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Report of the

Workshop on a Synthesis of the Cod and Climate Programme

New Bedford, USA
5–7 May 2003

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 INTRODUCTION AND TERMS OF REFERENCE

The **Workshop on a Synthesis of the Cod and Climate Programme [WKCCP]** (Co-Chairs: K. Drinkwater, Canada and K. Brander, ICES/GLOBEC) met in New Bedford, USA from 5–7 May 2003.

The terms of the reference (C: Res.2002/2C11) for the workshop were to:

a) review what we have learned from the workshops, theme sessions and other activities of the Cod and Climate programme over the past 10 years;
b) present and discuss synthesis papers on specified topics related to the life history of cod;
c) finalize the plan to publish these synthesis papers as a book on cod.

There were 14 participants from 5 countries (Canada, Denmark, Greenland, Norway, and USA) and the ICES/GLOBEC Coordinator. A list of participants is provided in Appendix 1.

1.1 Background

The WGCCC has been active for over 10 years. At its 1998 meeting, synthesis of the results from the program was identified as one of the major components of its long-term strategic plan. It was decided at the 2000 meeting that this synthesis should take several forms, the most important being the writing of a book on cod. This book would introduce topics addressed by the Working Group; summarize our present knowledge of these topics and comment of how the WG has contributed to them. In keeping with the aim of the WGCCC, comparative studies between stocks would be emphasized. At the 2002 WGCCC meeting, an outline of the topics (book chapters) was approved, potential authors identified and a Workshop was proposed for 2003 to present the topic syntheses and to provide a forum for comments and feedback. This would ensure completeness and provide an opportunity for interaction between chapter authors in order to resolve issues over content, links, gaps and overlaps between chapters. A plan would be developed to revise the synthesis chapters, have them reviewed and finally published. The present Workshop has reviewed progress to date and the options for publication.

2 DISCUSSION OF PUBLICATION OPTIONS

Publication options were explored prior to the WG meeting and three options were discussed at the meeting, to obtain the opinions of the participants. The options were (a) a special issue of the ICES Journal of Marine Science, (b) a book published by Kluwer, or (c) a book published as part of the IGBP Science Series by Springer.

The ICES Journal editors were very receptive to the idea of publishing the work as a special issue. This option would provide wide distribution and the contributions would be considered as primary publications. The disadvantages would be that the result would be a series of individual papers, rather than a collective, linked-up text. We would have to pay publication costs or provide a guaranteed sale.

Kluwer requested a full proposal, which they sent out for review. They have come back with an offer to publish a book of up to 500 pages, with some colour diagrams. There would be no financial obligations on the WG, free copies for all co-authors and royalties on sales over a minimum number. This option would allow a book format and give us greater flexibility over content and presentation. The book would be written with a wider, less specialized audience in mind than the Journal option.

The IGBP has offered to publish the book in its scientific series (the offer was subject to approval by their editorial board at the time of the Workshop, but has since been confirmed). They requested a paragraph or two on each chapter to and other information about size, scope and potential market for the publisher. Final details from the publisher (Springer) are still awaited.

The Workshop discussed the three options and decided that the material should be published as a book and not as a series of papers, hence we would not publish in the ICES Journal. The Kluwer offer is very reasonable and is on the table, but the editors were asked to explore the IGBP option further. Participants felt that there were advantages to the latter, since it would be in a series dealing with related IGBP programmes and would reach an audience of scientists, science managers and policy makers who are concerned with the global change issues dealt with by IGBP. This was felt to be important if we are to influence the funding of similar programs in the future. K. Drinkwater will send the IGBP their required documentation. K. Brander and K. Drinkwater, as co-editors, will assess the relative merits of the Kluwer and IGBP proposals and make a decision. If there is time, the two book proposals will be posted on the ICES web site and comments from the co-authors will be sought.

3 REVIEW OF CHAPTER OUTLINES

For the majority of the chapters, outlines were provided prior to the meeting and posted on the ICES website. A few others provided outlines immediately after the meeting. During the meeting, presentations were made on each of the chapters except the Introduction and Summary chapters. Discussions followed each of the chapters to identify potential links, gaps and overlap between chapters and to comment on the material.

3.1 Chapter 1 – Introduction

Lead Authors – Keith Brander and Ken Drinkwater (to be written with input from all)

This chapter will introduce the book, briefly discussing the importance of cod in the history of the North Atlantic, the development of the fishery, and the recent problems in the fishery. It will go on to introduce the ICES/GLOBEC Cod and Climate Change program and its objectives. Finally, it will discuss the purpose of the book and what will and will not be covered. This will include the major questions that will be addressed by the book. It will stress the role of climate in the various life history stages of cod and the importance of comparative studies, i.e. the examination of the life history strategies across the full range of environmental conditions, and what can be achieved by this kind of approach. Examples of previously published comparative studies will be given.

3.2 Chapter 2 – Stock Structure and History

Authors - Gudrun Marteinsdottir, Daniel Ruzzante and Einar Nielsen

1 Introduction

During last century, cod stocks in all areas of the North Atlantic have undergone dramatic changes. During the last decades, cod populations have been exposed to gradually rising fishing pressures due in part to improvements in technology that result in increasingly efficient fishing practices. At the same time, all stocks have been exposed to changing environmental conditions, which, together with increasing fishing pressures, are thought to be responsible for the historical fluctuations in stock abundances and structures. Stock sizes and the age and size structures of stocks have consequently been depleted. Such drastic changes in population sizes have raised concerns about potential (selective) changes in genetic composition and loss in genetic diversity. Today many of the stocks are heavily overfished and some are considered to have reached the stage of recruitment overfishing.

We will highlight the importance of understanding genetic structure for the conservation of diversity, diversity which is intimately linked to a population's ability to respond to environmental change. Due partly to lack of information resulting from limitations in the molecular techniques available up to the recent past, genetic structure has often been ignored in fisheries management. Such neglect occurred probably at the expense of increased risk of overexploitation of minor or less productive components of stock complexes. In this chapter we will review the changes that cod stocks in the North Atlantic have undergone during the last decades. Emphasis will be on genetic diversity and its potential changes and on their relationship with changes in stock abundance and age structures in response to fishing and changes in environmental conditions.

2 Stock Structure

2.1 *Geographical location of cod stocks in the North Atlantic*: This section will describe the location and distribution of all major cod stocks in the North Atlantic. A map showing schematically the location and distribution of all known cod stocks as well as the location of spawning sites, when known, will be included.

2.2. *Genetic identification*: This section will review our state of knowledge concerning the genetic composition of cod in the northwest, central and northeast Atlantic, as well as in the North and Baltic Seas. Where available, inferences based on results from tagging and morphometric studies will be incorporated. We will also discuss insights from studies of mixed stock analysis and of hybrid zones.

3 Cod fishery and stock variability

3.1 *Fishing effort and landings*: In this section, the trends in the fishery among all major cod stocks in the North Atlantic will be described. The review will include information on annual landings, yield and fishing mortality

3.2 *Changes in stock abundance and age structures in relation to exploitation and environmental condition*: In this section, variability in stock size and structure will be reviewed. The review will include information on stock abundance, spawning stock biomass and age structures. Fluctuation in stock abundance and changes in age structures will be discussed in relation to changes in exploitation patterns and environmental conditions.

3.3 *Changes in Genetic variation*: This section will review our knowledge of long term temporal dynamics of the genetic composition of cod stocks

4 Discussion

The discussion will be loosely framed into three sections: (1) trends in the fishery and its effects on stock size and composition in relation to the environment (2) Genetic diversity in relation to exploitation and the environment (3) Analytical approaches to examine changes in the genetic composition of exploited populations.

(1) Trends in the fishery and its effects on stock size and composition will be discussed in relation to changes in the environment. Attempts will be made to highlight trends that are common among stocks as well as consider the main causes for variability in landings and stock abundance and genetic variability.

(2) We will discuss the possibility that genetic structure may change with changes in population abundance, emphasizing the importance of, and need to undertake long term temporal studies of population structure. Such studies have been attempted with a number of species including cod using archived material (otoliths or scales) from which DNA can be extracted. Examining the long term temporal dynamics of the genetic composition of populations enables an examination of the relationship between census and effective population sizes, knowledge that can be of fundamental assistance for the prediction of a population's ability to respond to environmental change.

(3) We will also discuss the need to combine approaches that examine differentiation as measured with markers that are assumed to be neutral or nearly neutral, and approaches that specifically target adaptive differentiation.

3.3 Chapter 3 – The Cod and Climate Change Programme

Authors – Svein Sundby, Brian Rothschild and Bob Dickson

This chapter will provide an historical perspective by tracing the evolution of the Cod and Climate Change programme, how it has been organized, and how it has interacted with, and made use of, studies in other branches of science (oceanography, meteorology, geochemistry, economic history, data exchange and others). It will also address the programme's successes as well as its failures in an attempt to point the way for future studies. It will review the retrospective studies undertaken by the programme that examined large events, both biological and environmental, in an attempt to reveal the importance of climate variability on fish stocks. The high "signal-to-noise" ratio offered by such events was the attraction and focus of what were termed BACKWARD-FACING Workshops that included investigations of the tilefish kill of the 1880s off the northeastern seaboard of the United States, the biological response to the cooling of the 1960s in the Northwest Atlantic and the gadoid outburst in the North Sea in the 1960s and 1970s. It will examine the development of a theoretical approach, not just correlative studies. In addition to history, the chapter will reflect on what the CCC programme has achieved.

3.4 Chapter 4 – Physical Oceanographic Setting

Authors - Ken Drinkwater and Harald Loeng

The purpose of this chapter is to provide a description of the physical environments occupied by cod. It will point out the wide range of hydrographic properties and oceanographic features in which cod live. The paper will provide a review of the environments and the interannual variability but will also attempt to categorize the physical environment for each stock for possible use in comparisons of biological features.

1 Introduction

The introduction will focus on the importance of the physical environment to cod, point out the wide geographic distribution of the cod as well as the diverse habitat and topography they occupy, indicate the wide range of hydrographic properties they inhabit, and note the importance of advection to many of the stocks. Some examples will be given of evidence for the physical environment affecting cod.

2 Physical Processes in the North Atlantic

This section will provide background on the physical processes that contribute to the observed physical environment of the cod habitat and their variability.

2.1 *Processes controlling mean conditions and seasonal variability*: A general description of the circulation in the North Atlantic will be provided with greater emphasis on the currents in the regions occupied by cod. The importance of atmospheric heat fluxes to the seasonal temperature variability and freshwater runoff to the salinity variability will be discussed. In addition we will address stratification and the factors controlling it, such as T, S, and wind mixing. A brief discussion of tidal mixing, which is important on, for example, Georges Bank, will also be undertaken.

2.2 *Processes controlling interannual variability*: The main processes controlling interannual variability in the physical environment (temperature, salinity, currents, and stratification) will be discussed. This will include the NAO, variations in the local heat fluxes and freshwater runoff, and the winds.

3 Environmental conditions in cod habitat throughout the North Atlantic

3.1 *Description of the mean conditions and seasonal variability*: A description of the seasonal temperature, salinity, stratification and currents experienced by cod will be given for as many of stocks as possible. A table of physical parameters for each stock will be developed in an attempt to compare and contrast the types of physical environments the cod occupy. Parameters will include mean temperatures and salinities as well as the seasonal variability experienced by larvae, juveniles and adult cod and the strength of the tidal, seasonal, low-frequency (meteorological band) and mean currents in the cod's habitat.

3.2 *Description of the interannual variability*: The interannual variability in the hydrographic properties, stratification and currents will be described again for as many cod stocks as possible. Another table will be produced with physical parameters associated with the interannual variability of the physical environment.

4 Discussion

The discussion will focus upon a comparison of the various habitats occupied by cod. What do they tell us about the species? How does the interannual variability in temperature and salinity compare between stocks? Are there any physical environmental parameters that help to explain behaviour? Can the stocks be categorized by their physical environment?

5 Summary

A summary of the main conclusions will be given.

3.5 Chapter 5 – Biological Oceanographic setting

Authors – Mike Heath, Greg Lough and Kurt Tande

1 Overview

The biological oceanographic environment of cod includes its prey, predator and competitor species within the food web. The range of species which will fall into these categories will change systematically throughout the life history, and vary in space and time. However, the most dramatic change in species interactions occurs at the end of the pelagic juvenile phase when cod begin to settle and adopt a more demersal habit and piscivorous diet. In this chapter we shall focus on the pre-settlement larval and pelagic juvenile phase, and explore the basis for connections between zooplankton and the oceanographic processes affecting their production, and the growth and survival of cod larvae and juveniles.

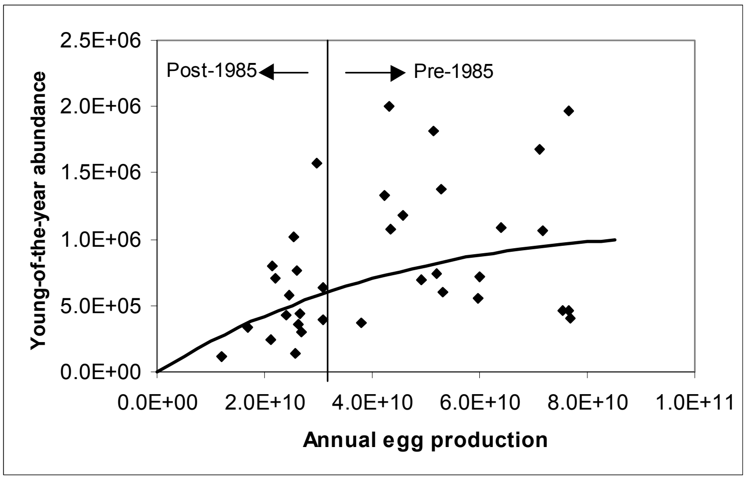
Diet studies on larval and juvenile cod from the mid-northern side of the geographical range show a predominance of *Calanus finmarchicus* developmental stages in the diet. Early larvae focus on naupliar stages, whilst the late larvae and juveniles consume the later copepodites. Given this association it is natural to search for correlation relationships between year-to-year variations in the abundance of *C. finmarchicus*, and the growth or survival rate of pre-settlement cod. However, in general, such exercises have been inconclusive.

2. Example of the search for Cod-Calanus correlations using data from the North Sea.

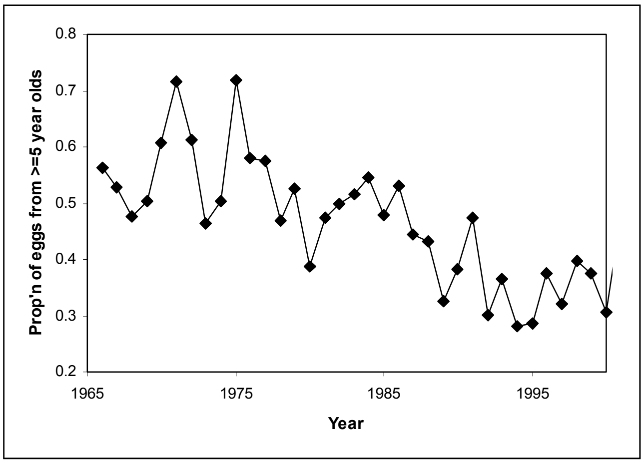
Assessment outputs on numbers at age for the North Sea and West of Scotland cod stocks were recomputed to harmonize differences in assumed natural mortality rates. A backcalculation method was used to estimate the young-of-the-year (O-group) abundance at the end of August each year, and the corresponding annual egg production estimated from maturity and fecundity data. Further details are available from the report of the EU-STEREO project. Time series of young-of-the-year abundance and annual egg production for these two units were highly correlated, so they were combined to provide data for the whole stock complex.

There was strong temporal structure to the relationship between young-of-the-year abundance and corresponding egg production, with all of the values post 1985 having an egg production of less than $3x10^{10}$ thousand eggs.

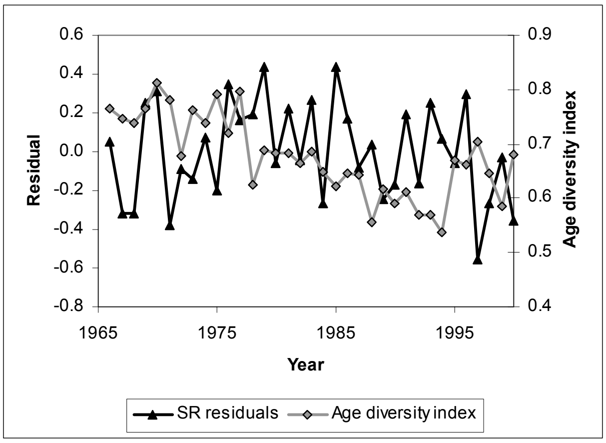
A Ricker stock-recruitment relationship was fitted to the data. Residuals from this fitted function showed a unimodal distribution implying that the data formed a single group.

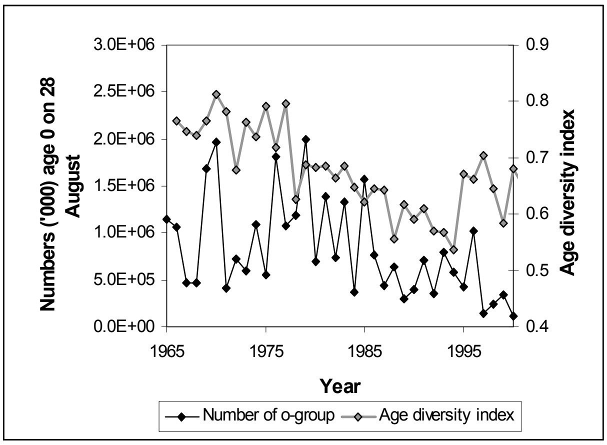


As the North Sea and West of Scotland cod stock has declined over the period since 1960, so the age structure of the stock has progressively changed. The age diversity index defined by Marteinsdottir and Thorarinsson (1998), which measures the numerical contribution of older fish to the mature population, has decreased from approximately 0.75 in the late 1960s, to 0.6 at the turn of the century. In terms of egg production, the contribution of 5-year and older fish to the annual production, has declined from 50–60% to around 30% over the same period (in the North Sea, greater than 50% of age 4 cod are mature, whilst off the west of Scotland greater than 50% of 2 year old cod are mature).



Unlike the situation at Iceland, where the age diversity of the stock explains a significant component of the recruitment variability (Marteinsdottir and Thorarinsson 1998), there was no relationship between diversity and either young-of-the-year abundance, or residuals from the fitted Ricker stock-recruitment relationship for North Sea plus west of Scotland cod.





Residuals from the fitted Ricker function were related to environmental indices. In the case of cod, which is distributed in both the northern and southern North Sea, separate indices were employed for the northern and southern North Sea:

- North Atlantic Oscillation (NAO) index. The NAO is an index of atmospheric conditions in the North Atlantic and reflects the intensity of the pressure gradient between Iceland and the Azores. When the NAO is low, southwesterly wind stress over northwestern Europe usually declines, and vice versa, with consequences for shelf sea circulation.
- Northern North Sea seawater temperature averaged over the upper 30 m of the water column. Sea temperatures in the region 57ºN–62ºN, 1ºW–6ºE were extracted from archive records supplied by the ICES Hydrographic Data Centre.
- Southern North Sea seawater temperature averaged over February-June in the upper 30 m of the water column. Sea temperatures in the region 52ºN–56ºN, 1ºW–6ºE were extracted from archive records supplied by the ICES Hydrographic Data Centre.
- Spring (April-May) biomass of *Calanus finmarchicus* copepodite stages 5 and 6 in the northern North Sea 56ºN–61ºN, 2ºW–6ºE. Calanus biomass was derived from Continuous Plankton Recorder (CPR) abundance data supplied by the Sir Alister Hardy Foundation for Ocean Science as described by Broekhuizen *et al.* (1995) and Heath *et al.* (2002).
- Spring (April-May) biomass of *Calanus finmarchicus* and *Calanus helgolandicus* copepodite stages 5 and 6 in the southern North Sea 51ºN–56ºN, 2ºW–8ºE. Calanus biomass was derived from Continuous Plankton Recorder (CPR) abundance data supplied by the Sir Alister Hardy Foundation for Ocean Science as described by Broekhuizen *et al.* (1995) and Heath *et al.* (2002).
- Spring (April-May) biomass of *omnivorous zooplankton* in the northern North Sea 56ºN–61ºN, 2ºW–6ºE. Biomass was estimated from Continuous Plankton Recorder (CPR) species abundance data supplied by the Sir Alister Hardy Foundation for Ocean Science. Species were assigned as omnivores and their biomass estimated from abundance as described by Broekhuizen *et al.* (1995) and Heath *et al.* (2002).

As expected from previously published studies (O'Brien et al 2000) the residuals from the fitted Ricker stock recruitment model were inversely related to temperature data. Taking the period 1966–1998 as a whole, the strongest relationship was with data from the southern North Sea (r^2=0.35). When the time series was broken down into pre- and post 1985 periods, the relationship with southern North Sea temperature became slightly weaker with time, and that with the northern North Sea slightly stronger.

3.6 Chapter 6 – Growth and Condition

Authors - Larry Buckley, Jean-Denis Dutil and Tara Marshall

1. Introduction

Cod stocks are found across the North Atlantic and over a wide range of latitudes. They also migrate over long distances and occupy different habitats in the larval, juvenile and adult stages. Thus cod experience a wide range of environmental conditions during their life. Food availability may change on a seasonal or an annual basis and in response to changes in cod abundance. As a result, different stocks may experience slow or fast growth and this may in turn have an impact on key aspects of their ecology such as mortality.

This chapter will review the wide range of growth and condition trajectories across stocks in an effort to assess potential impacts of climate change on the species. Factors influencing growth will be reviewed and relationships between growth, condition and reproduction will be examined. The main emphasis will be on how stocks representative of different climates compare in the relationship of growth and condition to environmental factors, particularly in the larval and adult stages. The impact of these differences on stock production and resilience will be discussed.

2. Larval and Pelagic-Juvenile cod

2.1 *Variations in size at age and other life history characteristics*: Several factors may influence size at age including water temperature, photoperiod, food availability and size-selective mortality. Several of these variables may change in concert and isolating the effects of an individual variable has proven difficult. Nevertheless, using data from field, laboratory, mesocosm and modelling studies we will attempt to identify the key factors affecting growth and size at age during the first months of life in representative stocks covering the range of Atlantic cod.

Stocks vary in a number of early-life history characteristics including spawning time and duration. Some stocks spawn in coastal waters, while others spawn on offshore banks. Eggs and larvae may be retained in a gyre or transported over considerable distances to nursery areas. Water temperature, photoperiod and food availability vary annually, interannually and among stocks. Due to the wide variety of environmental conditions experienced, it is likely that different environmental factors may play critical roles in regulating growth in different stocks. Also, a single environmental factor may have positive, negative or no effect on growth depending upon the stock under consideration.

2.2 *Variations in recent growth and condition*: Condition during the larval stage has been estimated using a variety of approaches ranging from morphometrics to histology and biochemistry (for a review see Ferron and Leggett 1994). By far most available data on condition are based on the relationship between length and weight. During the larval stage variable shrinkage during capture and subsequent handling limit the utility of this approach. While other approaches to estimation of condition in fish larvae offer considerable potential (e.g. lipid class analysis and lipid biomarkers) available data are too limited to allow comparisons among stocks. Consequently, for the larval and pelagic-juvenile stage the emphasis will be placed on estimates of short-term or recent growth based on otolith microstructure analysis and nucleic acid analysis. Both methods can provide information on growth over a period of a few days. Short-term growth in the pelagic early-life stages is analogous to condition in older fish in that both more strongly reflect conditions over the more recent past rather than integrated over the life of the individual. We will examine trends in short-term growth for a limited number of stocks to gain insight into the relationships between environmental variability and growth. Both empirical growth models and individual-based bioenergetics models (IBM) will be considered.

2.3 *Relationship of growth to mortality and recruitment*: Several studies on larval and pelagic-juvenile cod have demonstrated positive relationships between size at age and subsequent recruitment of a year class (Ottersen and Loeng 2000). A connection between growth and mortality has been reinforced by the demonstration of selection for fast growth within a cohort. The relationships among growth, mortality and recruitment will be explored with respect to the environmental variability experienced by different stocks during their first months of life. We will consider the impact of growth during the pelagic early-life stages and the likely success or failure of a cohort or year class.

3. Adult cod

3.1 *Variations in size at age and other life history characteristics*: Several factors may influence size at age including size-selective fishing which may obscure relationships between size at age and other factors. Several papers will be discussed to show that lengths at age and weights at age correlate with other factors as well, including density-dependent and density-independent factors such as stock abundance and surface and bottom temperature. Results of laboratory experiments will also be included to describe fish size and dissolved oxygen availability effects.

Stocks vary in life history characteristics. Some stocks live in cold water, sometimes also in hypoxic waters. They are characterized by a smaller size at age, recruit at an older age, become sexually mature at a later age and a smaller size and produce fewer eggs than stocks living in more favourable environments. Thus growth production at the stock level will be shown to vary considerably among stocks. Differences in age and size structure (different sizes have different requirements) may explain part of this variability, but differences in habitat characteristics will be shown to play a role (as evidenced by analysis restricted to common age groups).

3.2 *Variations in condition*

3.2.1 *Condition vs growth*: The relative merit of analyses based on measures of size at age or measures of condition will be explored. Do condition and size at age tell the same story? The growing literature on cod condition will be reviewed. The point will be made that condition looks at growth from a different angle. When measured systematically or at critical periods of time, condition provides insight into the degree of success or failure of individual fish in the population. Growth and condition may covary during some periods of time and in some stocks, but they may not in others with condition sometimes showing a better correlation with factors in the environment. Fish condition is on average higher and varies much less in warm water stocks compared to other stocks (this is also true within stocks see Marteinsdottir and Begg 2002).

3.2.2 *Condition on growth*: Condition will be shown to affect key metabolic processes including growth capacity. Negative growth periods result in a deterioration of the metabolic machinery and this in turns affects survival, swimming capacity, maturation processes. Furthermore, the capacity of the digestive system is negatively affected during prolonged negative growth periods. Because they experience large seasonal variations in condition, poorly productive stocks must expend more energy on growth during a short growth season to achieve an observed annual increase in size at age. Growth compensation, a well documented response to periods of food deprivation, may also be retarded. We will discuss the impact of this phenomenon on annual growth.

3.2.3 *Trends in condition and size-at-age*: In the Northwest Atlantic, several stocks collapsed in the early 1990s and have failed to recover up to now. We will review the evidence showing trends in condition and size at age in the 1980s and 1990s and discuss the possible contribution of changing climatic conditions. Some evidence will be shown that links those trends across stocks in response to similar changes in environmental conditions. The relationships among fishing mortality, condition and size at age will be compared for slow and fast growing cod: does size selective fishing operate similarly under different climatic regimes?

3.3 *Variation in maturity*: Maturity can be considered in two contexts: firstly, the transition from immature to mature states and, secondly, the annual cycle of gonadal development that mature individuals undertake prior to spawning. They are differentially affected by temperature. In the case of the former, long-term changes in lengths and ages at 50% maturity have been noted in many cod stocks (Trippel *et al.*). While examples of increased rates of maturation predominate there are also stocks showing decreases in the rate of maturation. The long-term trends in maturation for cold and warm-water cod stocks will therefore be compared.

The temperature conditions experienced by mature individuals also have implications for gonadal development. Temperature effects on the rate of gonad development in cod will be reviewed and its implications for the timing of spawning will be discussed. If possible, a model describing the temperature dependency of gonadal maturation will be used to predict the duration of gonadal maturation and spawning time for different cod stocks. There is also evidence that cod alter their spawning migration routes to adjust ambient temperature conditions to achieve desired gonadal maturation rates (Comeau *et al.* 2002). Such adaptive behaviours could have implications for spatial and temporal patterns in egg production.

3.4 *Impact on yield and surplus production*: The relationship between growth production and surplus production will be examined both within and among stocks. Low growth production translates into low surplus production and there are instances of no annual growth resulting in no surplus production in some years. Correlations are strong when all stocks are examined, but are not so strong within stock. The impact of slow growth and poor condition on the numbers of fish required to reach a target TAC will be compared for 2 stocks, a productive one (GB) and a less productive one (NGSL). We will describe how changes in growth and condition affect those numbers.

4. Discussion

The discussion will emphasize what the larval and adult stages have in common and in what respect they diverge. We will put a major emphasis on contrasts between different thermal regimes: would we draw different conclusions on key factors if we examined different climatic environments? Factors not addressed in this chapter will be listed and briefly discussed, for instance phenotypic plasticity (e.g. contraction and expansion of vital range, changes in habitat selection in response to changes in environmental conditions) and genetic adaptations; cod in different stocks may differ in their growth capacity under a similar set of environmental conditions. Provocative statements on vulnerability of different life stages and different stocks to climatic changes under different exploitation regimes will be presented.

5. Summary

A summary of the main conclusions and questions will be given.

3.7 Chapter 7 – Recruitment

Authors – Fritz Köster, Mike Fogarty and Jan Bayer

Geographic and temporal patterns of recruitment variability can be related to climatic factors, particularly temperature, but determining the causes and processes remains a difficult task. The main question to be addressed in this chapter will be how does climate change (compared to fisheries and biological factors) affect recruitment? The chapter will review the status of our understanding from sexual maturity to the entering of juveniles into the fishable stock. It will include empirical information on the variability of the stock-recruitment relationship to seek insights into the mechanisms controlling recruitment. The critical life stages in reproductive success will be identified and the processes affecting these stages for different environments from the cold northern stocks to the warm southern stocks, to the estuarine stocks in the Baltic and the Southern Gulf of St. Lawrence. Indices will be identified for the various stocks that represent processes affecting cod. Hypotheses on the factors controlling the critical life stages will be discussed and tested. These life stages include egg and larval production, juveniles and settlement. A comparative study of the recruitment and recruitment processes from most of the major stocks will be presented and discussed. Detailed studies of the recruitment processes in the Baltic and Georges Bank will be highlighted and contrasted.

3.8 Chapter 8 – Egg and larval transport

Authors - P. Pepin and ?

1 Outline

The purpose of this chapter is to provide an overview of the current knowledge about the drift and distribution of cod eggs and larvae among cod stocks. The paper will review the current state of knowledge about the circulation regime in the environments in which cod live and concentrate on the features which most readily influence the egg and larval stages and how this may impact on their vulnerability to changes in environmental forcing.

2 Introduction

Cod produce pelagic eggs which for most stocks rise toward the surface where they hatch into larvae. For populations which spawn in brackish waters, the vertical ascent of eggs towards the surface is restricted by the density structure of the water column. Larvae then develop in the upper water column until they reach a size where they become competent to undertake exploratory vertical migrations to identify suitable bottom habitats into which they will settle. During their time in the water column, eggs and larvae are subject the effects of ocean currents which can cause them to be retained within the spawning area and/or be dispersed over great distances to nursery areas.

This chapter will review knowledge of the ontogeny of vertical distribution for stocks across the range of cod in association with knowledge of the local circulation and the factors that are likely to influence transport. The emphasis will be on investigating how the characteristics of each stock allows for a consistent pattern of drift or retention in the light of variations in physical forcing.

3 Ontogenetic variations in vertical distribution

What is known about the vertical distribution of eggs and larvae in various spawning environments? This section will review the existing information on the vertical distribution of eggs and larvae and how the distribution changes with age/size. In addition, we will summarize the existing knowledge about the buoyancy of cod eggs (and possibly larvae). The information will be used with data on the vertical density structure in the spawning areas to predict the vertical distribution of eggs, which would in turn provide an indication of what aspects of the circulation are likely to determine the pattern of drift or retention.

4 Transport and retention

The role of transport on the distribution of eggs and larvae has been inferred from two sources: [1] plankton collections of eggs and larvae, and more recently [2] numerical circulation models parameterized with biological observations. We will describe what knowledge there is about the magnitude and variability in transport that has been derived from these sources of information, and put some emphasis on the questions that still need to be resolved.

5 Inter-stock transport

To what extent does inter-stock transport play a role in the dynamics of cod? The most important example of this comes from the Iceland/Greenland cod stocks where it has been proposed that transport across the Denmark Strait has played a role. However, similar questions clearly arise when it comes to the stocks in the Western North Atlantic where the proximity of management units is far more important than in the Eastern North Atlantic. Using information on seasonal temperatures and development times, we will attempt to assess what physical constraints would be required for exchange among stocks or management units to be significant.

6 Discussion

The discussion will focus on what we have learned about the role of transport in the dynamics of cod and what questions remain to be addressed. What is needed from the physical oceanographic community and how do we compare predictions with observations? Is there evidence that inter-annual variations in transport affect recruitment patterns and does this vary depending on the nature of the physical system in which cod spawn?

3.9 Chapter 9 – Distribution and Migration

Authors - Geir Ottersen and Doug Swain

1 Introduction

Cod are widely distributed over shelf waters of the North Atlantic, across a wide range of latitudes and environmental conditions. Many stocks make seasonal migrations over long distances and occupy different habitats during spawning, feeding and overwintering periods. Interannual variability in distribution patterns may also be pronounced. Climate, in particular sea temperature, is one of the primary factors, together with food availability and suitable spawning grounds, in determining the large-scale distribution pattern of cod.

In this chapter we will review the wide range of distribution and migration patterns observed in North Atlantic cod stocks, with special emphasis on between-stock comparisons. Factors influencing differences in distribution and migration between stocks and between years within stocks will be reviewed, with particular attention to responses to environmental variation.

2 Seasonal migrations of cod

Differences and similarities between stocks and between life history stages within a stock with regard to migrations between spawning, feeding and overwintering grounds will be discussed. The adaptive and ecological significance of these migrations and of the different strategies adopted by different stocks will be examined.

Interannual variation in the timing and extent of migrations will be documented. Causes of these changes, including variability in climate, prey availability and fishing, will be examined.

3 Habitat associations of cod

Habitat selection by fishes depends on a variety of biotic and abiotic factors such as prey abundance, substrate, depth and temperature. Since fish are ectotherms, temperature has a significant effect on physiological processes such as metabolism and growth. This makes temperature one of the key determinants of habitat quality for fishes, though other abiotic factors such as oxygen concentration, cover and salinity may also play an important role in habitat selection. In addition, biotic factors, such as the distributions of prey, competitors and predators (including conspecifics), are important components of habitat quality.

This section will examine habitat associations of cod, comparing environmental preferences between populations and between life history stages within a population. Cod often also show striking differences in habitat associations between seasons. This seasonal variation in habitat preferences will be described and compared between populations. Ecological factors underlying ontogenetic and seasonal changes in environmental preferences will be examined, as will reasons for differences between populations in habitat associations.

Finally, interannual variation in habitat associations within stocks will be described. Factors responsible for this interannual variation, including fluctuations in climate, changes in the distribution of prey, and changes in environmental preferences, will be examined.

4 Geographic range and its variation

The geographic region occupied by a population is affected by its environmental preferences, by the distributions of its prey and predators, and often by the size of the population. Habitat selection is often predicted to be density-dependent, with geographic range expanding as population size increases and contracting as it declines. Shifts in geographic range have also been related to fluctuations in climate, in the distribution of prey or in the age structure of the population. Variation in geographic range will be described between and within populations, and the factors underlying this variation will be examined. Case studies testing between density-dependent habitat selection and other possible explanatory mechanisms for variation in range will be presented. Ecological and fishery-related consequences of changes in geographic range will be described.

5 The future: distribution and migration within a climate change setting

Although the uncertainty is high, climate change scenarios tend to indicate higher temperatures 50–100 years ahead in most, although not all, of the areas presently inhabited by cod. Windiness and wind direction are also expected to be altered. An increased range of environmental conditions within a season or year may be expected, as well as more frequent occurrences of extreme events. Since most cod stocks are highly influenced by climate, such changes may have a major impact on distribution and migration. If the environmental change is strong enough, profound alterations of ecosystems, involving local extinction of species and habitat expansion of others cannot be ruled out. Possible impacts of climate change on the distribution and migration of cod will be explored.

6 Summary

A summary of the main topics dealt with and conclusions drawn will be given.

3.10 Chapter 10 – The Role of Cod in the Ecosystem

Authors – Jason Link, George Lilly, Bjarte Bogstad

1. Introduction/Background
   1.1 Global importance of Atlantic cod (*Gadus morhua*)

- 1.2 General influences affecting cod stocks (e.g., overfishing, climate, etc.)
- 1.3 Recognition that changes in cod stock size can alter how an ecosystem functions

2 Cod as predators
- 2.1 Major Cod Diet Components and Feeding Patterns/Food Habits
  - 2.1.1 General pattern
  - 2.1.2 Highlight ontogeny
  - 2.1.3 Diet composition, frequency of occurrence, amount of food consumed, etc.
  - 2.1.4 Morphological, physiological, regional, and habitat constraints on diet
  - 2.1.5 Spatial variation
  - 2.1.6 Temporal variation
    - 2.1.6.1 Years/decades
    - 2.1.6.2 Season
- 2.2 Impacts of cod feeding on prey and food web effects of cod predation on the ecosystems they live in
  - 2.2.1 Total removals/consumption
    - 2.2.1.1 Scaling individual consumption to population levels
    - 2.2.1.2 Estimate of predatory removals
      - 2.2.1.2.1 Impacts on prey
        - 2.2.1.2.1.1 mortality
        - 2.2.1.2.1.2 distribution
        - 2.2.1.2.1.3 alternate prey
        - 2.2.1.2.1.4 energy flows
        - 2.2.1.2.1.5 others
  - 2.2.2 Type of ecosystem and food web influences interaction strengths
    - 2.2.2.1 Simple vs. species rich food webs
    - 2.2.2.2 Simple vs. complex physical oceanography

3 Major Predators of Cod (juveniles and adults)
- 3.1 Global e.g. species listing/showing major predators, frequencies, diet compositions, etc.
- 3.2 The amount of cod removed by predators, and how significant is it or could it be?
- 3.3 A mention of larval cod dynamics

4 Major Competitors of Cod
- 4.1 Global e.g. species listing/showing major predators, frequencies, diet compositions, etc., including fisheries on forage prey (e.g., herring, capelin, etc.)
- 4.2 Caveats of how difficult it is to demonstrate competition in the field
- 4.3 Implications for competitors
- 4.4 Implications for other fisheries (e.g., whales-capelin-cod in Barents Sea)

5 A Comparative Study of Cod Trophic Dynamics: A contrast between various types of ecosystems, with a synthesis of the different roles of cod in an ecosystem.
- 5.1 List of major "cod ecosystems"
- 5.2 Changes in cod stock abundance, climate
  - 5.2.1 History of over-exploitation
  - 5.2.2 Climate history
- 5.3 Changes in diet composition, amount, frequency of occurrence, etc.
  - 5.3.1 Five or 10 year blocks, since early time series (1960s or so)
- 5.4 Changes in predator abundance, consumption and frequency of cod diet
- 5.5 Changes in potential predator competitor abundance and diet composition
- 5.6 Changes in habitat and benthos and forage fish
- 5.7 The story we saw in these ecosystems for the past 40–70 years
- 5.8 What does this tell us about the role of cod in ecosystems subjected to intense fishing, climate change, and other factors?

6 Summary and Conclusions
- 6.1 Generalities of the role of cod in ecosystems
- 6.2 Synthesis and recommendations

3.11 Chapter 11 – The response of Cod to Climate Change

This chapter will address the question of what is the expected response of cod to climate change given likely climate change scenarios and our understanding of cod? Up-to-date climate scenarios will be used to indicate possible changes to the oceanography of the North Atlantic. These will be used to predict the possible impacts in the distribution, growth, migration times and routes, recruitment, and abundance of cod. While many of the impacts will be, by necessity, qualitative, models and historical observations presented in the early chapters will be used to attempt some quantitative predictions of changes to the cod stocks. Potentially large changes will occur at the environmental extremes of the cod's range, from disappearance of cod in warm water regions and a large extension of its range in the north. Cod are not isolated but embedded within the marine ecosystem and the impact of climate change will affect the entire ecosystem. Thus, comments about the ecosystem response to climate change will also be discussed and how this might influence cod populations.

3.12 Chapter 12 – Implications for Fisheries Management

Authors - K. Brander and ?

1 Outline

Preceding chapters provide much new information concerning processes by which environmental factors influence cod dynamics over a range of time and space scales. Such information can help to improve our interpretation of past variability in cod stocks, and our ability to distinguish changes due to fishing activity from those due to other causes. It can also improve our forecasting of cod stocks and of the consequences of possible management actions. It can enhance the design and interpretation of surveys, monitoring and other observational programmes. Effective application of new information is however by no means simple or inevitable and the difficulty of developing applications from the Cod and Climate Programme and of communicating with assessment scientists will be discussed.

2 Introduction and background on changes in fisheries management

Fisheries management has moved on from being concerned only with the principal commercial species and now tries to consider the state of the marine ecosystem in a broader manner. Cod is a key predator in sub-Arctic systems of the North Atlantic, but of decreasing importance further south. In some marine ecosystems it has declined in importance over recent decades, with consequences for the ecosystems and for fisheries management, which will be evaluated.

3 Population dynamics and life history process affected by environmental variability:

Environmental factors can be shown to affect catchability, natural mortality, growth, maturity, fecundity, recruitment, transport in early life, migration and distribution. The effects may be studied at individual, population or ecosystem level and they may act directly, indirectly or interactively. Three principal requirements for application of environmental information in relation to fisheries management will be reviewed:

- that the effects are substantial - some examples and sensitivity analyses will be given;
- that the environmental factors causing the effects can be measured in an appropriate, timely and affordable way - issues such as measurement of ambient temperature will be reviewed;
- that the underlying processes are credible and complete.

A case will be put forward that the "burden of proof" concerning environmental effects should change and that it is no longer adequate to assume that the future environment will be like the past i.e. the time period over which population information is available. Environmental effects should not be treated as noise around a stationary mean.

4 Measuring and predicting environmental factors

This has been the subject of several workshops within the programme and some of the conclusions will be reviewed in relation to their application. Climate scenarios are widely applied for evaluating climate impacts and can be used in relation to fisheries management. In order to do so effectively programmes such as Cod and Climate Change need to establish dialogue with the climate modellers in order to ensure that the appropriate information is produced.

5 Key questions affecting fisheries management

Evidence for the relevance of the Cod and Climate Change programme to fisheries management will be provided by addressing some key questions, including:

- can variability in production between stocks and between years be ascribed to environmental and climatic factors?
- what are the consequences of climate variability for sustainable fisheries?
- how can reference points used in fisheries management advice be adapted to include information about climate variability?
- will the adaptive capacity of cod stocks under climate change be compromised by selective fishing?

6 Examples and future developments

Examples of present applications of environmental information will be presented. The possibilities for extending these will be discussed, together with promising avenues for future applications.

7 Summary

A summary of the main conclusions will be given.

3.13 Chapter 13 – Summary

Authors – Keith Brander and Ken Drinkwater (with help from all authors)

The final chapter of the book will be a summary which will seek to provide a broad overview, drawing on the experience a research community who have worked on the issues for over a decade. It will address some of the specific issues which arise concerning the species itself and how these may be tackled in future, but also more general implications for the study of marine ecosystems. It will discuss the insight gained into sustainability, management and the consequences of physical changes on a component of the global system. It will seek to answer those questions that were raised in the introductory chapter.

4 DISCUSSION OF CHAPTER OUTLINES

Each chapter presentation was followed by extensive discussions, which are summarised here. No presentations were given for Chapters 1 and 13, but discussions relevant to these chapters, especially Chapter 13 are provided below.

4.1 Chapter 2 – Stock Structure and History

The chapter outline mentions adaptive changes due to fishing. Situations in which genetic changes may be environmentally induced should also be considered, as should phenotypic versus genotypic characteristics. The long-term fisheries management issues arising from adaptive change need to be addressed somewhere within the book. K. Brander, as lead author on the chapter on fisheries management (12), and the authors of Chapter 2 will determine how and where this topic is to be included. The Workshop was reminded that the focus of the chapter needs to remain on stock structure.

There is no dedicated chapter on the reproduction of cod, but it was decided that this could be divided over several chapters, with mention of related issues, such as composition of the cod stock, egg quality, timing and location of spawning. G. Marteinsdottir's work on Icelandic cod will be excellent for this and T. Marshall and co-workers in Bergen have published on cod egg quality. The co-authors of the recruitment chapter (7) agreed that they would cover some of the material on reproduction. Since the topic will be spread over several chapters it will have to be well coordinated to avoid overlap and ensure the important points are covered. The editors will ensure that this is done. It was pointed out that reproduction and related issues will also be partly included in the update of the Cooperative Research Report on Cod Life Histories for each of the major cod stocks in the North Atlantic (ICES CM 2003/C:10).

Stock structure and migration are linked topics. Cod tagging results need to be included in the book, but have not been mentioned in the Chapter 9 outline (Distribution and Migration). Authors from chapters 2 and 9 are to communicate on how tagging will be presented. At current high fishing mortalities and consequently reduced life expectancy, the frequency of long-range recoveries may be lower than in earlier times, when for example tags were recovered from fish migrating between Iceland and Norway. One may thus form a different view of migration depending on the level of fishing. The topic of subpopulations should be discussed in chapter 2.

A common map is needed to show the location of the principal stocks and K. Drinkwater agreed to develop this and send it to co-authors for their comments and use.

Cases in which there is controversy or uncertainty over stock separation should be mentioned and discussed in order to show what types of information are used to separate stocks and the kinds of stock units (e.g. management-related; biologically based) which are adopted. The time scale required to establish stocks is also of interest. For example there were cod in the Mediterranean during the last ice age, and most of the northern stocks have re-colonised since. Inclusion of such information could be left for the chapter on climate change. Some stocks have come and gone, such as the northern Labrador stocks (North Atlantic Fisheries Organization or NAFO divisions 2GH). In other cases the boundaries have been re-drawn at different times, such as the inclusion of the eastern English Channel and the Skagerrak stocks with the North Sea stock.

The Workshop recommended that one or two stocks should be dealt with in detail, e.g. Icelandic stock. This could highlight the interplay between science and management.

4.2 Chapter 3 – Cod and Climate Change Programme

R. Dickson has confirmed his willingness to write about the Backward-Facing (BF) Workshops. His section will deal with the methodology of combining modelling and observational information (targeted data mining) to lead to conclusions about specific events, such as the 1882 tilefish kill and the "gadoid outburst" in the North Sea. Detailed investigations and data assembly are carried out prior to the workshop, leaving the discussion and synthesis of the material for the workshop. Data from many disciplines of science have been used in the BF Workshops, e.g. meteorology, physical and biological oceanography, microchemistry on quahog shells as an index of temperature, etc. It is also notable that observations of unusual biological events, such as the tilefish kill, can act as the trigger for the compilation of information which led to improved understanding of the physical oceanography of the region in question.

In terms of listing the failures of the CCC as appears in the summary, this needs to be carefully thought out. Perhaps it will be more about issues that were not addressed or for which little progress was achieved rather than "failures".

Background on the organizational structure of GLOBEC and ICES and how the CCC fits into these organizations would be helpful.

The Workshop recommended that a list of CCC publications and meetings should appear in an Appendix. K. Brander will help with this.

Several collaborations or spin-offs from the CCC programme show the influence of the programme and should be mentioned. They include the Trans-Atlantic Study of Calanus (TASC) program and the studies of the Baltic cod ecosystem. An account of the development of the Baltic programme should be included in this chapter. There is also the Canadian programme on Growth dynamics and regulation of energy allocation in Gadoids of different life strategies and in different environments (GADOLIFE) which was a direct result of the 2000 CCC sponsored Growth Workshop.

4.3 Chapter 4 – Physical Oceanographic Setting

One of the main features of cod is their wide distribution. Why do they spawn where they do? If density dependence is an important factor controlling early life mortality, why do they spawn in restricted areas? Is dispersion important? Areas which cod could inhabit (e.g. south-east Iceland) but don't, may indicate limits imposed by the physical oceanographic setting (i.e. there may be no spawning sites from which eggs and larvae will be reliably transported into these otherwise suitable areas). It was agreed that this will be covered in Chapter 9 (Distribution and Migration). It was also noted that for some stocks we still do not have definitive and complete information on spawning locations, e.g. Northern Cod off Newfoundland, Northern Gulf of St. Lawrence cod, and North Sea cod, while most others are well know. It was also pointed out that the spawning locations and concentrations undergo large variability from year to year.

A discussion of scales is needed in this chapter; we need to examine physical oceanography from the long-term and the basin scale (e.g. NAO) to the short-time, small spatial scales and microscales (e.g. turbulence). Participants felt strongly that a discussion of mesoscale features such as fronts and eddies is required. These are important, especially to the fate of cod larvae.

Should chapter 4 deal only with physical information or should it also include relevant information on cod habits and life history? For example, should this chapter mention temperature preferences for cod or leave it to Chapter 9 (Distribution and Migration)? If the latter then chapter 4 would present information on general temperature trends in the various regions occupied by cod. However, the average temperature is not necessarily what cod experience (their ambient temperature). Ambient temperatures have been estimated from detailed survey information on distribution in relation to temperature fields and more recently data storage tags have provided such information. B. Rothschild stated that he had pressure data from tags on fish that he could provide. These appear to show limited vertical movement. Which chapter should discuss this information? Co-authors of Chapter 4 and 9 were instructed to coordinate their presentations.

A discussion of the predictability of the physical environment (or lack of it) needs to be included in Chapter 4. Chapter 12 will be dealing with climate scenarios, but some common elements will need to be coordinated with chapter 4.

Chapter 4 needs to focus upon the variability and not just the means.

4.4 Chapter 5 – Biological Oceanographic Setting

M. Heath, who was not able to attend the meeting, provided the outline for this chapter, dealing in some detail with the relationship of cod and plankton in the North Sea. The scope of the Chapter needs to be widened and should review zooplankton - cod relationships more generally. For example, what relevant information has come from the Trans-Atlantic Study of Calanus (TASC) and related programmes, including the continuous plankton recorder (CPR)? How are the effects of climate on cod mediated via zooplankton dynamics? The role of changes in transport, e.g. Atlantic inflow into the Barents Sea or the North Sea may be important (and may require some discussion with chapter 4 authors). Chapters 4 and 5, on the Physical and Biological Settings should, to some extent, be regarded as complementary and matching parts of the introduction to the subject of cod and climate. The meeting participants were very aware that Chapter 5 might not be an easy to write, because the scope is potentially very wide.

The chapter should draw on zooplankton work in relation to CCC from several studies, e.g., the Baltic, Georges Bank and Faroes. In the Baltic, scientists are unable to predict recruitment from knowledge of cod egg production alone. The temporal and spatial overlap of the first hatching larvae and their prey, in particular *Psuedocalanus*, is essential. The importance of particular zooplankton was determined by a top-down view of the food chain. On Georges Bank, *Calanus* is not considered to be an important food source for cod. There is evidence for food limitation in young cod, but there have been problems establishing a relationship between recent growth and prey availability. The influence of zooplankton on dynamics of larval fish has not been established. On the Faroes, recent studies suggest a negative relationship between *Calanus finmarchicus* and cod recruitment. The argument is that in years when *Calanus* dominates the waters over the Faroes Plateau, they appear as larger, later stages and displace the neritic species that normally occupy the Plateau. The neritic species, which are small, may be needed for the first feeding cod larvae.

While the importance of *Calanus finmarchicus* for cod is recognized for most of the northern stocks and should be stressed, several other stocks do not feed on *C. finmarchicus*, e.g. Georges Bank and the Scotian Shelf, or also feed on other zooplankton, e.g. North Sea (where *Paracalanus* and *Pseudocalanus* are also important). The chapter could indicate for which stocks *C. finmarchicus* is the most important zooplankton species and what are the most important species for the other stocks. A chart of the North Atlantic showing the spatial distribution of the dominant zooplankton species for cod would be informative.

Differences in the role of zooplankton on larval versus juvenile dynamics could be addressed.

What are the implications of zooplankton studies and what have we learned from food web (bottom up) studies and from GLOBEC programs, in particular? With the experience of the US GLOBEC programme in mind, it was suggested that G. Lough, who is familiar with the Georges Bank program, be invited as a co-author and he has now agreed.

There should be some mention of other predators of zooplankton besides cod, i.e. what are cod's competitors?

The limits of our ability to measure zooplankton abundance should be mentioned and the consequences for our ability to determine linkages between zooplankton and cod dynamics.

4.5 Chapter 6 – Growth

In his presentation, L. Buckley indicated that, from his laboratory and model studies, it appears as if photoperiod rather than temperature is the most important factor determining growth differences of cod larvae, probably by regulating the amount of time available for feeding. This suggests that factors affecting light levels, such as cloud cover, may have an effect on interannual differences in growth rates. He did not explore the effects of differences in food availability and acknowledged that there could be places where this is important. The chapter would examine both larval and pelagic juvenile growth models. It will include empirical models from both field and laboratory studies and then deal with bioenergetic models of growth. There is little information on growth in the transitional phase between early juveniles and adults.

Questions centered on the role of the prey in these studies and in general. The studies used average prey fields, while some participants felt that prey patchiness and random encounters with the prey needs to be considered. Cod larvae are rarely sufficiently abundant to affect the prey abundance.

J.-D. Dutil presented information on adult growth. Although size selection by fishing will be mentioned in the chapter, it will not be considered in great detail. Results can be unexpected, e.g. fishing has been shown to remove slow growers at high stock size and fast growers at low stock size in the Gulf of St. Lawrence.

The role of temperature in determining interannual growth was discussed. J.-D. Dutil noted that some stocks show a strong relation and others not. K. Brander has shown strong relationships for several stocks. A question that should be addressed in the chapter is on what time scale does growth respond to temperature, daily, weekly or monthly?

Most of the proposed chapter focuses upon somatic growth but what about gonadal growth? The latter is considered very important to population dynamics and it was noted that gonadal growth is sensitive to population abundance. The recruitment chapter was not planning on addressing this issue and felt it should be covered in the growth chapter.

Realized growth can be compared to model growth, where the model used unlimited food at a particular temperature. In winter, the northern cod and Gulf of St. Lawrence cod do not feed, so it is unclear how this fits in with the model assumptions. What about the seasonal pattern of condition? How does this change for warm water stocks? Condition tends to be better in faster growing stocks. It was thought that Baltic cod might not have any seasonal change in condition. F. Köster was willing to supply the data on condition in the Baltic in order to examine this.

A synthesis of bioenergetic work for both small and large cod is missing. Could this appear in the growth chapter? How does this change with different environments? The Workshop was told that some of this would be covered but not an extensive treatment.

The growth chapter is important for fish management and will provide background for fisheries managers; however, this audience will not be knowledgeable about many of the technical details. This lead to questions about how much detail to include on models. While it was felt that there should not be too much, the Workshop agreed that more technical details could perhaps be included in boxes inserted into the chapter.

Staying with management issues, a proportion of the error in short-term forecasts is due to errors in prediction of size-at-age, e.g. using the average of the last three years. Can we reduce this source of error?

There is less information on juvenile growth than for adults and larvae. The Workshop felt it was important to cover juvenile growth, even if only to identify it as a gap in our knowledge.

A discussion arose about the genetic aspects of growth. Some felt that the available evidence showed these effects to be small. Laboratory studies using Bay of Fundy and southern Gulf of St. Lawrence cod indicate cold waters stocks grow better under cold conditions.

T. Marshall, another of the co-authors on the growth chapter, who unfortunately could not attend the meeting, will be contributing to a discussion on the effects of condition on egg production and maternal ages and sizes. She will look at fecundity and its relationship to growth and condition. The Workshop suggested that both potential and realized fecundity should be mentioned. J.-D. Dutil stated that potential survivability would not be discussed in the chapter.

The use of data from stock assessments was brought up. J.-D. Dutil stated that the emphasis of the presentation was on lab study results. There are problems with growth data from stock assessment, but they will be used for comparative and modelling purposes.

It was noted that increasing temperatures might lead to increased growth rates but also to possible increases in disease mortality. This, however, will not be covered in the growth chapter.

4.6 Chapter 7 – Recruitment

The Workshop was reminded that the observed recruitment variability in cod stocks can be produced by minimal changes in egg and larval mortality rates. It was suggested that the chapter should examine this theoretically and why cod are different from other fish species, such as herring that have a much different fecundity rate.

The co-authors indicated that their chapter would be framed in terms of hypotheses regarding the factors controlling recruitment. Some of these will highlight results from GLOBEC studies, such as on Georges Bank, or those in the Baltic. It was felt that since the CCC programme is part of GLOBEC, presenting results from the GLOBEC studies was highly desirable.

Recruitment comparisons between stocks will be undertaken and a list of stocks to be used was presented. The Workshop noted that the Skagerrak stock, which was listed, is now assessed as part of the North Sea stock, which was not on the list. The co-authors indicated that the North Sea was intended to be included. The Eastern Scotian Shelf stock also was not on the list but will be added. There are problems with the data for the Northern Cod but some might be useable.

Possible interchange between stocks needs to be mentioned, (e.g. between Browns and Georges banks) since this can affect mortality rates. No examples of major interchange were put forward from the eastern side of the Atlantic, but there are many examples where a stock management unit (e.g. the North Sea) includes a number of more or less separate spawning units for which no separate estimates of spawning biomass or recruitment are available. The simplest solution is to stick with existing stock management units, for which assessments are carried out. Survey data could provide another option, but bringing these together would be a big undertaking and many of the stocks do not have such surveys or they are only available for a limited number of years, which would restrict the scope for comparisons. Assessment data will allow more comparisons to be made and these data are available from the Cod and Climate website. Caveats about the use of assessment data should be mentioned e.g. the dangers of using SSB rather than egg production to express reproductive output. Larvae surveys (where they exist) could be used to check VPA recruitment estimates. This is an important issue that should be discussed in the chapter. The shortcomings of assessment data, which have important implications for fisheries management, should be mentioned in the Chapter dealing with Fisheries Management (12).

There is a strong inverse relationship between cod survival and the detrended North Atlantic Oscillation (NAO) on Georges Bank and also a relationship between the NAO and plankton, which will be explored in the chapter.

In the comparisons between stocks, the co-authors noted that they would be looking for coherent patterns and phase relationships between recruitment. Questions arose as to why there should be phase relationships. It may be that relationships on the western side of the Atlantic might arise due to exchange between stocks. It was suggested that the relationship of the NAO with Northern cod would not necessarily be the same as for the Georges Bank cod stock. There well might be lagged effects of the NAO in some areas. In addition, the question of whether recruitment variability differs between bank and shelf ecosystems will be addressed as part of the comparisons among stocks.

The chapter will discuss how our understanding of recruitment processes has increased over the time scale of the CCC programme, how such information may be integrated into stock assessment models and how it influences reference points and predictions of recruitment. Suggestions for improvements will also be given. Potential overlap with Chapter 12 (Fisheries Management) should be discussed between the co-authors of both chapters.

The chapter should discuss the interaction of environment and fishing in relation to recruitment, e.g. increased sensitivity to environmental variability when age distributions have been truncated by heavy fishing.

Non-linear dynamics need to be considered, especially where no linear correlations are found between forcing functions and output.

Because they are used as part of a routine management advisory process, assessment models tend to be conservative and do not use information about effects of environment on recruitment and growth. High standards of credibility and reliability are set and it is not easy to incorporate new knowledge about processes into assessments (e.g. Baltic example). Fishermen often suggest environmental causes of changes in fish stocks while regulators usually blame fishing. In the CCC programme the main approach has been analytical – identifying and studying the processes which give rise to observed population variability. The premise is that to manage a system you have to understand it. An alternative approach, which may be useful for management advice on complex systems such as cod populations or ecosystems, would be to apply systems analysis and control theory, following some of the methodology being developed in the IGBP GAIM (Global Analysis Integration and Modelling) project. This is essentially a top-down approach, which begins with questions like "What are the principles for constructing representations of the marine ecosystem that aggregate away the details while retaining all the system-order items? What levels of complexity and resolution have to be achieved in marine ecosystem modelling?" This may be an interesting issue to introduce in this chapter or elsewhere, but may be best left as a separate box.

There was a discussion of density dependent mortality. Mortality on eggs and larvae was thought to be density independent, while on juveniles and adults it may be density dependent. Egg production may be density dependent (i.e. related to adult abundance and feeding). Mortality on the early life stages should be addressed in this chapter.

Size-based rather than species and age-based modelling was suggested as a new approach, that does not assume a steady state. One could use such models to explore how climate would be expected to affect size structure and look at recruitment by size rather than age. Although a general application would include the whole ecosystem, not just cod, it was proposed that a size-based approach could be developed for cod on its own. While this is future work, it might be ready in time for inclusion in the book. J. Bayer and B. Rothschild will consider this further.

The scope of the recruitment chapter may have been set too wide, with requests to include too many related aspects. The co-authors will need to consider the overall balance and length, but it was felt that at this stage it perhaps is better to include too much and cut later.

4.7 Chapter 8 – Larval transport

The chapter should include a section on biophysical modelling, as it is an important component of published transport studies. A good example might be the Baltic, where cod have switched from being retained over one of the deeper basins to being transported towards the shallower coastal regions. This example also links transport with feeding, growth and survival.

Examples of interstock transport should be discussed. Larval drift from Iceland to Greenland is well documented, but other situations, in which such occurrences are less regular or well documented, should also be included e.g. transport between some of the NW Atlantic stock areas and transport from West Greenland to northern Labrador.

The role of retention was a lead hypothesis in several programmes, notably the US GLOBEC programme and the conclusions should be presented in this chapter.

The Workshop felt that one of the priority items was to identify another co-author for this chapter. This person should have experience with models. The co-editors will deal with this through discussions with Pierre.

4.8 Chapter 9 – Distribution and Migration

Settlement of cod was discussed together with the question "Where do juvenile cod settle?" It was suggested that successful settlement usually occurs on coastal or offshore banks. In the western Irish Sea they settle in the deeper areas (>100m) but most occur in shallow waters after a few months. The co-authors of Chapters 8 (Transport) and 9 should agree between them who will discuss settlement.

Temperature plays an important role in determining overall distribution of cod stocks (i.e. range within the North Atlantic) and also affects the location and behaviour of individual fish. It will be discussed in this chapter using information from published sources, including the CRR updated report. The Workshop discussed three temperature issues:

1. temperature differences between stocks (average temperature or seasonal range which they experience),
2. temperature differences within a stock and the methodologies for determining ambient temperatures, and
3. temperature data from data storage tags.

There may be some overlap with Chapter 5 (Physical Oceanography) and the co-authors should coordinate their coverage of the temperature information.

The Workshop suggested that the rates of migration, including daily rates, if available, should be discussed.

Transport of larval and juvenile cod from Iceland to Greenland will be dealt with in Chapter 8, but the return migration of the adults should be dealt with here.

Tagging information as evidence of migration should be reviewed.

There is evidence that some stocks (e.g. at Greenland) extend their range under favourable conditions (high abundance, ideal environmental conditions) and contract when conditions become unfavourable.

Information on spawning areas should be mentioned, especially in terms of migration to and from the spawning sites, if appropriate.

4.9 Chapter 10 – Role of Cod in the Ecosystem

There are clear regional differences in the importance of cannibalism in the diet of cod. For some stocks this is substantial, although it tends to be patchy in both space and time. Why cannibalism arises in some stocks and not others was felt to be a question worth pursuing. The co-authors stated that they planned to mention cannibalism in the chapter.

The switch in Greenland from a cod-dominated system to one dominated by shrimp, and a somewhat similar change after the decline in the northern cod stock off Newfoundland, will be discussed in depth. Worm and Myers have addressed the interaction of cod and shrimp in various regions of the North Atlantic in a recently published paper. The differences and interactions between management strategies for these species is important for Chapter 12 (Fisheries Management). The switch from cod to shrimp led to a discussion of alternate steady states, an idea that should be presented in the book, if not in Chapter 10, then in the summary Chapter (13).

The chapter should use a comparative approach and should bring out both the relative importance of physical environment compared to fishing and predator-prey interactions in structuring the ecosystem. Cod are a dominant component of the fish community in some (northern) ecosystems and a minor player in others. Paradoxically, the systems in which they are a small component (e.g. the Celtic Sea) are generally those where their per capita production rates is highest.

Although work on the role of cod in the ecosystem was undertaken within the CCC during the Backward Facing Workshops, in particular those on the Northwest Atlantic and on the Gadoid Outburst, this was of a limited nature. Extensive studies in the Baltic on species interactions and the role of cod in the ecosystem should be reviewed in this chapter. A co-author familiar with the Baltic and the North Sea would be helpful for this chapter (and Henrik Sparholt has accepted an invitation to be a co-author).

Predation is difficult to estimate in most cases and Multispecies VPAs are of limited value, as they tend to overestimate predation. Further diet information is needed. One suggestion was to use size preference plots. J. Link suggested not going into much detail on this as assumptions about mortality and consumption rates are highly uncertain. This brought up the question of model development versus using outputs from present models.

J. Link asked how much of the feeding behaviour should be reviewed in Chapter 10? It was felt by the Workshop that the chapter should not go into much detail on this subject. In any event, little is known on this subject, on the microscale level.

It was suggested that community size spectra could be used to comment on the ecosystem. Comparison of size spectra between Georges Bank and the North Sea has shown a steeper slope in the North Sea that has been interpreted as due to harvesting practices. Published papers should be referred to, but there may not be time to undertake new work in this area.

There was a lengthy discussion on mortality. Since there is no chapter devoted to this subject, the Workshop felt that predation mortality should be covered in Chapter 10. There will also be some discussion on mortality in Chapter 6 (Growth). The increases in M in eastern Canadian stocks need to be addressed somewhere in the book along with the implications of a non-constant M on fisheries models.

4.10 Chapter 11 – The Response of Cod to Climate Change

No co-authors have been assigned yet for this chapter and all of the participants will be invited to provide input for this chapter. K. Drinkwater provided climate scenarios for 2020, 2050 and 2080 taken from the Arctic Climate Impact Assessment (ACIA) document that is presently being written. Workshop participants divided into three groups to discuss the scenarios and their possible impacts on (i) recruitment, (ii) distribution, migration and transport and (iii) growth. The outcomes from these three breakout groups are given in Appendix 3.

Many aspects of future climate scenarios are highly uncertain (e.g. changes in wind, cloud, ocean circulation; effects on mesoscale features e.g. fronts; regional effects) and there was some discussion about the utility of considering impacts. Nevertheless, the programme has climate change in its title and one of the main aims of GLOBEC is to explore the possible consequences of climate change, therefore we have a responsibility to address the issue.

It was agreed that some information regarding scenarios needs to be included in the chapter. ACIA climate scenarios were available at the workshop, but these scenarios may not be published by the time the book was ready for publication. If necessary, other scenarios will have to be developed. Unfortunately, to date no regional models of climate change scenarios are available for the North Atlantic.

Some participants felt that the details of the scenarios were not that important and that we will probably have to begin with a fairly general approach and first order effects. For example a range of possible changes in temperature could be inserted into growth models to predict possible changes in weight. In general we may expect that the production of cold water stocks should improve and warm water stocks decline. There are problems, however, such as effects on seasonality in temperature and uncertainty concerning changes in near bottom temperatures. While near-surface temperatures in most areas can be expected to change over a range somewhat similar to air temperatures, the near bottom temperatures may increase, if the excess heat is mixed down, or decrease, if the excess heat stays in the surface layers and stratification increases, thereby reducing vertical mixing.

The evaluation of impacts would be based on a combination of observed past responses to climate variability and modelling. Results from GLOBEC studies, such as on Georges Bank, may be used to predict responses in particular systems.

The range of physical variability is large and there may be changes in variances as well as in the means. Extreme events may have highly non-linear impacts (e.g. high or low temperatures events over periods of a few days or weeks can cause mass mortalities either directly or indirectly via processes such as oxygen deficit). Other fish or marine species (e.g. tile fish and corals) could be used as examples where we do not have direct evidence for cod, but suspect that similar processes could apply. The recent kill of cod in Smith Sound, Newfoundland might be a suitable example to include as a box. The changes to the cod stocks off West Greenland during the warming of the 1920s can also be used.

Relationships between cod population variables (growth, recruitment) and temperature are often parabolic in shape. Effects will therefore be greater at the extremes and care is needed when using average temperatures. Cod growth appears to increase with temperature over the observed range, even though experimental work shows that growth of larger fish in particular would be expected to decline at some of the warmer temperatures, which they actually experience in the wild.

The question arose as to whether the chapter would focus on cod or also consider changes to the overall system, including the prey fields, since cod cannot be isolated from the ecosystem. The Workshop thought it best to keep a narrow focus, i.e. on cod, but comments on possible ecosystem changes should be included where they impact upon cod. A bioenergetic life history model with temperature as a variable, or possibly a size based model, would be valuable for this chapter, but it is unlikely that such models could be developed in the available time.

The structure of the chapter was discussed. Was it to deal with different life stages and with both small and large scales? K. Drinkwater felt that the chapter should be targeted for managers, to give them an indication of likely changes in cod dynamics and the scope of those changes. It was then suggested that we should formulate clear questions of what we wish to achieve.

A suggestion was made to construct a table that would list the response to specific climate changes by life stage, i.e. for larvae, juveniles, and adults. This would include growth, mortality, survival, recruitment, etc. An example of how such a table might look is given in Appendix 3.

K. Drinkwater agreed to take the lead in writing this Chapter with help from the other co-authors.

4.11 Chapter 12 – Implications for Fisheries Management

Another co-author is needed for this chapter. Fred Serchuk (USA) was suggested as a possible candidate and will be contacted by K. Brander.

There was a suggestion to compare cod production per unit area across different stocks (similar to an analysis carried out by Myers *et al.*). This would be useful, but there are a number of difficulties, including how to estimate available cod habitat. Thermal as well as bathymetric suitability could be included. Environmental habitat indices will be covered in the distribution and migration chapter. A paper by J.-D. Dutil and K. Brander comparing productivity of North Atlantic cod stocks and limits to growth production is in press. The chapter should also discuss carrying capacity, how it may be affected by changing climate and what the implications are for biological reference points.

When the CCC programme started the major scientific problem was felt to be accounting for variability in recruitment. Now it is acknowledged that variability in growth is as important as recruitment or in some cases more important. This needs to be brought out in the chapter.

Another suggested change of assessment and management perspective concerns the "burden of proof" in relation to effects of environmental variability and climate change. Whereas previously such variability could be regarded as natural fluctuation around a stationary mean and one could regard the effects as "noise", which increased the uncertainty of forecasts, there is now sufficient evidence of trends in temperature and possibly other environmental variables that it is no longer sensible to assume a stationary mean. Even if the trend is small compared with interannual variability, the impact for medium and long-term management strategies must be considered. The "burden of proof" has shifted and in future there should be a requirement to include climate effects when formulating medium and long-term management advice, unless they can be shown to make no difference. Some Workshop participants questioned the time scale over which this should apply. K. Brander speculated that expected trends in temperature would probably have significant effects within, say 30 years. Short-term (days to weeks) operational forecasts of environmental factors may also provide valuable information for interpreting estimates of distribution and abundance from fishing surveys.

In a situation where a stock undergoes a gradual decline due to environmental factors, retrospective assessment methods, such as VPA and rate estimates (growth, recruitment) based on historic data may fail to detect and ascribe the trends correctly and may systematically overestimate the stock biomass. If the resulting advice on catch levels is too high, then fishing mortality rates may increase, producing a positive feedback on the decline in biomass.

4.12 Chapter 13 – Summary

Although no presentation was made on the summary chapter and no formal discussion was held on the final chapter, the Workshop agreed that co-authors of all the chapters would have an opportunity to contribute to the summary. K. Brander and K. Drinkwater would take the lead. Some of the discussions following earlier chapters touched on topics that the Workshop felt would fit into the summary chapter. They included:

1) What message do we want to provide to research managers?
2) Is the strategy, which the CCC programme adopted, a good model for other species?
3) What are the chances that if we observe events (e.g. high NAO), we will be able to predict the consequences correctly?
4) Can we make observations that would provide different or better insights and better forecasts, e.g. high frequency observations at the time of spawning?
5) Decision theory should be discussed

5 OTHER BOOK ISSUES

K. Brander and K. Drinkwater will circulate a list of abbreviations and names for the various cod stocks.

Comments and recommendations on future research can be made at the end of each chapter, but some will be covered in the summary chapter.

If new analyses are presented in the book, sufficient information should be provided so that the reader can assess what was done. Such material could be placed in a box if the discussion is of a very technical nature. If there is substantial new science, then the authors are encouraged to write it up quickly and have it published, so that it can be referenced.

An average of 35 pages per chapter including figures should be used as a guide. However, up to 50 published pages for the major chapters (in particular 6 through 10) is acceptable.

The format for the references will depend upon the publisher. Once a publisher is chosen K. Brander and K. Drinkwater will notify the authors of the required format.

5.1 Timetable

The following timetable was agreed for the further preparation and review of drafts.

May	2003	Synthesis Workshop
September	2003	Chapters can be submitted to editors
September	2003	Meeting of co-authors at ICES ASC to review progress and deadlines
Autumn	2003	Co-editors review and coordinate submitted chapters
December	2003	Final deadline for all draft chapters to be received
January	2004	Co-editors to send chapters out for review
March	2004	Date requested for return of external reviews
May	2004	Final drafts of the chapters to be returned to the co-editors
May	2004	Climate and Fisheries Symposium in Bergen
Summer	2004	Send completed book to publisher

Authors were asked to submit their drafts earlier than the end of 2003 if possible, in order to spread out the internal review process which will take place before the material is sent out to external referees in early 2004. A password protected area of the ICES/GLOBEC website will be set up by K. Brander to exchange material, to develop crosscutting themes between the chapters and to post drafts when completed. This will be crucial in order to coordinate the chapters.

5.2 Potential Reviewers

Each of the chapters will undergo external reviews. Co-authors were asked to consider possible reviewers for their chapters and to send suggestions to the co-editors (K. Brander or K. Drinkwater)

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APPENDIX 2: AGENDA FOR CCC SYNTHESIS WORKSHOP, 5–7 MAY, NEW BEDFORD, MASS., USA

5 May	9–12	Welcome and Introduction (Brander, Drinkwater)
		Discussion on workshop procedure, publication

Most of the Workshop will be made up of presentations of the individual chapters. At this stage no presentation will be made for the Introduction or Summary chapters. These will be discussed on the last day. Presentation and discussion for each chapter should be approximately 1 hour. We will attempt to cover 2–4 chapters per morning or afternoon. No set time table is given in order to allow more discussion where it is warranted.

Cod and Climate Program (Rothschild, Sundby and Dickson)

		Stock Structure and History (Marteinsdottir, Ruzzante and Nielsen)
	12–13	Lunch
	13–17	Physical Oceanographic Setting (Drinkwater, Loeng)
		Biological Oceanographic Setting (Heath, Tande and Lough)
		Growth (Buckley, Dutil, Marshall)
		Recruitment (Köster and Fogarty)
6 May	9–12	Larval Transport (Pepin and ?)
		Distribution and Migration (Ottersen, Swain)
		Role of Cod in the Ecosystem (Lilly, Link and Bogstad)
		Lunch
		Implications for Fisheries Management (Brander)
		Response of Cod to Climate Change (General Discussion-Drinkwater)
7 May	9–12	Discussion (Brander, Drinkwater)
		–Identification of Gaps and Overlaps
		–Coordination of Chapters
		–Summary Chapter
		–Time Table for Revised Drafts, Reviews
		–Technical Issues (e.g., diagrams, formats)
		–Identification of potential reviewers

APPENDIX 3: REPORTS FROM THE THREE BREAK-OUT GROUPS ON THE IMPACTS OF CLIMATE CHANGE.

As part of the discussion on Chapter 11 pertaining to the response of cod to climate change, the workshop divided into three separate break-out groups that were given different topics to address. The following are their reports.

(i) Break-out Group dealing with Impacts on Growth/Reproduction

Warming in the Arctic may cause cooling in other areas (further cooling of very cold waters would be detrimental) but we assume it will warm up everywhere. We made no assumption on food availability; if it increases, activity costs decrease and the scope for growth increases. If it does not, lack of food increases activity costs and higher basal metabolic rates would be detrimental. The following are some impacts due to the warming.

Larval fish

Cold-water

Faster developmental rate for the eggs, all stocks

Decreased predation as a result of increase in larval growth (if food follows).

Conversion efficiency increased

Warm-water

Faster developmental rate for the eggs, all stocks

Food-limited if food does not follow same trend because metabolism rate is increased.

Decrease of larval growth and increased mortality due to predation or other factors.

Even if growth increases, it will not keep pace with predation.

Juveniles

Possibly different impacts for coastal habitats compared to deeper waters, dependent on stratification, otherwise much the same as for larvae

Cold water

Juveniles will settle earlier to the bottom due to faster growth in the larval period. Will have a positive impact on growth potential in later ages.

Adults

Cold-water stocks

1ºC increase more effect on growth

Increase in standing stock biomass/growth production per capita enhanced

Faster growth in larval stage will have positive impacts on subsequent growth

Increased length of growth season favours more growth production

Increased condition and less variability in condition, as a result less mortality

Warm-water stocks

1ºC increase less effect on growth

Growth season limited to winter, no growth in summer

Lower standing stock biomass and thus lower growth production

Reproduction

Effective reproductive output increased due to changes in temperature and K (growth) in cold water

High temperatures are detrimental if food availability is low

What is the upper temperature limit for maturation?

Genotype forms

Selection of cold vs. warm water forms

Stratification/mixing aspects important

(ii) Break-out Group dealing with Impacts on Recruitment

This break-out group focussed their discussion in terms of a table and how different climate variables will affect different life stages of cod.

	Life Stage			
	Eggs	**Larvae**	**Juveniles**	**Adults**
Winds				
Turbulence	Change in encounter rates with predators	Change in encounter rates with predators and prey	None	None
Wind-Driven Currents	Advection and Dispersion Affected	Advection and Dispersion Affected	Advection and Dispersion Affected	Minimal
Storm Frequency	Episodic Advection and Dispersion Affected	Episodic Advection and Dispersion Affected	Minimal	Minimal
Storm Tracks	Differential Latitudinal Effect	Differential Latitudinal Effect	Minimal	Minimal
Regional Issues	Minimal	Minimal	Minimal	Minimal
Precipitation/ Run off				
Baroclinic Flow	Advection and Dispersion Affected	Advection and Dispersion Affected	Minimal	Minimal
Sea Level	Longshore Transport Affected	Longshore Transport Affected	Minimal	Minimal
Cloud Cover				
Predation on Cod	Reduced Loss to Visual Predators Possible	Reduced Loss to Visual Predators Possible	Reduced Loss to Visual Predators Possible	Minimal
Timing of Spring Bloom	None	Match-Mismatch Effect Possible	Minimal	None
Sea Surface Temperature	Effect on Development Time	Change Growth, Activity and Mortality	Change in Growth Activity and Mortality	Change in Growth
Stratification	Change in Advection/ Dispersal and Vertical Distribution	Change in Advection/ Dispersal Change in Prey Availability	Minimal	None
Fronts	Temperature Effects. Passive Concentration and Predation Risk	Temperature Effects. Passive Concentration, Predation Risk, Prey Capture Success	Temperature Effects. Passive Concentration, Predation Risk, Prey Capture Success	Minimal

(iii) Break-out Group dealing with Impacts on Distribution, Migration and Transport

General brainstorming

Temperature increase expected to be higher at high latitudes.

Shift of cod distribution towards the north.

– West Greenland, Labrador, Newfoundland, Barents Sea cod may expand their habitat.

Fish may cross between the Atlantic and Pacific and visa-versa round the polar basin.

Southern stocks such as the Celtic Sea and Georges Bank, even the North Sea may disappear.

More prey (pelagic forage fish) will become available to cod, but the pelagics may eat cod eggs.

Spawning areas may shift northwards but gradually.

– There may be more spawning in current northern spawning areas and less in current southern areas.

– Later, actual movement to completely new areas.

Stocks like the Faroese and Georges Bank have little possibility to move to other areas.

Higher temperature and similar circulation patterns as today will increase import at Greenland from Iceland due to lower egg and larval mortality

Increase in temperature is expected to be favourable for Barents Sea cod:

– Habitat expands towards east and north, particularly for juveniles during winter.

– Areas presently covered by ice may open up for cod

– Distribution of capelin important.

– If their distribution expands towards the north cod may follow. If temperatures too high for capelin, then also cod are in trouble.

– Expansion of herring range will complicate Barents Sea ecosystem.

– Species that today do not enter the Barents Sea (e.g. mackerel) may strongly influence ecosystem.

Circulation

Little information on regional climate scenarios makes it difficult to predict circulation changes. In particular more information is needed on winds.

At Iceland may get abrupt shifts in temperature and circulation due to changes in water mass distribution (Atlantic/Arctic/Polar regimes).

In the Gulf of St Lawrence and NE Scotian Shelf, migration patterns may change when ice coverage decreases. The cod may move into coastal areas earlier and leave later. It may even stop migration, but water is still expected to be colder in the Gulf after warming than where they presently over-winter.

If circulation/retention around areas like the Faeroes or Georges Bank breaks down, the cod will be in trouble (but this is not expected).

If thermohaline circulation breaks down:

– Goodbye to Greenland cod

– Cod in the Barents Sea and Icelandic waters will be in trouble.

Interaction with prey

There is a chance of increased mismatch under climate change, both between peaks in phyto- and zooplankton and between cod and zooplankton.

Fisheries management implications

If there is an eastward movement of Barents Sea cod, this has strong implications for Norwegian/Russian management.

Enhanced transport from Iceland to Greenland and enhanced migration back will complicate the situation. Should Greenlanders/EU fish what they can at Greenland before the fish will return to Iceland?

There are large implications especially for southern stocks that might be on the verge of disappearing. Fishermen and managers may argue “Eat them before they disappear”.