The situation of the Baltic cod stocks has reached such a critical stage, that national and international authorities (e.g. the Nordic Council of Ministers and ICES) have decided to place more emphasize on the subject of cod stock enhancement. Drastic changes have occurred in understanding the type of problems facing the Baltic cod fisheries (e.g. reproductive disorders, species interactions) and pathways of contaminants through changes in the food chains. All these aspects are considered in detail by different subgroups in the present project.
Feasibility studies on ranching of cod undertaken in Norway (e.g. Svåsand & Kristiansen 1990) include assumptions which are not entirely applicable to the Baltic situation. Even under the more favourable Norwegian conditions, ranching of local populations has yet not fully proven to be commercially viable (Sandberg & Oen 1993). At present, cod ranching can be recommended only in areas, where the carrying capacity of the ecosystem is not filled by natural reproduction, which might be the case in some areas of the Baltic Sea, e.g. the Bothnian Sea (Larsson & Pickova 1993). However, comparing the Norwegian and Baltic areas it has further to be considered that the types of fisheries are different: while the Norwegian cod fishery is largely coastal and cost effective, the Baltic cod fishery is much less effective and the price received for landed cod is low. Thus, under present commercial conditions and on basis of the available knowhow in culture technology and especially in face of the low hatching success and the low survival of yolk-sac larvae experienced for Baltic cod, ranching for commercial purposes seems to be not attractive in the Western and Central Baltic Sea.

On the other hand, during periods of low oxygen supply in the deep basins, the largely reduced reproductive volume for cod in the Baltic provides a very specific situation which seems to be indicative for a stock enhancement approach if other factors like problems in the condition of parent stock or diseases are not counteracting. However, as our understanding of major biological/physical processes regulating survival and growth of 0-goup cod is still very limited, a more thorough evaluation of the feasability and the possible impact of stock enhancement programmes is expected for the end of the Baltic CORE project.

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