GLOBEC

Global Ocean Ecosystems Dynamics

A Component of the U.S. Global Change Research Program

GLOBEC: Northwest Atlantic Program

GLOBEC Canada/U.S. Meeting on N.W. Atlantic Fisheries and Climate

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This is a report of the *GLOBEC: Northwest Atlantic Program* from the GLOBEC Canada/U.S. Meeting on N.W. Atlantic Fisheries and Climate held at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, Canada on June 19-21, 1990.

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Preface

As part of the ongoing planning process for GLOBal ocean ECosystem dynamics (GLOBEC), a three day meeting was held in June 1990 in Halifax, Canada. The meeting was cosponsored by the Canadian Ocean Production Enhancement Network research program (OPEN), the Northern Cod Science Program (NCSP), and the US National Science Foundation. Bedford Institute of Oceanography kindly agreed to host the meeting.

The specific objective of the meeting was to plan an experiment in the Northwestern Atlantic to study the marine ecosystem and its role, together with that of climate and physical dynamics, in determining fisheries recruitment. The underlying focus of the GLOBEC initiative is to understand the marine ecosystem as it relates to marine living resources and to understand how fluctuation in these resources are driven by climate change and exploitation. In this sense the goal is a solid scientific program to provide basic information concerning major fisheries stocks and the environment that sustains them. The plan is to attempt to reach this understanding through a multidisciplinary program that brings to bear new techniques as disparate as numerical fluid dynamic models of ocean circulation, molecular biology and modern acoustic imaging. The effort will also make use of the massive historical data sets on fisheries and the state of the climate in a coordinated manner.

The meeting began with a set of plenary presentations and discussions on various aspects of the problem of fisheries in the context of the physical and biological environments and their responses to changes in climate. Background documents that reflect the material in these plenary talks and references to introduce the reader to the various aspects of the problem are included later in the report. The plenary session was followed by two sets of working group meetings, the first set based on specific components of the system (fish, zooplankton, benthos and physical oceanography) and the second set based on specific components of the anticipated research effort (population dynamics, modeling, physiological rates and sampling/technology). The reports of the working groups are included below as provided by the group chairs and reporters.

The text is organized to provide the reader with the results of the meeting in a number of ways. An executive summary (Section 1) reviews the problems addressed at the meeting and the major recommendations that came out of the working groups. This is followed by a more detailed summary, in an annotated outline format (Section 2), of the rationale, objectives and scientific questions set forth at the meeting. It is hoped that this will prove useful to the investigator who wishes to get a picture of the major motivations for various parts of the program. This is followed by various discussions of technological needs, logistics, data base issues and a summary of relevant non-GLOBEC programs which are expected to contribute to the program. The synopsis of the meeting is followed by a set of short overview papers (Section 3) with references to various aspects of the problem. Individual working group reports (Section 4) are included in their unabridged form, to provide the reader with details arrived at by consensus. Finally, for the reader seeking even more information, we provide a bibliography, glossary, and a list of meeting attendees as appendices (Section 5).

Mark E. Huntley   Donald B. Olson
Irving, Texas
August 15, 1990.

Postscript

Planning efforts in late 1990 have expanded the potential for GLOBEC studies across the North Atlantic Ocean. At the October meeting of the International Council for the Exploration of the Sea (ICES) in Copenhagen, the Study Group on Cod Fluctuations formally presented its recommendations for a pan-Atlantic comparative study of cod populations. The group's white paper suggested field studies at specific sites (including Georges Bank, the Scotian Shelf, the Grand Banks of Newfoundland, the Iceland Shelf, the Norwegian Sea and the North Sea) and recommended an analytical strategy involving biophysical models nested at scales ranging from small to meso-, regional and basin scale. These recommendations were met with encouragement that the Study Group be formally established (having previously been a Study Group by correspondence only) and that its activities be expanded during the coming year. The linkages with GLOBEC are clear, both conceptually and logistically. It is hoped that ICES and its member nations will continue to encourage and promote this developing relationship. The result would be a new understanding of interactions between climate, ocean physics, and zooplankton populations across the Atlantic Ocean basin.

Mark Huntley

Miami, Florida
January 24, 1991

1 EXECUTIVE SUMMARY

1.1 Introduction

One of the fundamental rationales for the existence of marine science is to support research leading to a wise use of marine resources. While our basic knowledge of the ocean, its physics, and the nature of its ecosystems have progressed remarkably in the past few decades, our ability to provide reasonable advice as to the response of any fishery to the combination of exploitation and the effects of climate change is still rudimentary. This document provides the outline of a program required to make a quantum leap forward in this area using the best tools available to modern molecular biology, statistics, physical oceanography, acoustics and population biology. The target fisheries and region for study is the northwestern Atlantic shelf edge with its extremely productive banks.

The banks of the northwestern Atlantic such as the Grand Banks and Georges Bank have been exploited as one of the major fisheries resources on the globe since at least the 1~00s. This trend has continued to the present, with 1988 New England landings of cod, scallops and pollock amounting to $133.4 million dollars. Combined, this is approximately equal to the value of the lobster harvest for that period. The groundfish on Georges Bank are at their lowest stock size since estimates were begun. A rise in populations of pelagic species such as dogfish and skates suggests that the place which groundfish hold in the ecosystem may be being replaced. Furthermore, the most recent National Marine Fisheries Service report on the status of fishery resources off the northeastern United States concludes in the case of scallops that "current fishing effort is far beyond what the resource can sustain." Much of the stock decline is due to the effects of overexploitation. The effects of fishing on stocks, are, however, strongly influenced by variations in the physical and biological environment within which the fishery exists.

Climatic effects on fisheries have been reasonably well established in a number of regions although the exact processes by which these effects occur are not well understood in any situation. It is also well established that climate variations can substantially modulate the influence of exploitation and, within the extremes suggested in the recent climate record, can completely eliminate regional fisheries without any effects of fishing. These climatic variations range from the effects of the last ice age, which probably reduced the viable habitat for the species mentioned above by up to 90% through a combination of lowering temperature, salinity, and sea level and increases in sea ice cover; to historically documented decadal time scale fluctuations in winds, sea temperature and salinity that have a correlation with cod stock declines in recent decades. There is ample evidence for a broad range of climatic fluctuations in the past and some grave doubts about future variations tied to natural cycles and the effect of man through greenhouse warming and modifications to the marine environment tied to pollution.

In order to extract an understanding of the interactions between the physical environment, the primary and secondary producers in the marine ecosystem and the higher trophic level species relevant to commercial fisheries, a multidisciplinary approach is necessary. The GLOBEC Canada/U.S. Meeting on Northwest Atlantic Fisheries and Climate was held to consider the advent of such a multidisciplinary program on Georges Bank, and to recommend specific scientific elements which might be included in a full-fledged field program under the aegis of GLOBEC during the early 1990s. The following recommendations are intended to serve as guidelines, not as mandates, for formulation and implementation of the field study. These were made with strong consideration given to the ten necessary criteria for GLOBEC study sites.

1.2 Site Selection

Georges Bank is an ideal location in which to study the potential effect of global climate change on marine planktonic populations. Global climate models predict that significant changes are likely to take place there. The banks along the edge of North America from Georges Bank to the Grand Banks sit at the edge of the boundary between the subpolar and subtropical gyres. They are therefore sensitive to fluctuations in the current systems - the Gulf Stream and Labrador Currents - which form this boundary. Variations in these current systems are likely to be some of the strongest signals expected as part of global climate change.

1.3 Fish

Target species should emphasize cod and include haddock. Local populations should be defined by frequent surveys, molecular and biochemical techniques, with a focus on locating key spawning sites. A key objective of population dynamics is to study the development of larvae with respect to the onset of seasonal vertical stratification. Process studies should focus on mechanisms controlling population dynamics, such as how food and feeding may change with climate, how adults locate spawning sites, and how the population is retained or exported from the area. Historical data should be exploited to a greater degree. A Historical Data Working Group should be established to make quality data sets available to the community; paleoecological studies should be encouraged. Modeling is particularly required for understanding the physical dynamics of Georges Bank, annual energy budgets of the target species, distinguishing between the effects of fishing pressure and climate change, and as a means to improve statistical techniques. New technology is needed to improve hardware and software for hydroacoustics, and to develop a variety of techniques relying on biochemistry and molecular biology to provide indices of physiological state such as growth, feeding, and reproduction.

1.4 Zooplankton

Target species should emphasize *Calanus finmarchicus* and include *Pseudocalanus* spp. and *Centropages* spp. Local populations of *Calanus'* are thought to overwinter in the nearby Gulf of Maine; the dynamics of their spring-time advection onto Georges Bank should be studied in detail. Population dynamics studies should focus on understanding reproduction, growth and mortality in relation to physical transport processes. Process studies should be aimed at understanding how local physics controls the distribution of zooplankton, and what processes control overwintering. Historical data are not as abundant as for fish, but are sufficient to determine the magnitude of signal required to detect effects of climate change. Modeling studies could make new sampling technology (e.g., acoustics and optics) more effective by helping to understand the relation between animal size and physiology; population dynamics could be better understood through coupled biological/physical numerical modeling. New technology is needed to rapidly assess physiological state, and to rapidly sample distributions of zooplankton from both moored and mobile platforms.

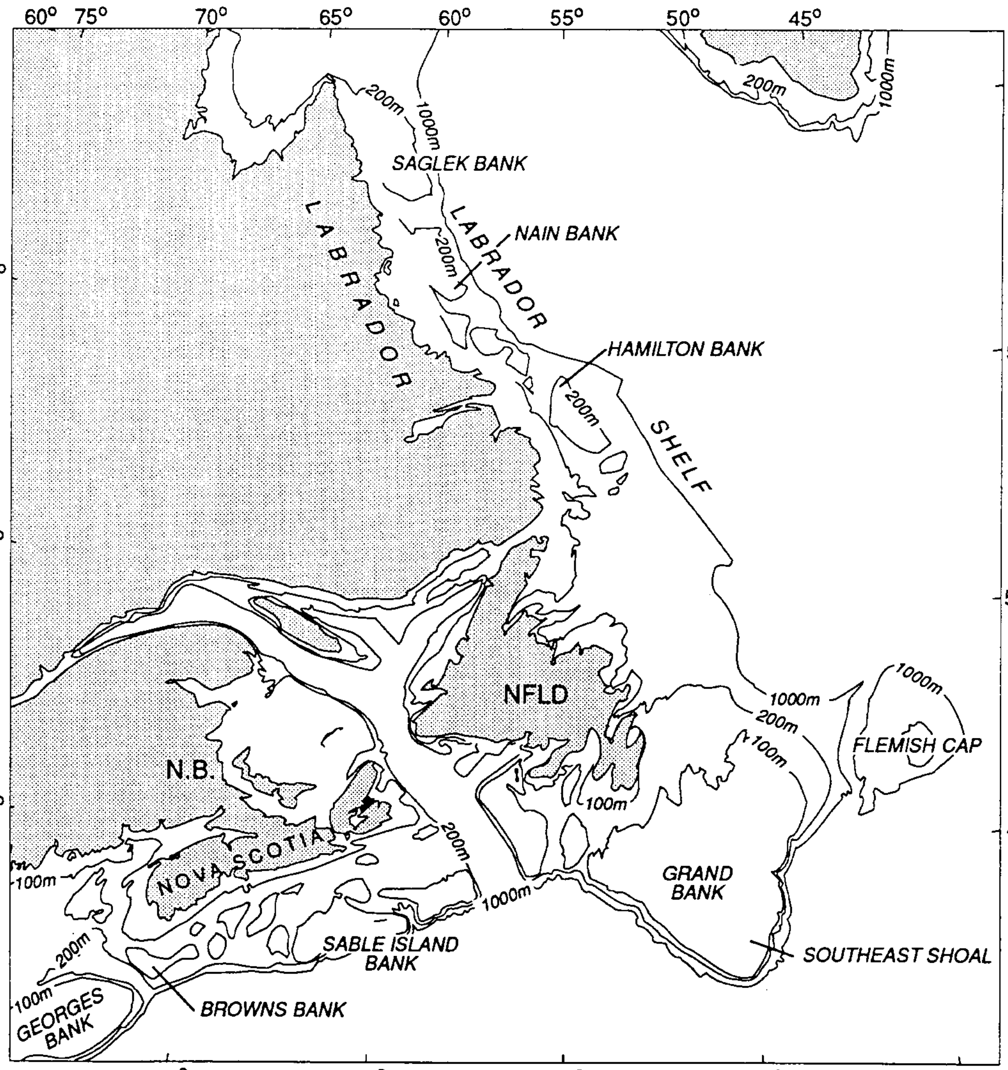

Fig. 2-1. The continental shelves of the Northwest Atlantic, from Hudson Strait to the Gulf of Maine, are populated by many submarine banks of various sizes and descriptions.

1.5 Benthos

Target species should include sea scallops *(Placopecten magellanicus),* but the focus might best be on types of meroplanktonic larvae and types of benthic habitat. Local populations could be studied by comparing a variety of larval types *(e.g.,* feeding vs. non-feeding larvae, spring vs. fall spawners). Population dynamics studies should focus on larval dynamics of any species which might produce distinguishable cohorts of easily identifiable larvae from a well defined adult population, and should not necessarily be restricted to scallops. Process studies should focus on understanding the relation between fundamental population dynamics parameters (e.g., growth, reproduction) and physical and biological forcing functions such as tides, storms, food availability and temperature change. Historical data are less abundant than for other groups, but efforts should be undertaken to use what data do exist. Modeling studies could help to understand how local physical processes favor different reproductive strategies, what causes interannual variation in scallop recruitment, and how changing physical and biological factors affect larval life histories. New technology is acutely needed to rapidly sample and identify larvae of different species.

1.6 International Interactions

GLOBEC activities should be coordinated with existing international studies including WOCE, NOAA's Atlantic Climate Change Program (ACCP), and the Joint Global Ocean Flux Study (JGOFS). The Georges Bank initiative should be closely coupled with two new Canadian programs; these are the Ocean Production Enhancement Network (OPEN), a $25.4M, four-year program focusing on cod and scallops in the waters off Nova Scotia and Newfoundland and in the Gulf of St. Lawrence, and the Northern Cod Science Program (NCSP), a $43M program focused on fisheries oceanography off northern Newfoundland and the Labrador coast. An ICES working group on Cod and Climate Change (CCC) and the new SCOR working group on pelagic biogeography present opportunities for broadening GLOBEC's activities across the North Atlantic

1.7 Field Program Logistics

The group endorsed a broad outline of a field program involving three basic means of studying Georges Bank: (1) Bank-scale survey cruises, (2) Process-oriented cruises, and (3) Moorings The recommended program would be carried out over a three-year period, with most effort focused in the first and third years.

The next step in the implementation process will involve the establishment of an implementation committee to provide the details of setting up a U.S. experiment. It is hoped that this will take place over the next year and come up with a plan for a program starting in the 1992-1993 time frame.

2 REPORT OF THE GEORGES BANK FIELD STUDY WORKSHOP

2.1 GLOBEC Site Selection

2.1.1 Introduction

The purpose of this section is to present the general guidelines for selection of GLOBEC study sites and in particular the Northwest Atlantic study site (Fig. 2-1). It sets forth the central program goals, the key questions, the criteria for site selection, and the process by which field studies will be designed. The scientific community will select sites by participation in a series of workshops which began in mid-1990.

2.1.2 The GLOBEC imperative

Global climate change appears imminent. Its effects on animal populations in the world ocean are neither obvious nor predictable. We do know that population variability is a strong function of physical processes acting through effects on recruitment, larval dispersal, growth and reproduction, but the mechanisms by which physical processes affect biology are poorly understood.

GLOBEC is a process-oriented program designed to elucidate *how* the dynamics of populations within a community are affected by physical processes. The goal of GLOBEC is to evaluate the potential for community, ecosystem - and ultimately - global ecosystem change.

2.1.3 Key questions

The first order questions posed by the GLOBEC program are:

(1) How do changes in ocean physics affect biological processes and population dynamics?

(2) How do population-level responses to physical dynamics affect the structure and stability of ocean ecosystems?

Answers to these questions will greatly improve our ability to gauge the effect of global climate change on marine animal populations.

2.1.4 The research strategy

The key elements of GLOBEC research should involve modeling and new technology in the context of integrated interdisciplinary field studies.

We suggest a focus on population dynamics processes of individual animal species. How are these species affected by abiotic factors, their own density, and the density of interacting species, both predator and prey? Interdisciplinary field studies are required to answer these questions. New technology should be a significant element of the research at all levels: in sampling, sample analysis, and data interpretation. Modeling should be used interactively, to both plan and verify experimental studies.

There is a dynamic interaction between these key elements of the research strategy (i.e., modeling, new technology, and field studies). The current blueprint for enacting the GLOBEC Science Plan calls for activities to begin on all fronts in 1990. Requests for Proposals (RFPs) have been issued for modeling studies in two areas: (1) conceptual models and (2) site-dependent models. The latter are linked to Field Program planning for a GLOBEC Field Study on Georges Bank; this planning will be accomplished by members of the GLOBEC Steering Committee in concert with a number of scientists in the community. With respect to new technology, instrumentation workshops will be held to specify performance criteria for new instruments; this process will require input from both modeling and field program planning activities, and should result in the issuance of RFPs in 1991. Initial results from modeling studies will help mold final plans for the Field Study, for which RFPs will also be issued in 1991. The Field Study should get underway in 1992 and run for three years; prototype new technology should be available for the field program. Results from the Field Study will be employed to verify models and improve new equipment. This applies generally to all potential GLOBEC field studies; it applies specifically to the Georges Bank Field Study only with respect to anticipated timing. Planning for subsequent field research programs will occur via a series of later site-selection workshops. Research activities at other sites could begin by 1993/94.

This general strategy will result in new approaches, insights and predictive capability from field research, new concepts from modeling, and new instruments from technology development. This is what makes GLOBEC revolutionary. GLOBEC research will arm oceanographers with new tools and new vision for the future.

2.1.5 Key research components of a GLOBEC field study

Marine populations fluctuate in abundance as the cumulative result of three processes: birth, mortality and transport. To understand the local rate of change in any pelagic population one must reliably quantify these processes, expressed conceptually as follows:

$$\frac{\textit{Change in numbers}}{\textit{Change in time}} = \textit{Birth - Death - Advection - Swimming}$$

A mathematical expression for the population rate of change might be:

$$\frac{\partial N_i}{\partial t} = N_i B(\theta,\Phi,N_j) - (\bar{\nabla} + \bar{\nabla}_S) \cdot \nabla N_i - M(\theta,\Phi,F,P_K) \qquad (1)$$

where N_i is the abundance of the ith taxon, B and M are the birth and mortality functions which depend on space (*x, y, z*), physical environmental variables (θ), competitive and predator abundances (N_j and P_K), food resources (Φ) and fishing pressures (F). The population levels are also influenced by movement of the populations by either behavioral attributes of the animal such as swimming $\bar{\nabla}_S(\theta,\Phi,P_K)$, and the flow fields in the environment as denoted by the velocity distribution, $\bar{\nabla}(x, y, z)$. Predator abundances are subject to many of the same influences (*e.g.*, x,y,z,t,θ,N_i).

Birth rate may be influenced by the relative distribution and encounter rates of mature adults, availability of food resources, fecundity, and by the influence of scalars in the physical and chemical environment *(e.g.,* temperature, salinity, oxygen). The rate of active transport, or "swimming," is primarily behavioral, and thus may be affected by anything in the environment which influences behavior, such as the presence of prey, predators, and the desirability of physical and chemical environments. The rate of passive transport will be determined by fluid dynamics at the appropriate scale, ranging from small-scale dynamics which will have the greatest effect on vertical motion, to large-scale dynamics which will have the greatest effect on horizontal motion. The mortality rate may be influenced by the availability of suitable food resources, encounters with predators, as well as by the effect of scalars in the physical and chemical environments.

Any GLOBEC study must quantitatively assess the magnitude of these first-order rates, but at the same time the study must go beyond superficial monitoring. It is the mechanisms which govern those rates - not only at the population level but also at the level of the individual - that must be studied. Although their relative importance may vary according to local climate, physical dynamics, or the population being studied, it is these mechanisms which must be understood.

2.2 Site Selection Criteria

GLOBEC study sites and field programs should fulfill a majority of the following criteria, for both scientific and strategic reasons:

2.2.1 Climate change context

Any GLOBEC research program should have a demonstrable capability to link its results to climate change. Whatever the presumed linkage *(e.g.,* increased seawater temperature, polar icecap melting, increasing ENSO events), the conceptual and data collection infrastructure should allow specific hypotheses to be addressed via direct testing or modeling. Global climate change is the phenomenon on which GLOBEC and all other geosciences funding initiatives are predicated; explicit acknowledgment is critically important.

2.2.2 Target species in benthos, holozooplankton and fish

The selected site should allow for simultaneous studies on at least one species among the benthos, one among the holozooplankton, and one among fish. The scientific rationale is that interactions among the species are probable, and thus studies on target species will complement one another. The strategic rationale is that such a study will allow for broad participation of biological oceanographers.

2.2.3 Definable populations

The research should be designed in such a manner that the target populations are, to the greatest possible extent, demographically and geographically distinct. GLOBEC explicitly seeks to understand how populations fluctuate in abundance in response to physical processes. The scientific rationale is axiomatic: in order to study the fluctuations in a population, one must first be able to define that population.

2.2.4 Population dynamics as the output

Research conducted under the aegis of GLOBEC may focus on a variety of processes which do not expressly operate at the temporal/spatial scale of the population. However, such studies should clearly demonstrate their importance to understanding population dynamics. Ultimately, GLOBEC research must describe the relation of population dynamics to physical processes that may result from climate change.

2.2.5 Focus on process and mechanisms

A key element of GLOBEC research is to understand the processes that give rise to observed fluctuations in populations. Descriptive studies are a necessary, but insufficient, component of GLOBEC research. A greatly improved understanding of mechanisms is critical if we are to model and ultimately predict population dynamics.

2.2.6 Historical database

Ideal study sites will have a considerable historical database on the distribution and abundance of target species, their physiology and ecology, local climate, and fluid dynamics at multiple scales. Such databases do exist, or are presently being created, in certain parts of the ocean. Historical data will aid not only in planning research, but also in model verification.

2.2.7 Modeling input

The improvement of our capability to predict, which is an ultimate aim of GLOBEC, presumes a significant emphasis on modeling. Modeling is considered sufficiently important that some effort will be devoted to modeling which is not directly linked to field programs. However, any field program should be able to demonstrate that modeling will be employed to both plan its execution and test its results. Interaction with independent modeling efforts is encouraged.

2.2.8 New technology

It is anticipated that new technology will be developed under the auspices of the GLOBEC program, for the express purpose of improving our ability to sample, analyze and interpret. Any GLOBEC field program should attempt to apply such new technology.

2.2.9 Relation to other programs

GLOBEC field studies should demonstrate conceptual, informational and logistic linkages to other research programs of similar scale and complementary aims. Such programs include global change research initiatives *(e.g.,* WOCE, JGOFS) and international efforts with similar aims *(e.g.,* France's National Recruitment Program, Canada's OPEN program). Shared resources and information will serve to strengthen all related programs.

2.2.10 Multiple agency support

The greater the inherent interest of multiple funding agencies within the United States, the greater the potential for significant long-term support of GLOBEC research. GLOBEC field research programs can improve their own chances for success by possessing facets which are attractive to as many agencies as possible. Obvious agencies include NSF, ONR, NOAA, DOE and NASA.

3 GEORGES BANK FIELD STUDY: SUMMARY AND RECOMMENDATIONS

In this section we summarize the recommendations of the Canada/U.S. Meeting on N.W. Atlantic Fisheries and Climate, extracted from the detailed Working Group Reports, which are presented in their entirety in Section 9 of this document. These recommendations are intended to serve as guidelines for specific studies to be proposed under GLOBEC.

For each taxonomic group - fish, zooplankton, and benthos - specific recommendations are organized according to Site Selection criteria, with the exception that criteria relating to climate change are first discussed in general as applicable to all populations considered, and aspects of international, inter-program and inter-agency activity are discussed in a separate section following this one (Section 4). An outline of the general logistics of the field study is suggested in Section 6.

3.1 Relation to Climate Change

Georges Bank is an excellent location for the study of marine planktonic populations in the context of global climate change. Coupled ocean-atmosphere models suggest that the greatest anomalies in climatic conditions will occur in the North Atlantic Ocean. Georges Bank is situated near the confluence of two major ocean currents of significantly different origin - the subpolar Labrador Current with associated flows in the shelf and slope waters, and the tropical/subtropical Gulf Stream. The position and dynamics of these currents might be expected to be greatly altered by global climate change. Such a location is ideal for a GLOBEC field study.

It is assumed that changes in the recruitment of fish, holozooplankton and benthic species with planktonic larvae are rooted in the early stages of life. Thus we can only understand the links between recruitment and climatic change if the population parameters in those early stages are described and understood. The key questions identified with respect to climate change are:

(1) Will global climate change produce the same events as in recent history, but in different places on the bank/shelf?

(2) Will global climate change produce the same events as in recent history, but at different times within the annual cycle?

(3) Will global climate change produce the same types of events, but of greater or lesser magnitude?

(4) Will global climate change produce different types of events in the key populations?

(5) How will global climate change alter physiology and behavior?

3.1.1 Approach

The general approach is to undertake studies which will address the role that climate plays in determining local and regional episodic events, mass transport, and total energy of the marine system. A better understanding of ocean/atmosphere coupling, together with a better understanding of how physical mechanisms affect populations, will lead to the basis for predicting how climate change will affect population dynamics.

3.2 Fish

3.2.1 Target species

The target fish species are recommended to include both cod and haddock. Cod is recommended because of the significant interest in cod populations throughout the North Atlantic. Haddock is worth considering as a related gadoid stock. Both cod and haddock populations on Georges Bank are depleted to the point that their future as the basis of viable fishery is in doubt. The interrelationships of these stocks to those on the Scotian Shelf and Grand Banks, where the haddock are also severely depleted, is an important issue requiring resolution.

3.2.2 Definable populations

It is generally agreed that cod and haddock on Georges Bank are populations distinct from those in other regions of the North Atlantic (e.g., Scotian Shelf, Grand Banks, Barents Sea). The identification and study of the Georges Bank populations can only come from a study which is highly resolved in both space and time. The following specific studies are indicated:

(1) Frequent surveys of Georges Bank and surrounding waters using sampling equipment which permits high spatial resolution in both the vertical and horizontal (e.g., MOCNESS, acoustics);

(2) The use of molecular and biochemical techniques to characterize stock structure; and

(3) Identification of key spawning sites and their characteristics.

3.2.3 Population dynamics

A key objective would be to study changes in numbers of cod and haddock larvae along the 80-100 m isobath in late spring with respect to vertical stratification. A cohort of larvae could be followed from the spawning ground and sampled at frequent intervals. The following specific studies are suggested:

(1) Growth rates of larvae in situ, using measurements such as changes in length, weight and daily growth rings of otoliths;

(2) Comparative studies of growth rate relative to stratification and development of the seasonal thermocline;

(3) Mortality estimates in the course of Lagrangian drifter experiments in which fish larvae are sampled at a high rate in space and time.

3.2.4 Focus on process and mechanisms

Results of studies on processes will provide the principal insight into mechanisms controlling population dynamics. Specific processes recommended for study include:

(1) Direct effect of temperature on growth rates, seasonal energy budgets and stage duration of life history stages;

(2) Overwintering energetics;

(3) Studies of food and feeding, with consideration of how this may change as a result of reasonable climate change scenarios;

(4) Mechanisms by which adults locate spawning sites;

(5) Basic temperature preferences and tolerances of the species, and the behavioral mechanisms used to select and maintain position in desirable water masses;

(6) Mechanisms of retention and export on the banks;

(7) The relation of early life history stages to substrate characteristics;

(8) Effects of storms on behavior, distribution, and mortality.

3.2.5 Historical database

There is a broad variety of historical databases available for both cod and haddock, together with ancillary data on environmental conditions. These databases should be explored, and other methods of extracting historical information should be developed. Specific studies might include:

(1) Paleoecological studies on quantification of fish remnants *(e.g.,* scales, otoliths) and associated paleoindicators such as $^{16}O/^{18}O$ ratios to provide long time series on populations;

(2) Historical data on fish populations could be used to determine the degree to which Sequential Population Analyses smooth year-class variation; if year class variation is significantly smoothed, then individual population estimates may not be appropriate for determining relationships between populations and the environment;

(3) Determination of the viability of hindcasting physics and biology from existing data sets on catches and temperature records which may be long, but of uneven and unknown quality;

(4) Comprehensive analysis of data from groundfish surveys which have been conducted for decades on every bank from the New York Bight to Northern Labrador and Greenland. Particular attention should be paid to assessing how the pattern of aggregation varies with time, stock size and oceanographic conditions, and more use should be made of oceanographic data collected on these surveys;

(5) Establishment of a Historical Data Working Group to locate data sets, to evaluate their quality, recommend the application of appropriate statistical tools, and make the data sets available to the community.

3.2.6 Modeling

Specific modeling studies suggested in relation to populations of cod and haddock include:

(1) Increased modeling of the physical oceanography of Georges Bank, focusing particularly on (i) dynamics of advection on the South Slope, and (ii) forcing functions with emphasis on storms;

(2) Development of a full annual energy budget of each species, particularly cod;

(3) Models which incorporate improvements with respect to assessing effects of commercial fishing, particularly the consequences of fishing pressure on fish biology;

(4) Development of statistical methods which improve quantitative estimates of uncertainty associated with most measurements in fisheries and physical oceanography;

(5) Development and/or application of statistical tools which better handle and interpret multidimensional patterns and nonlinear characteristics of biological and physical oceanographic data sets, because common regression techniques are inadequate;

(6) Improvements in modeling of hydroacoustics and development of software to more rapidly process the enormous amount of data generated by acoustic instrumentation.

3.2.7 Technology

Certain developments in technology recommended under the GLOBEC program will be applicable to all taxonomic categories of interest, particularly in the case of field sampling instruments. These general recommendations for new instrumentation are discussed in Section 5. Here we recommend the following advances in technology which would be of special value for studies of fish:

(1) Improved biotechnological methods for assessing feeding rates and identifying food items;

(2) Improved hardware and software for hydroacoustic techniques to locate, identify and quantify aggregations of fish, from larvae to adults;

(3) Development of genetic markers useful in characterizing stock structure;

(4) Development of methods which permit one to differentiate between environmental and heritable components of growth rate;

(5) Fast, affordable tools for biogeochemical analysis of core samples;

(6) Improved biochemical methods for measuring growth rate;

(7) Innovative methods for measuring mortality.

3.3 Zooplankton

3.3.1 Target species

Calanus finmarchicus is designated as the primary target species because (1) it dominates the zooplankton biomass on Georges Bank during the winter and spring; (2) it is an important item in the diets of larvae and pelagic juvenile stages of commercially important cod, haddock and herring; (3) abundant data are available on the physiology and ecology of *Calanus* spp.; and (4) reasonably good historical data sets are available for *Calanus* on Georges Bank.

Other species, notably *Pseudocalanus* spp. and *Centropages* spp., are also recommended for study, primarily because they dominate the copepod biomass in summer and fall, and also constitute an important fraction of the diet of larval fish on Georges Bank.

3.3.2 Definable populations

It is not known whether the *Calanus finmarchicus* on Georges Bank form a distinct population, or whether they are in some sense continuous with the population(s) in the Gulf of Maine or on the Scotian Shelf. However, it is clear that *C. finmarchicus* must overwinter at depths which are greater than anywhere on the Bank, and it is supposed that the springtime flux of this species onto Georges Bank derives in large measure from animals which break out of their overwintering state and rise to the surface waters in the southwestern portion of the Gulf of Maine. In order to clearly define the *C. finmarchicus* population(s) on Georges Bank, the following study components are indicated:

(1) Frequent surveys of the entire Bank, encompassing adjacent deep waters of the Gulf of Maine and Slope Waters, particularly in late winter and spring, to obtain high resolution samples in both the horizontal and vertical;

(2) The use of biochemical and genetic marker techniques to clearly distinguish populations.

3.3.3 Population dynamics

The primary objectives recommended for the holozooplankton component of the Georges Bank field study are to investigate the population dynamics of *Calanus finmarchicus* from January through June, in terms of birth, growth and death and in the context of physical transport processes on Georges Bank. Particular emphasis should be placed on understanding how the population is affected by the onset of seasonal stratification. The following specific studies are indicated:

(1) Growth rate measurements which, as much as possible, use new techniques;

(2) Comparative studies of growth and mortality relative to seasonal stratification, both above and below the thermocline;

(3) Quantification of the effects of advection and diffusion on local rate of change in numbers;

(4) *In* 3i~~ measurements of birth rate, particularly of the winter spawners.

Similar studies could be carried out on populations of *Pseudocalanus* spp. and *Centropages* spp.

3.3.4 Focus on process and mechanisms

Process studies would be carried out primarily on cruises designed specifically for that purpose, in conjunction with investigations of processes affecting other taxa. Research would include the following studies:

(1) Effect of food and feeding on in situ rates of growth, incorporating studies of moulting;

(2) Processes which control overwintering;

(3) Egg production rates estimated from both shipboard laboratory incubations as well as in situ, and the relation of reproductive activity to environmental variables;

(4) Rates of mortality in relation to predation (which would require proper identification of predators);

(5) Assessment of what factors limit the biogeographic range, so that hypothetical results of climate change may be used to predict effects on populations;

(6) The role of mass transport in maintaining or dispersing populations and aggregations, in both the vertical and horizontal.

3.3.5 Historical database

Although there are not as many historical data for copepods in the Northwest Atlantic as exist for fish, some data are available. These should be "mined" and used for hindcasting where possible, as well as for analysis of historical variance, which could be used to assess the magnitude of signal required to identify effects of climate change. Most of the same questions posed for fish populations (Section 3.2.5) are appropriate here.

3.3.6 Modeling

It is recommended that specific modeling studies include:

(1) Improvements in understanding of allometric relationships, which would better define the limits of technology which generates data on size-frequency distributions *(e.g.,* acoustics, optics);

(2) Development of coupled biological-physical numerical models for copepod populations in the Georges Bank study area and appropriate subregions.

3.3.7 Technology

Certain developments in technology recommended under the GLOBEC program will be applicable to all taxonomic categories of interest, particularly in the case of field sampling instruments. These general recommendations for new instrumentation are discussed in Section 5. Here we recommend the following advances in technology which would be of special value for studies of zooplankton:

(1) Improved biotechnological methods for assessing growth rates;

(2) Development of moored net sampling devices;

(3) Development of image analysis systems or molecular genetics techniques which would enable identification of species and developmental stages;

(4) Advent of new biochemical techniques which permit rapid measure of physiological state, such as general locomotory capability, reproduction, and entrance into and exit from diapause;

(5) Innovative methods for measuring mortality;

(6) Development of better, more freely available, calibrated acoustics hardware.

3.4 Benthos

3.4.1 Target species

There is some merit to developing a GLOBEC study around the problem of regulation of abundance and distribution of the sea scallop, *Placopecten magellanicus.* This could complement studies on *Placopecten* production and settlement dynamics planned for the Canadian OPEN program. In addition, there is a good historical data base from the fishery for this species. However, the funds available for benthic research in the Northwest Atlantic might better be spent in two alternative ways: (1) to develop a better understanding of the role of physical processes in the ecology, and success of, various key types of meroplanktonic larvae; and (2) to investigate the role of the benthic habitat, both as substrate and as a food supply, for the target demersal fishes.

The rationale for erecting these priorities is as follows. There is concern about whether a sufficiently representative cohort of sea scallop larvae could be well enough tracked in space and over sufficient time to assess accurately how physical processes played a role in dictating eventual abundance and distribution of settlers. That dampens enthusiasm for an exclusive sea scallop population focus to the benthic component. On the other hand, benthic population ecologists almost universally acknowledge that the most critical gap in our understanding of benthic population dynamics is the dearth of knowledge of the ecology of larval life stages of benthic forms. The Northwest Atlantic study affords an important opportunity to erect and test critical hypotheses concerning the ways in which physical processes contribute to the behavior, success, and fate of meroplanktonic larvae as a function of various fundamental differences in larval types. In addition, the understanding of population regulation of the target fish, the codfish, would be grossly incomplete without a benthic study of how the bottom habitat and food availability influence growth, survival, and success of cohorts of codfish. Such a study should in addition evaluate how cod and alternative ground fish, especially the elasmobranchs, interact through mutual exploitation of benthic food and overlapping benthic habitat preferences.

3.4.2 Definable populations

The sea scallop has a well-defined population on Georges Bank, with stock assessment work done annually to update that knowledge. For any study of sea scallops, the Georges Bank population could probably be viewed as reasonably closed and adequately defined.

The recommended study of how benthic invertebrate larvae respond and are influenced by a suite of potentially important physical processes can be assessed without explicit identification of adult populations. These studies probably require only that relatively discrete cohorts of larvae of different types be followed and their behavior, survivorship, and ecology be compared:

(1) holoplankton vs. meroplankton;

(2) feeding vs. non-feeding larvae;

(3) phytoplanktivorous vs. zooplanktivorous larvae;

(4) larvae of long vs. short planktonic periods such as 6 vs. 3 weeks;

(5) spring vs. fall spawners;

(6) strong vs. weak swimmers;

(7) large vs. small larvae.

3.4.3 Population dynamics

A modest effort should be devoted to the study of population dynamics of sea scallops, focusing intensively upon larval dynamics. This should be coordinated with the studies of scallop settlement, production, and early juvenile survival conducted as part of the Canadian OPEN program. Because the scallop spawning is much later in the season than the pulse of *Calanus*, a proper study of cohorts of sea scallop larvae would require continuation of spatially and temporally dense sampling later into the year.

Studies of population dynamics of other benthic invertebrates should be considered if a good candidate species is identified. The ideal target species would have a well-defined adult distribution, spawn heavily and synchronously, and possess easily identified larvae.

3.4.4 Focus on process and mechanisms

Studies should be conducted to assess how fundamental parameters of population dynamics, such as reproduction, growth, larval dispersal, behavior, growth, settlement, and survival, vary directly and indirectly as a function of physical and biological forcing:

(1) fronts of different types;

(2) stratification of the water column;

(3) advective regime;

(4) tides;

(5) storms;

(6) wind field;

(7) temperature change;

(8) freshwater inputs;

(9) primary (food) production; and

(10) effects of predators and competitors.

Such studies should be plausibly chosen to be able to yield information useful in predicting the potential effects of climate change. Research projects should address the role of changes in forcing functions (e.g., temperature, turbulence, advection, food, predators, competition, substrate type) on physiological, behavioral, and population responses (e.g., growth, feeding, migration, predation, and settlement site selection).

3.4.5 Historical database

There exist fewer historical data on larval scallops, crabs, and non-exploited meroplanktonic forms than for either zooplankton or fishes. Planktonic samples may be available from previous Georges Bank studies: the potential to exploit these sources should be explored.

3.4.6 Modeling

Numerous modeling studies on either the meroplanktonic stages alone or on the full life history of target benthic invertebrates are encouraged.

(1) Data that demonstrate how various physical processes cause differential responses of larva with different life history and ecological characteristics should be used to test and develop new models to explain the selective basis for various patterns of reproduction among benthic invertebrates (e.g., patterns with depth, latitude, body size, habitat, etc.);

(2) For the sea scallop cohorts, bio-physical coupling models should be developed to explain and predict the causes of spatial and temporal variation in recruitment of scallop year-classes;

(3) Ecosystem models of planktonic communities that include larva of benthic forms of different types are necessary to understand how selective pressures differ as a function of varying life history traits of larvae. These should include evaluation of the role of potential food limitation and predation and how these biological factors themselves are influenced by changing physics;

(4) Present models of feeding of benthic animals are extremely crude and need further development and testing;

(5) More progress can be expected on the role of physical vs. biological factors in dictating patterns of habitat selection by settling larvae of benthic invertebrates.

3.4.7 Technology

Certain developments in technology recommended under the GLOBEC program will be applicable to all taxonomic categories of interest, particularly in the case of field sampling instruments. These general recommendations for new instrumentation are discussed in Section 5. Here we recommend the following advances in technology which would be of special value for studies of meroplankton:

(1) Development of devices to identify and quantify larvae of selected species, perhaps using immunology or other biotechnological tools; and

(2) Development of an automated larval sampler which could be deployed on a mooring.

4 INTERNATIONAL INTERACTIONS

4.1 GLOBEC: North Atlantic Activities and Other Entities

GLOBEC efforts to understand the effects of climate change on the biology of the Georges Bank region need to be carefully planned to coordinate activities with the two major Canadian efforts and with the international Cod and Climate Change (CCC) program being planned under the auspices of ICES. In addition, other national and international programs such as WOCE, ACCP, JGOFS, CoOP have elements which are of mutual interest. Here a short synopsis of these overlapping elements will be outlined. The reader should look to the planning documents for these other entities for details of their full science plans.

4.2 Canadian Initiatives: OPEN and NCSP

As reflected by the venue chosen for the meeting, GLOBEC activities in the North Atlantic should be carefully coordinated with the Canadian efforts to understand their fisheries and the massive changes they are undergoing. The status of Canadian cod stocks has recently been reviewed by Harris (1990) in a report that is one of several pieces of evidence which has caused great concern in Canada for the status of the cod fisheries. In response to these concerns the national government, local provincial governments and industry have combined to fund a massive effort to better understand the ecosystem of Atlantic Canada and its fisheries.

One of these efforts is the Ocean Production Enhancement Network (OPEN), which is a four year program focusing on cod and scallops. Field work aimed at addressing the recruitment problem of cod on Sable Island Bank, scallop distributions, growth and survival in the Gulf of St. Lawrence, Nova Scotia and Newfoundland, and migration of cod in the Labrador/ Newfoundland shelf will be complemented with laboratory, data analysis and modeling studies as part of this $25.4M program. The program is outlined in a 115 page overview document available from the OPEN Secretariat, Dalhousie University, Halifax, Nova Scotia, Canada B3H 4J1. The OPEN effort provides a wealth of opportunities for collaboration and, with its data from alternative field sites, provides an excellent comparative data base which will complement the envisioned Georges Bank work. GLOBEC planning needs to be carefully coordinated with that of OPEN and should allow funding for active cooperation between Canadian and U.S. Scientists.

Another program centered in Newfoundland is the Northern Cod Science Program (NCSP). It is aimed at a fuller understanding of the oldest continuously exploited cod stock in the western hemisphere (see section 8.2, Northern Cod). The $43M program will focus on fisheries oceanography and predator-prey dynamics off northern Newfoundland and the Labrador coast. Again, there is opportunity for collaborative work on a range of issues. Of particular interest are the long time series data and attempts on the part of programs like NOAA's ACCP to reconstruct and understand the physical mechanism behind climate change in the subpolar regions.

Nova Scotian regional efforts include ongoing programs on the Scotian Shelf, Gulf of Maine and Georges Bank. Efforts such as the 1982-89 southwest Nova Scotia Fisheries Ecology Program (Smith et a~., 1989) which focused on the Browns Bank region, provide many lessons for use in GLOBEC planning. Future cooperative field work should be strongly encouraged with an emphasis on interactions between U.S. and Canadian scientists.

4.3 Other International Programs

On a broader scale the GLOBEC Georges Bank initiative is part of a pan-Atlantic effort to understand the relation between gadoid stocks and climate change. An ICES working group on Cod and Climate Change (CCC) is presently in the process of completing an initial study via correspondence (S. Sundby, Bergen, Chairman). The basic idea behind this planning process is to stimulate an international effort to understand the impact of climate variability on cod stocks throughout the Atlantic Ocean. Of particular interest are the various responses of different cod populations to climate variations in different regions of the cod's range. Differences in the regional data bases available for addressing the question of cod and climate make inter-regional comparisons a high priority. For example, spawning, egg and larval distributions are much better known for the Arcto-Norwegian cod than for other populations, suggesting that some progress might be made in test simulations using regional physical models. The knowledge gained from such an exercise will in turn be useful for future attempts to simulate distributions on Georges Bank. Other areas of particular mutual interest between scientists studying the various cod stocks involve differences in genetics and cod physiology throughout their range. A combination of genetic, physiological, paleobiological and paleoclimatological work should provide important information on the long term relationship between cod and climate.

Another international science working group of interest in the context of GLOBEC is a new SCOR working group on pelagic biogeography. This newly constituted effort is interested in understanding the factors which control the distributions of various species in the marine environment. The working group should exchange ideas and plans with personnel involved in planning work as part of GLOBEC in the North Atlantic.

International aspects of the World Ocean Circulation Experiment are apt to provide data sets on the variations in conditions in the North Atlantic throughout the period of the envisioned GLOBEC work. In particular, Canadian and United Kingdom research in the subpolar Atlantic should provide data sets that address the nature of the ocean's response to the North Atlantic Oscillation (NAO, see section 8.6.1). A Nordic country effort at the Greenland-Iceland-Scotland sills will also provide important information in this context. A new SCOR Working Group on the Impacts of Fishery Harvests and Stability of Marine Ecosystems is bound to address issues which complement those considered by GLOBEC.

4.4 Other U.S. Programs

Other U.S. sponsored initiatives of interest to GLOBEC North Atlantic work include WOCE, ACCP, JGOFS and CoOP. U.S. WOCE is primarily concentrating on work in regions outside of the North Atlantic and therefore will not be of much relevance to the program at least in the near term. The NOAA Atlantic Climate Change Program, on the other hand, can be expected to provide considerable support in terms of large scale data analysis to interpret climate signals, through monitoring work to follow climatic variations through the 1990s and through the development of models with the explicit goal of better simulations of climate variations in the Atlantic. An effort as part of ACCP to provide a higher resolution geological record for the Northern Atlantic is also relevant to GLOBEC goals. U.S. JGOFS plans do not call for further field programs in the Atlantic, but several aspects of JGOFS equipment development and the time series studies at Bermuda are important to Atlantic efforts in GLOBEC. GLOBEC should consult with JGOFS scientists regarding long term moored technologies currently in development or use. The time series at Bermuda and its relationship to the longer Bermuda Biological Station time series provides an additional time series with respect to climate change in the North Atlantic. The relevance of these time series to the region north of the Gulf Stream requires further study.

The Coastal Ocean Processes Program (CoOP) has several aspects which overlap with the interests of the GLOBEC Georges Bank effort. CoOP is a multidisciplinary effort focusing on the transfer of properties in the coastal ocean. Particular overlap in interest will occur in relation to model development and testing, observation technologies and process studies. Of primary importance is the development of truly multidisciplinary cooperation within CoOP and between CoOP and GLOBEC.

5 NEW TECHNOLOGY

Recommendations have been made in previous sections regarding the requirements for technology which would be considered specifically important to the study of the various taxonomic groups: fish, holozooplankton and meroplankton. Here we make general recommendations on certain technologies that could be profitably used by multiple disciplines:

- **Development and application of biochemical techniques** which identify physiological and behavioral properties of organisms, and which (1) can be applied to small sample sizes, (2) can provide for rapid sample processing, and (3) may be taken to sea;

- **Improvement on aspects of acoustic technology as** applied to small particle sizes, requiring (1) improved theoretical models, (2) improved hardware which is standardized and more readily available, (3) improved software for handling high data rates and large data sets, and (4) a better understanding of the biological meaning of the data;

- **Development of instrumentation which** is capable of (1) identifying and enumerating organisms in the plankton, whether by size, species or biochemical characteristics, and (2) which can be deployed to collect data continuously or synoptically.

We specifically endorse the following initiatives to speed development in these areas:

(1) Biotechnology Workshops:

A small group of molecular biologists/biochemists should meet with an equal number of biological oceanographers to discuss the most promising techniques for the most pressing oceanographic problems. From this meeting, a series of short courses on techniques and ideas might be developed. Such courses would be advertised and open to the community at large. Biological oceanographers who learn to apply these new techniques will be in a much better position to forge collaborations and proposals to work with appropriate biochemists/molecular biologists on relevant GLOBEC problems.

(2) Technology Workshops:

A small group of engineers/technologists should meet with an equal number of biological oceanographers to discuss the most promising techniques for the most pressing oceanographic sampling problems. From this meeting, a series of workshops will be convened with the specific purpose of generating design criteria required to improve or develop high data rate sampling instruments. The design criteria will be used as the basis for Announcements of Opportunity or initiatives by funding agencies committed to providing improved technological capability to GLOBEC. Technologies which have been discussed at this writing include (1) acoustics, (2) optics, and (3) image analysis.

6 FIELD PROGRAM LOGISTICS

The GLOBEC Georges Bank field study is anticipated to begin in FY 1992 and to continue, in some aspects, for three years. In general terms, it is recommended that there be three principal and complementary sampling modes:

(1) Bank-scale Synoptic Survey Cruises;
(2) Process-oriented Cruises; and
(3) Biological/Physical Moorings.

Physical oceanographic studies and biological investigations of all taxa would be carried out in each of these sampling modes. Where possible, attempts should be made to coordinate these cruises with ongoing programs in the region *(e.g.,* OPEN). Cruises should be scheduled in the first and third years of the field program, with moorings operating continuously for the duration. This will permit results from the first year to help formulate altered strategies for the subsequent field program.

6.1 Bank-scale synoptic survey cruises

6.1.1 Survey domain and resolution

Survey cruises would cover a grid of approximately 20 km interline spacing, extending over the entire Bank to the 100 m isobath. In addition, selected transects should be run into the deep basins of the Gulf of Maine and the slope waters to the south in order to study exchange processes and to enable comparative studies of regionally disparate populations.

6.1.2 Timing

In Years 1 and 3, a total of 6 survey cruises, each of 2-3 weeks duration, should be conducted monthly from January through June. This amount of time is required to canvas the region at the appropriate resolution. Cruises of similar duration, but at lower frequency, may be sufficient to characterize the system for the remaining 6 months of the field year.

6.1.3 Critical measurements

Working groups agreed that survey sampling procedures of mutual interest would require the following general types of collections:

(1) Vertical distributions, abundance and physiological condition of target species, with an emphasis on differences above and below the seasonal thermocline;
(2) Vertical distribution and abundance of food (the definition of which depends upon the species of interest);
(3) Vertical distribution and abundance of predators;
(4) Physical, chemical and biological properties, focusing on vertical profiles of salinity, temperature, inorganic nutrients, beam transmission, downwelling irradiance and current velocities.

Key instrumentation may involve multiple net samplers *(e.g.,* MOCNESS, BIONESS), optical plankton counters, acoustics, silhouette photography and image analysis, and sonar for fish schools. Physical, chemical and biological properties could be sampled by a consortium of instruments including CTD, radiometer, beam transmissometer, ADCP, and chemical analysis of water samples collected by rosette. Innovative methods in biochemistry/biotechnology which are sufficiently developed would also be incorporated.

6.2 Process-Oriented Cruises

6.2.1 Domain and resolution

Locations of the process-oriented cruises would be determined on the basis of preliminary results garnered from initial survey cruises. Sites which have already been identified as being of key interest are major spawning sites.

6.2.2 Timing

Similar to the survey cruises, process-oriented cruises would be conducted primarily in Years 1 and 3, with an intermediate year permitted for data analysis and interpretation. The exact timing of the cruises will depend to a great extent on the determination of which periods are deemed to be critical to understanding population dynamics of the target species being studied.

6.2.3 Critical measurements

Measurements should focus primarily on processes at different time and space scales. Certain types of studies are envisioned as essential, and can be described with respect to general location:

- Fish larvae:
  - (1) A key spawning site, at which a cohort of larvae can be identified, followed using drogues, and sampled at frequent intervals;
  - (2) A location where feeding and growth can be measured with respect to development of seasonal stratification;

- Zooplankton:
  - (1) Near the northwestern boundary of the Bank, on the border of the Gulf of Maine, where intruding waters in late winter are thought to transport *Calanus* as it breaks out of its overwintering state;
  - (2) Measurements of physiological rates conducted in conjunction with drogue and stratification studies on fish larvae;

- Benthos:
  - (1) Major spawning sites, for as many as six different species, from which drogue studies can be used to follow aggregations of larvae until settlement and losses by diffusion and other physical processes to the settled patch could be estimated.

Measurements would concentrate particularly on shipboard and in situ estimates of physiological rates such as egg production, growth, and feeding, as well as key population dynamics parameters such as mortality. The theme of these cruises would be to attempt to follow localized aggregations and to monitor key changes in their demography, physiology, and distribution as it is affected by physical processes and behavior through time. Of great interest is the relationship of these population processes to the development of seasonal stratification. A variety of background physical, chemical and biological measurements made during the process-oriented cruises would provide continuity with data generated from the survey cruises.

6.3 Moorings

6.3.1 Domain and resolution

Approximately five mooring sites are desirable: four on Georges Bank and one in the Gulf of Maine. The four Georges Bank sites include one on the western edge adjacent to the Great South Channel, one on the northeast corner, one on the southeast corner, and one in the center of the Bank (Fig. 6-1).

6.3.2 Timing

Moorings could be deployed in fall/winter of the first field season and maintained for three years. It is anticipated that moorings might be relocated or brought on line at new locations as the field program progresses.

6.3.3 Critical measurements

It is recommended that each of the five mooring sites include a central, heavily instrumented, mooring and an array of four peripheral current meter moorings. Central moorings might include Acoustic Doppler Current Profilers (ADCPs) and a variety of hydrographic, bio-optical and bioacoustical sensors (bio-sensors), whereas peripheral moorings would include only current meters. Mooring arrays are necessary to properly quantify tidal components of the circulation.

Selected process studies should be conducted in the vicinity of mooring sites; similarly, survey cruise transects should be brought fairly close to these sites as well.

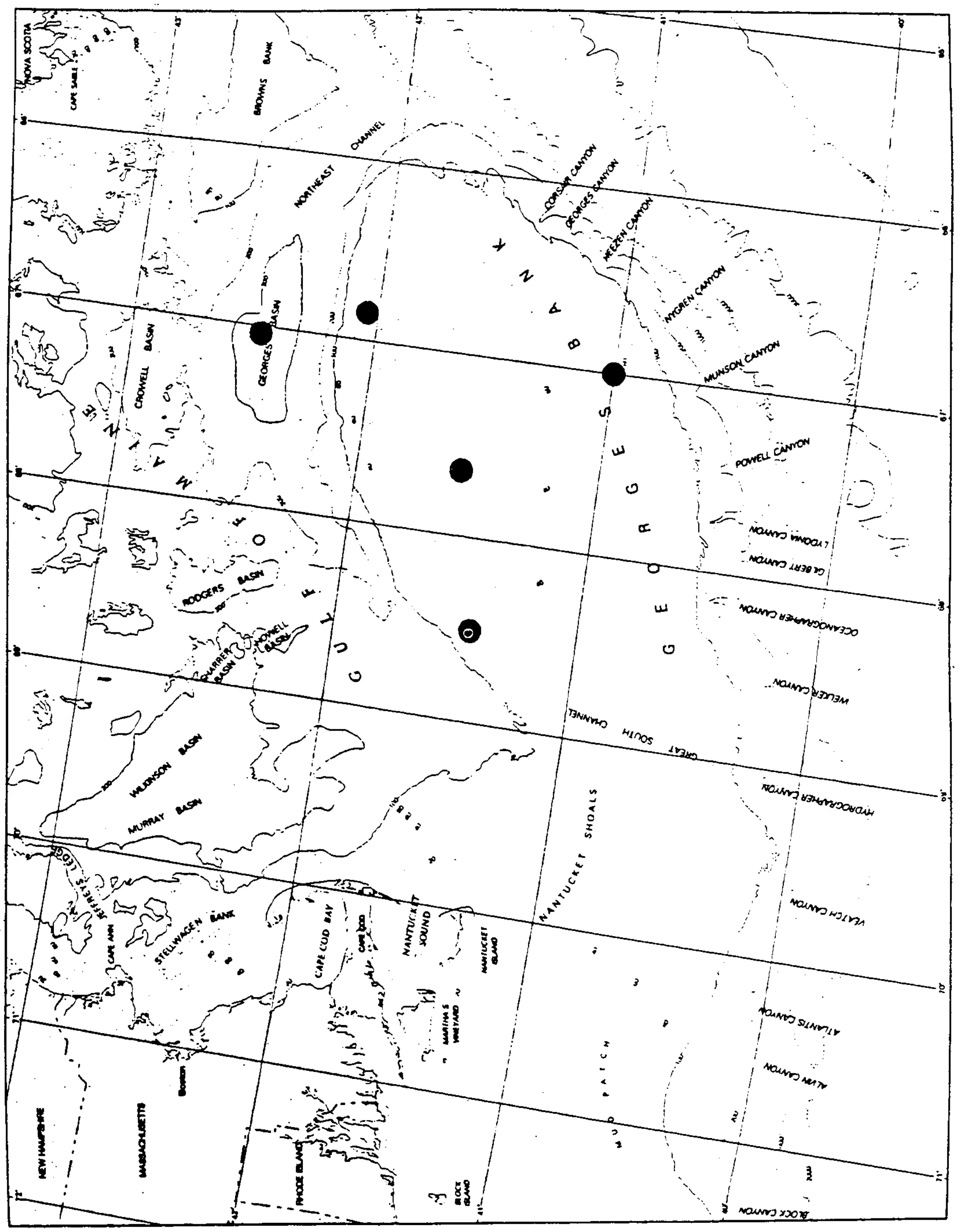

Fig. 6-1. Proposed mooring array locations (•) on Georges Bank and the Gulf of Maine.

7 DATA MANAGEMENT

It is expected that the GLOBEC Georges Bank study will provide a testing ground for a yet to be specified GLOBEC data policy and its implementation. To follow the initiative of the other Global Geoscience Initiatives, WOCE and JGOFS, it is important that a data policy be established that is both fair to the scientists participating in the program and that facilitates the timely, broad base use of the data. The latter aspect is particularly crucial in terms of the international interactions. Data should in general be available to the wider community within one year of its preparation.

Scientists must learn to work cooperatively with respect to data sharing and analysis if the multidisciplinary and international cooperation envisioned in the planning of these. programs is to see fruition.

Data handling and transfer mechanisms need to be established in order to facilitate the rapid/accurate exchange of data and the creation of a use-able long term data base. In many ways the existing historical data sets are an appropriate starting point. Much of the historical data on fisheries, regional hydrography and distributions of zooplankton are unavailable, difficult to use or incomplete in relation to the problems GLOBEC wishes to address. In this respect GLOBEC should cooperate with planned and underway efforts on the part of NOAA and JGOFS/WOCE to improve the data bases. In particular, an effort to make fisheries data sets available to the larger community and to facilitate the multidisciplinary training exercise needed for people with expertise in physical climate analysis and fisheries to work together. A Georges Bank data set organized in manner similar to the JGOFS data management system might be a first order goal. International data exchanges and cooperative analysis with respect to climatological data sets should also be a high priority.

8 BACKGROUND PAPERS

8.1 Georges Bank Cod

by Frederic M. Serchuk and Edward B. Cohen

The Atlantic cod, *Gadus morhua,* is a demersal gadoid species distributed in the Northwest Atlantic from Greenland to North Carolina. In USA Atlantic waters, three major groupings of cod have generally been recognized: (1) Georges Bank; (2) Gulf of Maine; and (3) Southern New England-Middle Atlantic (Wise 1962; Serchuk and Wigley 1986). Tagging studies (Smith 1902; Schroeder 1930; North American Council on Fishery Investigations 1932; 1935; Wise 1962), parasite infestation research (Sherman and Wise 1961), spawning time data (Colton et al. 1979), and growth rate analyses (Penttila and Gifford 1976; Serchuk and Wood 1979) indicate that minimal interchange occurs between the Gulf of Maine and Georges Bank groups, but that extensive mixing prevails between cod on Georges Bank and in the Southern New England-Middle Atlantic region. A seasonal southwesterly movement of cod from the South Channel area of Georges Bank occurs in autumn followed by a northeasterly return in spring. Wise (1958) postulated that the autumn movement was not a migration of Georges Bank fish as concluded by Schroeder (1930)) but rather a return of Southern New England-Middle Atlantic fish to their native grounds for winter spawning. The presence of ripe spawning individuals off the New Jersey coast (Smith 1902; Schroeder 1930; Wise 1958) and the occurrence of cod eggs and larvae as far south as North Carolina (Schroeder 1930; Berrien et al. 1978) suggest the possibility that cod in the Middle Atlantic may comprise a genetically distinct subpopulation, separate from those groupings found further north. However, the origin and fate of Middle Atlantic cod eggs and larvae have yet to be delineated, and hence the existence of the Middle Atlantic sub-population remains to be confirmed. Serchuk and Wood (1979) found strong affinities between Georges Bank and Southern New England-Middle Atlantic cod based on growth rates, research vessel survey abundance patterns and catch composition, recruitment patterns, and commercial catch size/age distributions. The relative absence of juvenile cod in inshore and offshore research vessel surveys in the Southern New England-Middle Atlantic region (Serchuk and Wood 1979) suggests that either the southerly populations are not self-sustaining or that offspring from the southern spawning move north as ichthyoplankton or larval nekton and subsequently return south several year later as adults.

The demographic similarities between Georges Bank and Southern New England Middle Atlantic cod are so pronounced that the two groups are presently considered to comprise a single stock (i.e., Georges Bank and South; commonly referred to as the Georges Bank stock).

The Georges Bank cod stock is the most southerly cod stock in the world. Georges Bank cod are omnivorous feeders and commonly attain lengths up to 130 cm (51 in) and weights up to 25 to 35 kg (55 to 77 lbs). Maximum age is in excess of 15 years, although young fish (ages 2-5) generally comprise the bulk of the catch. Sexual maturity is attained between ages 2 to 6; spawning occurs during winter and early spring. Commercial fisheries for cod on Georges Bank have existed since the 1700s and modern landings statistics are available since the late 1880s. Annual commercial catches since 1960 have ranged between 11,000 and 57,000 metric tons, and have averaged about 33,000 tons per year. The commercial fisheries are conducted year-round with otter-trawls and gill nets as primary gear. Recreational fishing is also important and recreational landings have averaged about 6,000 tons in recent years.

Cod in spawning condition are found on Georges Bank nearly year- round but peak spawning normally occurs between February and early March (Colton et a'. 1979). Spawning occurs over the entire Bank, but is frequently concentrated on the northeastern part (Northeast Peak). The pelagic eggs drift to the southwest and hatch in about 2-3 weeks at typical spring temperatures (Lough and Bolz 1989). A semi-persistent clockwise gyre on Georges Bank acts as a retention mechanism for cod eggs and early-stage larvae (Smith and Morse 1985; Lough and Bolz 1989). Lough and Bolz (1989) found that the cross-shelf distribution of larvae is consistent with estimated dispersion rates and observed and predicted near-bottom, cross-isobath currents. Larval retention is probably also enhanced by the proximity of larvae to the bottom in areas less than 70 m deep (Lough and Bolz 1989).

The transition from pelagic to demersal life normally occurs in late May-early June when larvae are about 4-6 cm in length or about 3 months old. Juveniles are typically associated with pebble- gravel substrates; the gravel beds probably reduce predation [due to the coloration of the cod on the gravel], and furnish an abundance of prey items. (Lough *et al.* 1989). Year-class strength appears to be set by the time cod become demersal juveniles. Growth of Georges Bank cod is rapid - age 0 fish attain an average size of 26 cm by the end of their first year of life. Sexual maturity commences at age 2 (40-60 cm), and by age 5 (70-80 cm) virtually all cod are sexually mature.

Assessments of the Georges Bank cod stock have been conducted since the early 1970s but virtual population estimates [VPA] only go back to 1978 (Serchuk and Wigley 1986; Hunt 1988; NEFC, NMFS 1989). Commercial CPUE indices for the USA otter trawl fleet exist since 1964 and Canadian CPUE data are available from 1967 to the present. Stock abundance and recruitment indices derived from autumn (1963 onward) and spring (1968 onward) USA research vessel surveys have been used to monitor changes and assess trends in population size and recruitment of the Georges Bank cod stock. Abundance indices are also available from Canadian research vessel surveys of Georges Bank (since 1986), and inshore spring and autumn bottom trawl surveys conducted by the State of Massachusetts since 1978.

VPA results indicate that fishing mortality on Georges Bank cod doubled between 1978 and 1985 (F=0.39 to F=0.84) and reached a record-high level in 1987 (F=0.95). Spawning stock biomass at the beginning of 1988 was a record-low, about half of that in 1978. Although strong year classes have been produced with regularity (1975, 1978, 1980,1983, 1985, 1987), significant rebuilding of the spawning stock has been hampered by a strong dependence by the fishery on mostly young fish (ages 2 and 3).

VPA results for the period 1978-1987 indicate that variability in year class strength is rather modest - the smallest and largest year classes differ by a factor of 7. The range in spawning stock biomass is more limited; the highest and lowest SSBs differ by only a factor of 3. Age 1 indices from the autumn USA research vessel surveys appear to accurately reflect relative year class strengths suggesting that year class size is determined during the first year of life. Patterns in recruitment of the Georges Bank stock are generally different from those observed in the Gulf of Maine cod stock.

8.1.1 References

Berrien, P. L., M. P. Fahay, A. S. W. Kendall, Jr., and W. G. Smith. 1978. Ichthyoplankton from the RV *Dolphin* survey of continental shelf waters between

Martha's Vineyard, Massachusetts and Cape Lookout, North Carolina, 1965-66. Tech. Series Rept. 15, Sandy Hook Lab., NEFC, NMFS, Highlands, New Jersey.

Colton, J. B., W. G. Smith, A. W. Kendall, P. L. Berrien, and M. P. Fahay. 1979. Principal spawning areas and times of marine fishes, Cape Sable to Cape Hatteras. Fish. Bull. 76, 911-915.

Hunt, J. J. 1988. Status of the Atlantic cod stock on Georges Bank, NAFO Division 5Z and Subarea 6, in 1987. CAFSAC Res. Doc. 88/73, 50 pp.

Lough, R. G. and G. R. Bolz. 1989. The movement of cod and haddock larvae onto the shoals of Georges Bank. J. Fish Biol. 35(Supp. A), 71-79.

Lough, R. G., P. C. Valentine, D. C. Potter, P. J. Auditore, G. R. Bolz, J. Neilson and R. I. Perry. 1989. Ecology and distribution of juvenile cod and haddock in relation to sediment type and a bottom currents on eastern Georges Bank. Mar. Ecol. Prog. Ser. 56, 1-12.

NEFC, NMFS (Northeast Fisheries Center, National Marine Fisheries Service). 1989. Report of the Seventh NEFC Stock Assessment Workshop (Seventh SAW), Woods Hole, Mass. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 89-04, 108 pp.

North American Council on Fishery Investigations. 1932. Proceedings for 1921-1930 No. 1, 56 pp.

North American Council on Fishery Investigations. 1935. Proceedings for 1931-1933 No.2, 40 pp.

Penttila, J.A., and V.M. Gifford. 1976. Growth and mortality rates of cod from the Georges Bank and Gulf of Maine areas. Int. Comm. Northw. Atlant. Fish., Res. Bull. 12, 29-36.

Schroeder, W.C. 1930. Migrations and other phases in the life history of the cod off Southern New England. Bull. U.S. Bur. Fish. 46, 1-136.

Serchuk, F.M., and S.E. Wigley. 1986. Assessment and Status of the Georges Bank and Gulf of Maine Atlantic cod stocks. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No.86-12: 84 pp.

Serchuk, F.M., and P.W. Wood. 1979. Review and status of the Southern New England-Middle Atlantic cod, *Gadus morhua*, populations. August 1979. NMFS, NEFC, Woods Hole Lab. Ref. Doc. No.79-37: 77 pp.

Sherman, K., and J.P. Wise. 1961. Incidence of the cod parasite, *Lernaeocera branchialis L.* in the New England area, and its possible use as an indicator of cod populations. Limnol. Oceanogr. 6, 61-67.

Smith, H.M. 1902. Notes on tagging of 4,000 adult cod at Woods Hole, Mass. Rept. U.S. Fish. Comm. 27, 193-208.

Wise, J.P. 1958. The world's southernmost indigenous cod. J. Cons. int. Explor. Mer. 23, 208-212.

Wise, J. P. 1962. Cod groups in the New England area. Fish. Bull. 63, 189-203.

Smith, W.G. and W.W. Morse. 1985. Retention of larval haddock *Melanogrammus aeglefinus* in the Georges Bank region, a gyre-influenced spawning area. Mar. Ecol. Progr. Ser. 24, 1-13.

8.2 Northern Cod

by Jake Rice

This stock, defined as those cod which inhabit NAFO Division 2J, 3K and 3L, has supported fisheries since at least the 1500s and probably earlier. It is generally agreed that some exchanges occur between Divisions 2J and 2H in the north and between Divisions 3L and 3N0 in the southern extremes of the stock. However, it is assumed that these exchanges balance in some way and may be fairly consistent from year to year. Based on export records, estimates of harvest levels have been developed going back nearly 150 years (Fig. 8-1). These records may not be completely accurate but warrant analyses due to the length of the series. Year to year variation is large, but trends on multiyear scales appear to be present; for example landing estimates in the 1890s appear lower than in the 1880s or 1900s. Overall, landings seemed to vary around or a bit above 200,000 t per year. With the development of the highly mechanized offshore trawler fisheries late in the 1950s, landings rose rapidly to over 600,000 t, and were at that level for most of the 1960s. Late that decade the stock collapsed, and despite intensified fishing effort, landings fell dramatically.

During this period more thorough biological sampling and reporting was instituted, so full age structured population estimates became possible. These estimates show clearly the collapse of the stock, reaching a nadir in 1975-76, and commencing rebuilding in the late 1970s (Fig. 8-2). The age 3+ biomass of cod for the Div. 2J3KL stock was just over 2.5 million tons during the early 1960s. Large amounts of fishing effort by foreign fleets caused the stock to decline and by the mid-1970s the population biomass had shrunk to an all-time low of about 500,000 t. When Canada extended its fisheries jurisdiction in 1977 and dramatically reduced the amount of fishing effort, the stock responded and by 1984 had increased to about 1.2 million tons. Since 1984 the biomass had declined slightly because of the size of the extremely weak 1983 and 1984 year-classes. The age 3+ biomass for 1989 is estimated to be about 800,000 t.

With reduced fishing mortality the stock rebuilt until the mid 1980s. By 1985 fishing mortalities had crept up to the range of 0.4 to 0.5, and the stock stabilized in size. The 1983 and 1984 year-classes were much weaker than the recent average recruitment (150 million fish at age 3, compared to an average of around 300 million), so the biomass of the stock has actually declined by around 10 % in 1989 and 1990. The 1986 and 1987 year-classes appear much stronger than average, however, and if harvest levels do not exceed the recent TACs (in the neighborhood of 200,000 t), further growth of the stock is expected.

It is generally believed that cod of the Div. 2J3KL management unit are comprised of a number of somewhat discrete subgroups that gather for spawning on the shoreward slopes of offshore banks between April and June. There may be many spawning components, some of which have been defined: Hamilton Bank, Belle Isle Bank, Northern Funk Island Bank, Southern Funk Island Bank, North Cape of the Grand Bank, and Woodfall Bank. While a large portion of the stock is distributed on these offshore banks during spawning, after that time large quantities of post-spawners move to inshore areas during the early summer to feed on capelin which have aggregated at the coast to spawn. It is during this time when cod are in inshore areas that a large degree of intermingling of the cod from the discrete offshore spawning components occurs.

Water movement over the continental shelves of Div. 2J3KL is generally southward. The Labrador Current, the largest influence on this southward movement, transports some of the coldest surface water in the North Atlantic. The vertical structure of 2J3KL water is comprised of three layers. The upper layer which extends to about 40-50 m has

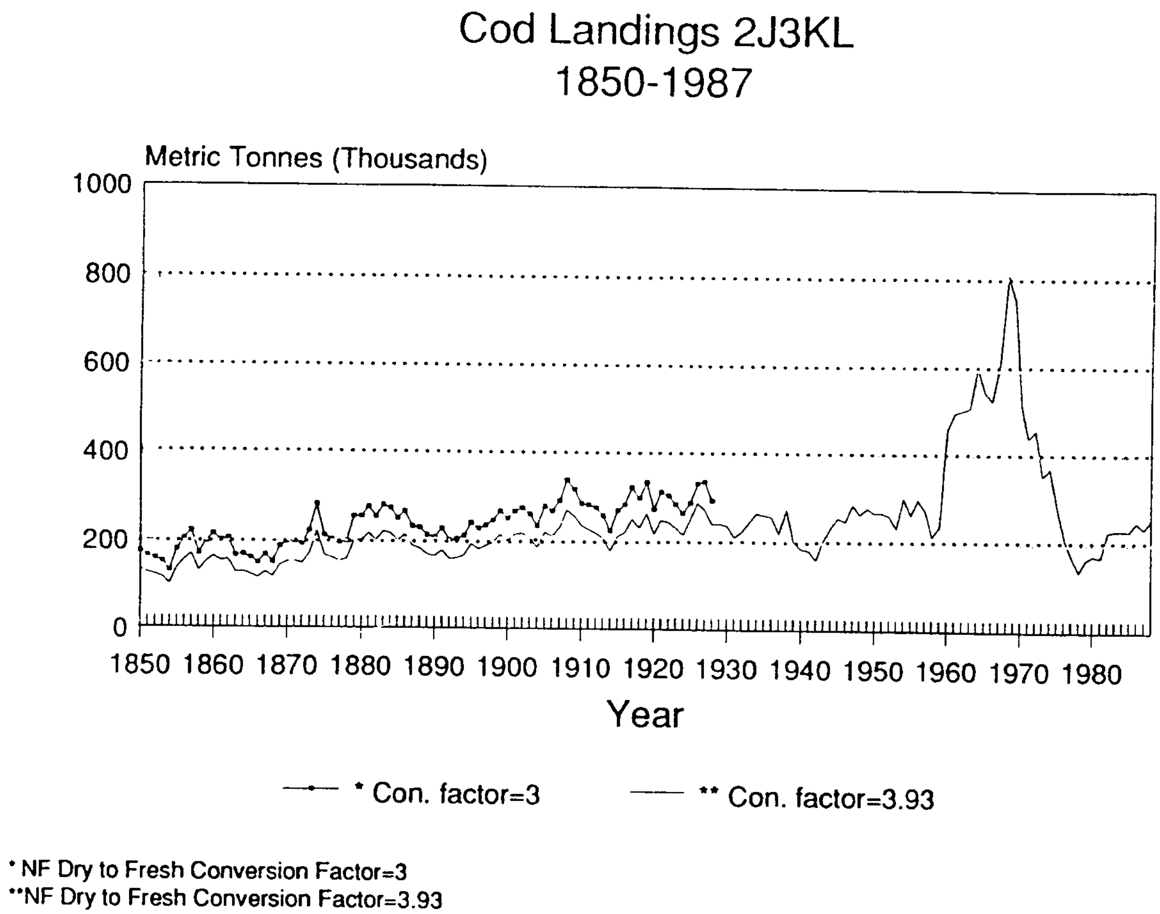

Fig. 8-1. Cod landings (10^3 metric tons per year) for North Atlantic Fisheries Organization (NAFO) divisions 2J, 2K, and 3L from 1850 to 1987.

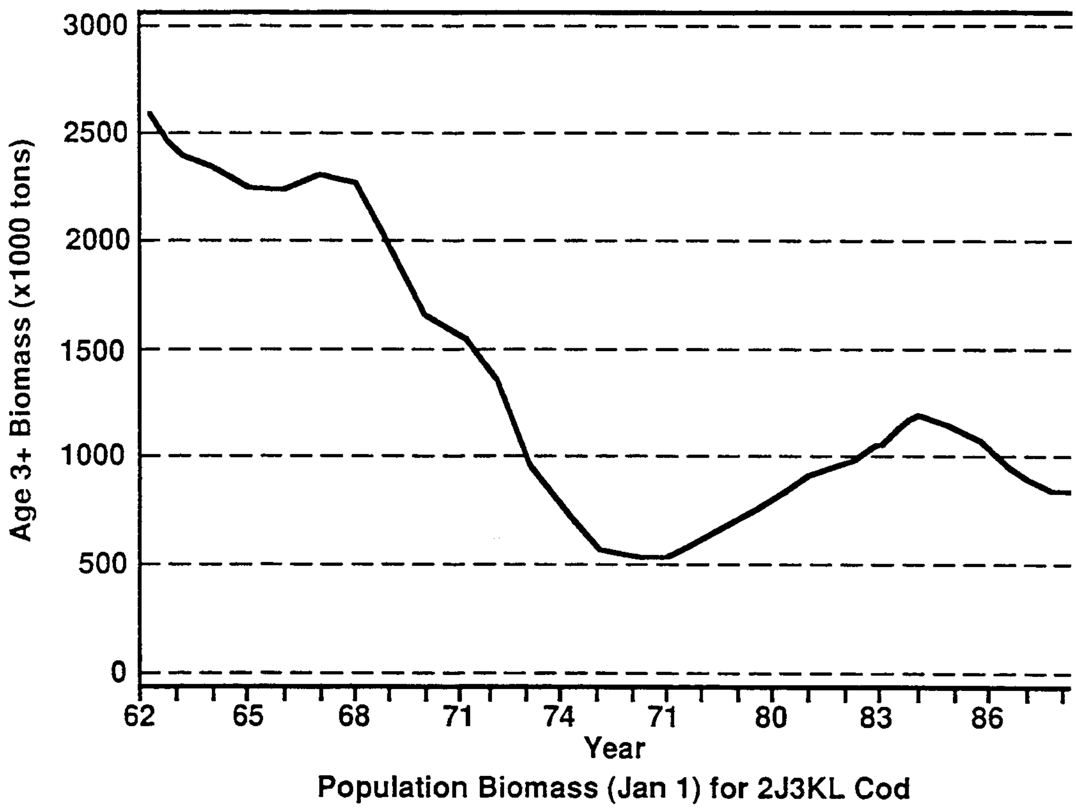

Fig. 8-2. Estimated population biomass (10^3 metric tons) of age 3+ cod in NAFO division 2J3KL, 1962-1989.

temperatures in the warmest months reaching 10 - 12°C. The cold intermediate layer extends to depths of about 150-200 m with temperatures as low as -1.8°C. The warmer bottom layer is influenced by waters from deeper more oceanic areas.

There is a public perception that the Northern Cod stock has actually collapsed seriously in the mid-late 1980s. This erroneous perception exists because the assessment estimates of the size of the stock did drop greatly from 1987 to 1989. This change arose from a re-evaluation of the research vessel data; decreasing confidence in the commercial catch-per-unit-effort, because of technological changes in the fishing fleet; and improvements in the sequential population analysis methods. The changed view of the stock applies to the entire rebuilding trajectory of the stock, however; the stock did not drop; rather the retrospective estimates all changed. Many of the reasons for the dramatic change in perception of the stock status arise from limitations on understanding how availability of fish to commercial and research gears is influenced by oceanographic conditions. Moreover, expectations of strong rebuilding prevailed in all clients, because of projections made in the mid 1970s, using recruitment estimates from the early years in Fig. 8-2. There are serious reservations about the reliability of many of the reported data from the early 1960s, but even with those uncertainties, the stock appears to have been much more productive in the 1960s than in the 1970s and 1980s. Both the oceanographic influences on availability and the changes in productivity make it vital to improve our understanding of environment-ecosystem interactions. Fisheries oceanography and predator-prey dynamics are major components of the $43 million Northern Cod Science Program. These initiatives provide a natural foundation for development of strong linkages to research programs on marine aspects of climate change nationally, continentally, and globally. Such linkages will be pursued aggressively.

8.3 Georges Bank Sea Scallops (*Placopecten magellanicus*)

by Frederic M. Serchuk and Edward B. Cohen

Sea scallops *(Placopecten magellanicus)* occur along the continental shelf of North America from the Strait of Belle Isle south to Cape Hatteras (Posgay 1957). North of Cape Cod, scattered concentrations occur in shallow water, often just below the low tide mark (Posgay 1950; Dickie 1953); further south aggregations are restricted to deeper, cooler offshore waters (Merrill 1971). Sea scallops are intolerant of water temperatures above 20-22°C (Posgay 1953; Dickie 1958), and hence the southern extremity of their range, and their distribution in coastal estuaries, are likely circumscribed by temperature (Dickie and Medcof 1963; Merrill 1971). Scallop beds sufficiently dense and extensive enough to support commercial fishing exist from Port au Port Bay, Newfoundland to the Virginia Capes (Posgay 1957), generally at depths between 40 and 100m (Merrill 1962; Posgay 1979). Although individualized movement of scallops within beds is common, tagging experiments (Baird 1954, 1956; Dickie 1953, 1955; Posgay 1963) indicate an absence of directed population movements or seasonal migrations.

Spawning occurs in late summer or early fall, varying slightly between years and areas (Bourne 1964). Spawning commences during July at the southern extremity of the range (i.e., North Carolina and Virginia) and proceeds northeastward as the year advances, ending in the northernmost regions by mid-October (MacKenzie et al. 1978). Sexes are separate, although occasionally hermaphrodites occur (Merrill and Burch 1960; Naidu 1970). Fertilization is external; individuals in the same general area may go from completely ripe to completely spent within a week (Posgay and Norman 1958). The environmental stimuli triggering spawning are unknown, but may be associated with thermal destratification and an increase in bottom temperature (Posgay 1953), tidal cycles (Dickie 1953), or temperature elevation and depression relative to thermal acclimation (Naidu 1970).

Fertilized sea scallops are buoyant, and undergo typical molluscan development as pelagic larvae (Merrill 1961; Culliney 1974). Sea scallop larvae have only a slight capacity for regulating their vertical distribution (Tremblay and Sinclair 1990a; 1990b). Scallop larvae in a stratified area on Georges Bank were strongly associated with the pycnocline while those at a well mixed site were distributed throughout the 40-50 m water column (Tremblay and Sinclair 1990a). There is some evidence of a weak diel migration by scallop larvae in a shallow embayment (Tremblay and Sinclair 1990b). The vertical distribution of scallop larvae on Georges Bank showed no relation to food concentration and was apparently determined by the position of the pycnocline (Tremblay and Sinclair 1990a). Even in the shallow embayment where some vertical migration was observed (Tremblay and Sinclair 1990b) the dominant factor in the vertical distribution was the pycnocline depth.

Duration of the planktonic phase in nature is unknown; laboratory culture experiments at 15°C indicated that spatfall occurs 35 days after fertilization (Culliney 1974). The distribution of spatfall is presumably related to prevailing surface current patterns during the pelagic period. Generalized sea surface circulation patterns indicate a prevailing southwesterly flow from Georges Bank (Bumpus 1976; Beardsley *et al.* 1976; Butman et *al.* 1982) suggesting that progeny of a given sea scallop aggregation are unlikely to settle out in the vicinity of the parental beds (Merrill 1965; Posgay 1979). Larvae spawned on Georges Bank, however, may frequently be retained there due to a semi-persistent gyre facilitating completion of metamorphosis in this region (Posgay 1979).

The interaction between larval scallops and the currents on Georges Bank needs to be more clearly defined. A tentative hypothesis is that the beds on the northeast peak, the northern edge and the great south channel areas of Georges Bank are thought to be self sustaining. This is likely due to larvae being retained on the bank by gyral circulation, long enough for the larvae to metamorphose and settle to the bottom. Scallop beds on Georges Bank may also receive larvae from the Gulf of Maine and Scotian Shelf and may supply larvae to the Mid-Atlantic region. The question of the source of supply of larvae to the various beds and the genetic makeup of the beds (i.e., are there several stocks or just one) need increased attention.

Sexual maturity may be attained as early as age 1, with the initial spawning occurring after deposition of the first growth ring (age 1.5 or 2) (Naidu 1970). Size at sexual maturity may vary from 23 to 75mm (Naidu 1970; Posgay 1979) but fecundity of the younger age groups contributes little to total egg production. By age 5 or 6, however, female scallops may each produce about 2 million eggs (Posgay 1979).

During the first several years of life, growth in both shell size and meat weight is rapid. Between ages 3 and 5, sea scallops commonly increase 50 -80% in shell height and quadruple in meat weight, while about 10% die, per year, from natural causes (Merrill and Posgay 1964). In this interval, the number of meats per pound is reduced from about 100 to 23. Between ages 8 and 9, annual growth falls to less than 10% per year, so that at age 8 (ca. 133mm shell height, 11 meats/lb) the increase in weight due to growth roughly balances the loss in weight due to natural mortality.

Scallop abundance on Georges Bank has recovered from the nadir reached in 1983-1984 and is now at a relatively high level (CUD 1989). Current US fishing effort is excessive and landings are above long term sustainable catch. However, US landings and catch per unit effort (CPUE) may remain high during 1989 and 1990 because of recent strong year classes (1982-1984) in the fishery. US landings were 6100mt and Canadian landings 4300mt in 1988. On the Canadian side landings are slightly below the long term historical average and fishing effort has recently decreased through reduction of the fishing fleet (M. J. Tremblay, pers. comm.).

8.3.1 References

Baird, F. T., Jr. 1954. Migration of the deep sea scallop (*Pecten magellanicus*). Maine Dept. Sea Shore Fish., Fish. Circ. 14, 8 pp.

Baird, F. T., Jr. 1956. The sea scallop (*Pecten magellanicus*). Maine Dept. Sea Shore Fish., Fish. Education Series, Unit No.2, 11 pp.

Beardsley, R. C., W. C. Boicourt and D. V. Hansen. 1976. Physical oceanography of the New York Bight. ASLO Spec. Symp. 2, 20-34.

Bourne, N. 1964. scallops and the offshore fishery of the Maritimes. Fish. Res. Bd. Can. Bull. 145, 60 pp.

Bumpus, D. F. 1976. review of the physical oceanography of Georges Bank. ICNAF Res. Bull. 12, 119-134

Butman, B., R. C. Beardsley, B. Magnell, D. Frye, J. A. Vermersch, R. Schlitz, R. Limeburner, W. R. Wright and M. A. Noble. 1982. Recent observations of the mean circulation on Georges Bank. J. Phys. Oceanogr. 12, 569-591.

Conservation and Utilization Division (CUD). 1989. Status of the fishery resources off the northeastern United States. NOAA, NMFS, NEFC, Woods Hole Laboratory. 110 pp.

Culliney, J. L. 1974. Larval development of the giant scallop, *Placopecten magellanicus* (Gmelin). Biol. Bull. 147, 321-332.

Dickie, L. M. 1953. Fluctuations in abundance of the giant scallop, *Placopecten magellanicus* (Gmelin), in the Digby area of the Bay of Fundy. Fish. Res. Rd. Can. MSS Rept. Biol. Sta. No. 526.

Dickie, L. M. 1955. Fluctuations in abundance of the giant scallop, *Placopecten magellanicus* (Gmelin), in the Digby area of the Bay of Fundy. J. Fish. Res. Bd. Can. 12, 797-857.

Dickie, L. M. 1958. Effects of high temperatures on survival of the giant scallop. J. Fish. Res. Bd. Can. 15, 1189-1211.

Dickie, L. M. and J. C. Medcof. 1963. Causes of mass mortalities of scallops (*Placopecten magellanicus*) in the southwestern Gulf of St. Lawrence. J. Fish. Res. Bd. Can. 20, 451-482.

Mackenzie, C. L., A. S. Merrill and F. M. Serchuk. 1978. Sea scallop resources off the northeastern U.S. coast. Marine Fish. Rev. 40, 19-23.

Merrill, A. S. 1961. The sea scallop fishery. Bull. Amer. Malacol. Union 28, 14.

Merrill, A. S. 1962. Abundance and distribution of sea scallops off the Middle Atlantic coast. Proc. Nat. Shelf. Assoc. 51, 74-80.

Merrill, A. S. 1965. The benefits of systematic biological collecting from navigation buoys. ASB Bull., 12, 3-8.

Merrill, A. S. 1971. The sea scallop. Ann Rept. (1970). Amer. Malacol Union. 24-27.

Merrill, A. S. and J. B. Burch. 1960. Hermaphroditism in the sea scallop, *Placopecten magellanicus* (Gmelin). Biol. Bull., 119, 197-201.

Merrill, A. S. and J. A. Posgay. 1964. Estimating the natural mortality rate of the sea scallop (*Placopecten magellanicus*). ICNAF Res. Bull. 1, 88-106.

Naidu, K. S. 1970. Reproduction and breeding cycle of the giant scallop *Placopecten magellanicus* (Gmelin) in Port au Port Bay, Newfoundland. Can. J. Zool., 48, 1003-1012.

Posgay, J. S. 1950. Investigations of the sea scallop, *Pecten grandis*. In Third Report on investigations of methods of improving the shellfish resources of Massachusetts. Comm. of MA, Dept. Nat. Res. Div. Mar. Fish., 24-30.

Posgay, J. 5 1953. The sea scallop fishery. In Sixth Report on investigations of methods of improving the shellfish resources of Massachusetts. Comm. of MA, Dept. Nat. Res. Div. Mar. Fish., 9-24.

Posgay, J. A. 1957. The range of the sea scallop. The Nautilus. 71, 55-57.

Posgay, J. A. 1963. Tagging as a technique in population studies of the sea scallop. ICNAF Spec. Pub. 4, 268-271.

Posgay, J. A. 1979. Sea scallop *Placopecten magellanicus* (Gmelin). In: Fish distribution. MESA N.Y. Bight Monogr. No.15. N.Y. Sea Grant Institute, N.Y.

Posgay, J. A. and K. D. Norman. 1958. An observation on the spawning of the sea scallop, *Placopecten magellanicus* (Gmelin), on Georges Bank. Limnol. Oceanoyr. 3, 142.

Tremblay, M. J. and M. Sinclair, 1990a. Sea scallop larvae *Placopecten magellanicus* on Georges Bank: vertical distribution in relation to water column stratification and food. Mar. Ecol. Prog. Ser. 61, 1-15.

Tremblay, M. J. and M. Sinclair, 1990b. Diel vertical migration of sea scallop larvae *Placopecten magellanicus* in a shallow embayment. Mar. Ecol. Prog. Ser., 67, 19-25.

8.4 Georges Bank Holozooplankton

by Cabell Davis

The plankton ecology of Georges Bank has been reviewed extensively in Backus (1987) and can be summarized as follows. A spring diatom bloom occurs in March in the well mixed region (<60m) and April in deeper areas (60-100m); diatoms remain dominant in the well mixed region year-round while dinoflagellates dominate the stratified deeper area during summer/fall, with maximum abundance near the seasonal pycnocline (O'Reilly *et al.*, 1987; O'Reilly and Busch, 1984). High biomass and productivity in the mixed area are maintained through tidally induced vertical mixing together with physical input of new nitrate (Walsh *et al*, 1987). About half the nitrogen demand of the primary production is supplied as nitrate input along the edges of the bank but the physical exchange mechanisms are poorly understood; recycling accounts for about 1/3 of the phytoplankton demand during winter and spring and about 2/3 during summer and fall (Walsh *et al.*, 1987; Loder *et al.*, 1982). Recent studies by Canadian researchers on the northeast flank suggest that tidal mixing processes may be the dominant physical factor controlling cross-frontal exchange in the mixed area (Harrison et al, 1990). On an annual basis, there is a high ratio of primary to secondary production compared to the North Sea, perhaps due to advective loss of plankton (Cohen and Grosslein, 1987). Estimates for seasonally averaged turnover rates of the bank water mass support this view (Mountain and Schlitz, 1987), but the time dependence on sub-seasonal scales is not known. In particular, the impact of storms and Gulf Stream rings on Georges Bank trophodynamics has not been examined (Mountain and Schlitz, 1987; Klein, 1987). Klein (1987) used a simple nutrient-phytoplankton-zooplankton model coupled to a kinematic model of circulation in the well mixed region of the bank. His model showed large loss rates of plankton from the region which were comparable to those found by Walsh *et al.* (1987), but he also noted that his physical loss rates were long term averages of short term events including storms and rings. He further discussed the need for more realistic zooplankton models which include population dynamics and spatial distributions outside the well mixed area.

The annual cycle and spatial distribution of zooplankton on Georges Bank are analyzed in Davis (1984a,b,c; 1987a,b). The zooplankton is dominated in numbers and biomass by the copepods *Calanus finmarchicus, Pseudocalanus newmanii, Pseudocalanus moultoni, Centropages typicus, Centropages hamatus, Paracalanus parvus,* and *Oithona similis. Calanus* and *Pseudocalanus* are winter-spring species, while *Centropages* and *Paracalanus* are dominant during fall. *0. similis* is abundant throughout the year but is not important in terms of biomass or production. Zooplankton production is highest during late summer - early fall due to rapid growth of small warm-water species, with most of the production going into predation by the chaetognath *Sagitta elegans,* the ctenophore *Pleurobrachia pileus,* and the omnivorous copepods *Centropages spp.*

Each of the dominant species has its own characteristic life cycle (Davis, 1987a) and therefore may be impacted differently by advective loss from the bank. *Calanus finmarchicus* is a large boreal animal which reaches maximum abundance in June accounting for the major portion of the spring zooplankton biomass peak. It enters diapause as fifth stage copepodids in mid-summer and spends the warm stratified months at depths of 200-300m in the Gulf of Maine and Slope Water. *C. finmarchicus* spawns on Georges Bank in February and produces two generations during its spring appearance there. During its growing season *Calanus* abundance is highest in the deeper regions of the bank (60-100m) than in the well mixed area, Gulf of Maine, or Slope Water. *Calanus* likely undergoes diapause to avoid the warm oligotrophic fall conditions. *Calanus* undergoes diel and seasonal vertical migration which depend on life stage. The life cycle of *Pseudocalanus moultoni* is similar to *Calanus'* in that it begins its population growth during the winter when it is carried onto the northwestern edge of Georges Bank by prevailing currents. *Pseudocalanus* (including *P. newmanii,* Frost, 1989) reaches maximum abundance in spring (May/June). *Pseudocalanus spp.* abundance decreases markedly after June as it gives way to *Centropages hamatus, C. typicus,* and *Paracalanus parvus.* The latter two species, during peak abundance, inhabit the warm surface layer on Georges Bank and the Gulf of Maine undergoing little or no diel migration. Their distributions are less restricted to the bank as is the case for their spring counterparts. *P. parvus* is not likely to be food limited on Georges Bank whereas *C. typicus* growth and reproduction are inhibited at mean bank food levels (Davis and Alatalo, 1990). *C. hamatus* lays bottom resting eggs which overwinter in the sediments and hatch out from August-September giving rise to a large fall population. This species, like other resting egg layers, has a well defined distribution restricted to the well mixed region. At present, we have only a limited understanding how physical processes interact with dynamics of dominant zooplankton species on Georges Bank.

In short, the effects of large scale physical forcing on ecological efficiency and consequences for recruitment at higher trophic levels are poorly understood. Significant insights can be gained by modeling interactions between physical transport and simple food chain dynamics as well as dominant or characteristic zooplankton species. Each species has evolved certain characteristics which are affected differently by advective transport out of favorable growth areas.

Changes in global climatic conditions can potentially have dramatic effects on Georges Bank plankton. The most direct effects might be through changes in sea surface temperature (SST). Prevailing winds from the North American continent cause an unusually large seasonal range in SST in the Georges Bank region. Since this area represents a faunal transition zone between colder boreal plankton to the north and warmer water species to the south, any general trends in land air mass could alter the SST and cause latitudinal shifts in this transition zone away from the Georges Bank region. Temperature changes larger than 2°C could cause significant latitudinal displacement in the relative abundance of planktonic species. Thus this region, due to its strong seasonality, may be relatively more sensitive to changing climatic conditions than other areas.

8.4.1 References

Backus, R. H. 1987. (ed) Georges Rank. MIT Press, Cambridge, Massachusetts, 593 pp.

Cohen, E. B. and M. D. Grosslein. 1987. Production on Georges Bank compared with other shelf ecosystems. In: R.H. Backus (ed), Georges Bank, MIT Press, Cambridge, Massachusetts, p.383-391.

Davis, C. S. 1984a. Interaction of a copepod population with the mean circulation on Georges Bank. J. Mar. Res. 42, 573-590.

Davis, C. S. 1984b. Predatory control of copepod seasonal cycles on Georges Bank. Mar. Biol., 82, 31-40.

Davis, C. S. 1984c. Food concentrations on Georges Bank: non-limiting effect on development and survival of laboratory reared *Pseudocalanus* sp. and *Paracalanus parvus* (Copepoda: Calanoida). Mar. Biol. 82, 41-46.

Davis, C. S. 1987a. Components of the zooplankton production cycle in the temperate ocean. J. Mar. Res. 45, 947-983.

Davis, C. S. 1987b. Zooplankton life cycles. In: R. H. Backus (ed.), Georges Rank. MIT Press, Cambridge, Massachusetts, p. 256-267.
Davis, C. S. and P. Alatalo. 1990. Effects of food concentration on growth and reproduction in *Centropages typicus* (Copepoda: Calanoida) reared in continuous laboratory culture. Submitted to Limnol. Oceanogr.
Frost, B. W. 1989. A taxonomy of the marine calanoid copepod genus *Pseudocalanus*. Can. J. Zool. 67, 525-551.
Harrison, W. G., E. P. Home, B. Irwin, and T. Platt. 1990. Biological production on Georges Bank: are tidal fronts primary sources of new production in summer? EOS 71, 96.
Klein, P.1987. A simulation of some physical and biological interactions. In: R.H. Backus (ed), Georges Rank, MIT Press, Cambridge, Massachusetts, p. 395-405.
Loder, J. W., D. G. Wright, C. Garrett, and B. A. Juszko. 1982. Horizontal exchange on central Georges Bank. Can. J. Fish. Aquat. Sci. 39, 1130-1137.
Mountain, D. 0. and R. J. Schlitz. 1987. Some biologic implications of the circulation. In: R.H. Backus (ed), Georges Rank, MIT Press, Cambridge, Massachusetts, 392-394.
O'Reilly, J. E., C. E. Evans-Zetlin and D. A. Busch. 1987. Primary production. In: R. H. Backus (ed), Georges Rank, MIT Press, Cambridge, Massachusetts, 220-233.
O'Reilly J. E. and D. A. Busch. 1984. Phytoplankton primary production on the northwestern atlantic shelf. Symposium on the biological productivity of north atlantic shelf areas, Kiel, West Germany, Mar. 2-5, 1982. Rapp. P-V Reun. Cons. int. Explor. Mer. 183(0), 255-268.
Walsh, J. J., T. E. Whitledge, J. E. O'Reilly, W. H. Phoel, and A. F. Draxler. 1987. In: R. H. Backus (ed), Georges Rank, MIT Press, Cambridge, Massachusetts, p. 234-246.

8.5 Physical Oceanography of the Northwest Atlantic Continental Margin

by Peter C. Smith and John W. Loder

The dominant driving forces for circulation and mixing on the continental shelves of the northwest Atlantic are the tides, surface wind stress, offshore currents and eddies, and buoyancy input associated with freshwater runoff and melting sea ice. At large scales, a continuous, buoyancy-driven coastal current has been traced over 5000 km from the west coast of Greenland to the Mid-Atlantic Bight (Fig. 8-3; Chapman and Beardsley, 1989). The basis for this inference is the observation that the freshwater component of the southern shelf waters is highly depleted in the oxygen isotope, ^{18}O**,** suggesting sources in the Labrador Sea such as glacial or sea-ice melt or Hudson Bay runoff. Strong seasonal variability has also been identified in both the salinity and transport of this current, consistent with that of the buoyancy sources (Smith and Schwing, 1990). Off Cape Sable, N.S., the maximum alongshore transport in Jan.-Feb. carries a pulse of low- salinity water from the Scotian Shelf into the Gulf of Maine, and the associated buoyancy flux then contributes to the development of the vernal circulation in the Gulf (Brooks, 1985).

Imbedded within the large-scale coastal flow are mesoscale [10-100 km)] circulations associated with the numerous submarine banks which populate the shelf. Vorticity constraints and certain forcing mechanisms *(e.g.,* tidal rectification; Loder, 1980) tend to produce anticyclonic (clockwise) residual gyres over these banks, but variable characteristics of physical size and circulation produce important differences in the significance of the gyres to the banks' marine ecosystems. These differences may be particularly relevant to the comparative analyses of GLOBEC.

Loder *et al.* (1988a) have examined and compared the physical regimes of four northwest Atlantic Banks using data from various multidisciplinary field experiments conducted over the last decade (Table 1). On the shallow plateau of Georges Bank, enhanced currents and mixing maintain vertically-uniform temperature year- around (Fig. 8-4b), whereas strong thermal stratification develops over the Newfoundland banks (Fig. 8-4a). [A smaller well-mixed zone also occurs over Browns Bank, but is not resolved by the smoothed hydrographic data in Fig. 8-4b.] Since the annual temperature cycle on Georges Bank is determined primarily by seasonal warming, the difference between the observed mixed- water temperature and that which would result from the net heat input at the surface may be used to estimate the rate of horizontal heat (and by inference, salt and nutrient) exchange (Loder *et al.,* 1982).

The depth-averaged mean circulation consists of a clockwise gyre on each of the four banks except Southeast Shoal, where a weak westward flow prevails (Fig. 8-5). The currents with periods of a day or less *(e.g.,* tidal) are typically 2 to 5 times stronger than the mean and low-frequency currents, but the excursion ($\int u\,dt$) variance, affecting horizontal exchange, is dominated by the low-frequencies. To characterize the physical exchange rates for the different banks, the time scales for mixing in three perpendicular directions have been estimated from moored current and density data, Lagrangian drifters and heat or salt budgets (Loder *et al.,* 1988a):

T_R = residence time (cross-isobath),
T_G = recirculation time (along-isobath), and
T_v = vertical exchange time.

A schematic summary of these scales (expressed as rates $\alpha T^{-1} \alpha$ arrow size and normalized by the residence time; Fig. 8-6) reveals that the recirculation time is typically of the same order as the residence time, suggesting that the gyres are of limited significance in "retaining" water or drifting particles on the banks. There is a suggestion, however, that Georges Bank maintains the highest ratio of residence to recirculation time. The vertical exchange rates are maximum on Georges and Browns Banks and minimum on Flemish Cap, where nutrient supply rate may limit production in the surface layer. The physical time scales are also useful in characterizing the bank ecosystems by comparison to the biological time scales, such as phytoplankton doubling or the duration of a critical phase in the early life history of fish eggs or larvae.

Some potentially important biophysical interactions in the Gulf of Maine have been explored as part of the recent field programs (Table 1). For instance, 7- year records from a mooring off Cape Sable, N.S., collected before and during the Fisheries Ecology Program (FEP), have revealed that deviations from the seasonal cycles of current and salinity are related to similar anomalies in the alongshore component of wind stress and, to some extent, the presence of warm-core Gulf Stream rings at the mouth of Northeast Channel (Smith, 1989a). The mechanism appears to be related to the wind- driven intrusion of Slope Water into the Gulf via Northeast Channel, and subsequent upwelling off southwest Nova Scotia. Such an event appears to have enhanced stratification and nutrient supply on Browns Bank in the spring of 1985, leading to the highest phytoplankton and zooplankton biomasses of the three-year FEP observation program (Perry *et al.*, 1989).

FEP variations of surface drift and particle dispersion, using clusters of satellite-tracked drifters, revealed a "leaky" gyre on the western cap of Browns Bank, characterized by consistent exit of drogues from the northern flank to the inshore area (Smith, 1989b). The residence time for the drogues was estimated at 10-14 days, equivalent to the average hatching time for haddock eggs, so the advection and dispersion of eggs and larvae may have important implications for survival and subsequent recruitment. Unfortunately, attempts to model the drogue trajectories using a 2-D barotropic model with wind and tidal forcing (Page and Smith, 1989) have been largely unsuccessful due to: 1) poor resolution and 2) the absence of baroclinic effects. In addition, model- derived interannual differences in particle displacements from the Bank during the spawning season could not be consistently related to gadoid egg and larval mortality (Campana *et al.*, 1989), but better baroclinic models are required before any biophysical conclusions may be reached.

Finally, the recent Georges Bank Frontal Study (Loder *et al*, 1988b) is providing an unprecedented, detailed picture of the physical processes occurring along the Bank's northern edge, while accompanying biological measurements promise to enhance our understanding of the ecosystem. In particular, repeated Batfish sections across the Bank edge indicate the formation of an internal hydraulic jump during off-bank tidal flow (Figs. 8-7, 8-8), and subsequent propagation onto the Bank as a packet of large-amplitude internal waves after the tide turns. This phenomenon considerably complicates the classical pictures of residual current *(e.g.,* Loder and Wright, 1985) and turbulence *(e.g.,* Garrett *et al.*, 1978) generation by the barotropic tidal current. In essence, the dynamics of the northern front on Georges Bank appears to be a combination of those of 1) a tidal-mixing front and 2) a tidally-forced stratified fluid at the shelf break. In addition, drifter measurements from the recent study suggest that there is a surface convergence at the front which, in conjunction with the along-bank jet, would distribute passive surface particles widely around the Bank, while retaining them in the frontal zone. The biological implications of these processes are presently under study. Clearly, however, understanding the biophysical interactions in this complex system requires consideration of both region-wide and local physics, including 1)

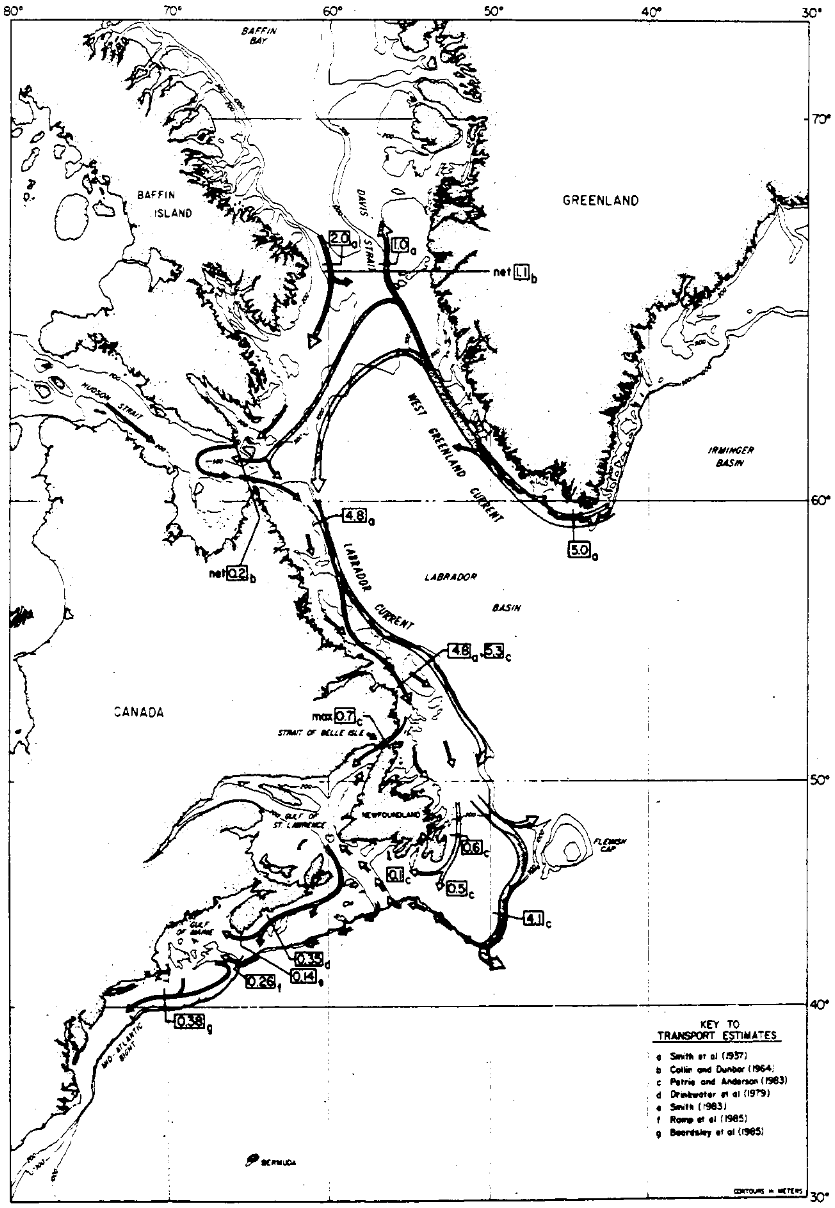

Fig. 8-3. Proposed circulation of coastal water from West Greenland to the Mid-Atlantic Bight. Broad arrows represent large surface currents; broken arrows are deep flows. Numbers in boxes represent transports in units of $10^6 m^3 s^{-1}$. (after Chapman and Beardsley, 1989)

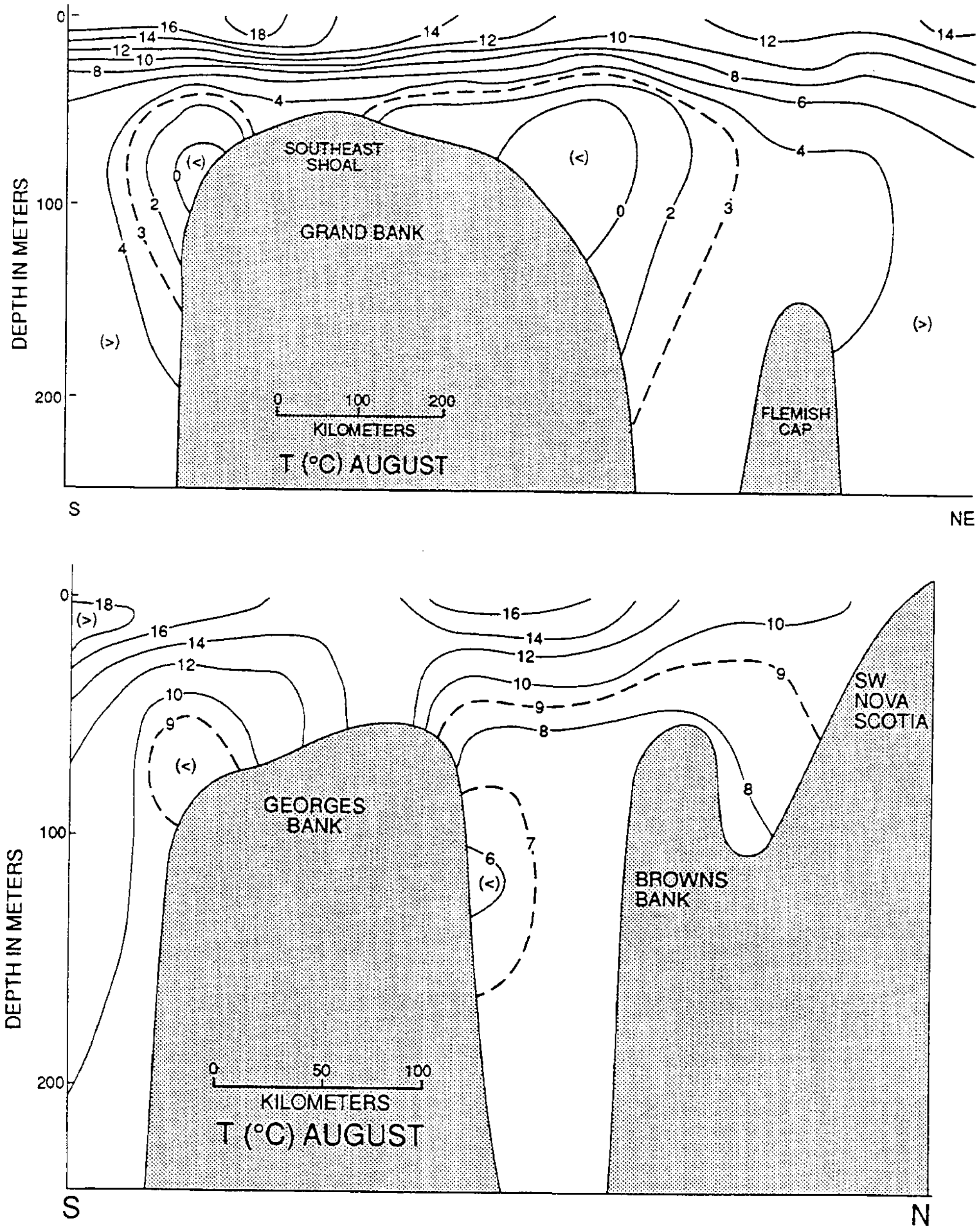

Fig. 8-4. Summer temperature structure over four submarine banks of eastern Canada. Note large differences in thermal stratification.

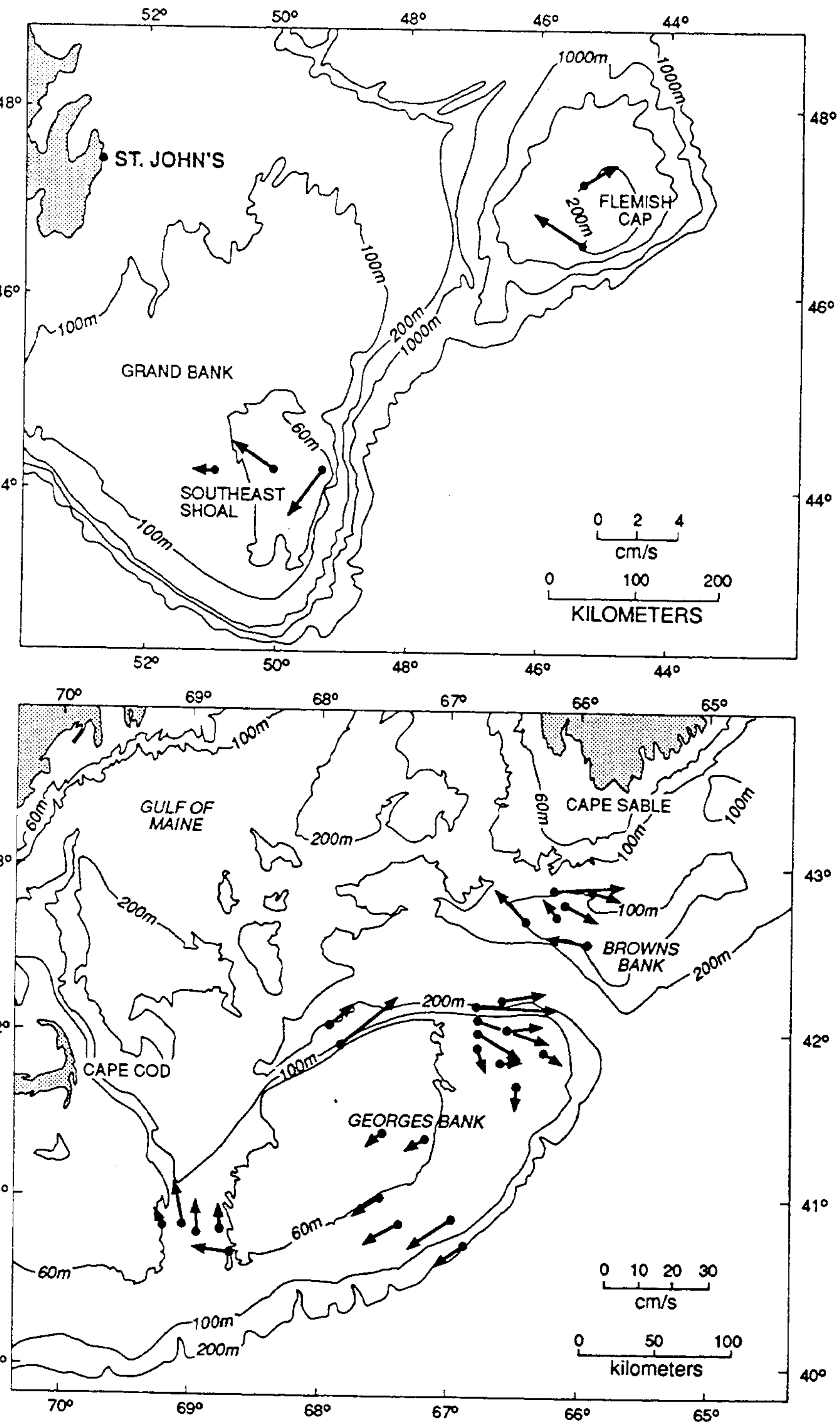

Fig. 8-5. Depth-averaged mean circulation on four submarine banks of eastern Canada.

an adequate thermohaline circulation model of the Gulf as a whole and 2) a careful representation of the physical processes in the vicinity of fronts and abrupt topography.

TABLE 1. Recent Multidisciplinary Experiments on the Northwest Atlantic Continental Shelf

EXPERIMENT	YEAR	BANK	TARGET SPECIES
Flemish Cap Int'l Exper.	1979-81	Flemish Cap	redfish, cod
S.E. Shoal Exchange Study	1986-89	S.E. Shoal	capelin
SWNS Fish. Ecol. Program	1983-85	Browns Bank	haddock, cod
Georges Bank Larval Herring Patch Study	1978	Georges Bank	herring
Georges Bank Frontal Study	1988	Georges Bank	lobster, scallop

8.5.1 References

Brooks, D. A. 1985. Vernal circulation in the Gulf of Maine. J. Geophys. Res. 90, 4687-4705.

Campana, S. E., K. T. Frank, P. C. F. Hurley, P. A. Koeller, F. H. Page and P. C. Smith. 1989. Survival and abundance of young cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) as indicators of yearclass strength. Can. J. Fish. Aquat. Sci. 46 (suppl. 1), 171-182.

Chapman, D. C. and R. C. Beardsley. 1989. On the origin of shelf water in the Middle Atlantic Bight. J. Phys. Oceanogr. 19, 384-391.

Garrett, C. G. R., J. R. Keeley and D. A. Greenberg. 1978. Tidal mixing versus thermal stratification in the Bay of Fundy and Gulf of Maine. Atmos.-Ocean 16, 403-413.

Loder, J. W. 1980. Topographic rectification of tidal currents on the sides of Georges Bank. J. Phys. Oceanogr. 10, 1399-1416.

Loder, J. W., D. G. Wright, C. Garrett and B.-A. Juszko. 1982. Horizontal exchange on central Georges Bank. Can. J. Fish. Aquat. Sci. 39, 1130-1137.

Loder, J. W. and D. G. Wright. 1985. Tidal rectification and frontal circulation on the sides of Georges Bank. J. Mar. Res. 43, 581-604.

Loder, J. W., C. K. Ross and P. C. Smith. 1988a. A space- and timescale characterization of circulation and mixing over submarine banks, with application to the northwestern Atlantic continental shelf. Can. J. Fish. Aquat. Sci. 45, 1860-1885.

Loder, J. W., K. F. Drinkwater, E. P. W. Horne and N. S. Oakey. 1988b. The Georges Bank Frontal Study: An overview with preliminary results. EOS 69, 1283.

Page, F. H. and P. C. Smith. 1989. Particle drift in the surface layer off Southwest Nova Scotia: Description and evaluation of a model. Can. J. Fish. Aquat. Sci. 46 (Suppl. 1), 21-43.

Perry, R. I., P. C. F. Hurley, P. C. Smith, J. A. Koslow and R. O. Fournier. 1989. Modelling the initiation of spring phytoplankton blooms: a synthesis of physical and biological variability off Southwest Nova Scotia. Can. J. Fish. Aquat. Sci. 46 (Suppl. 1), 183-199.

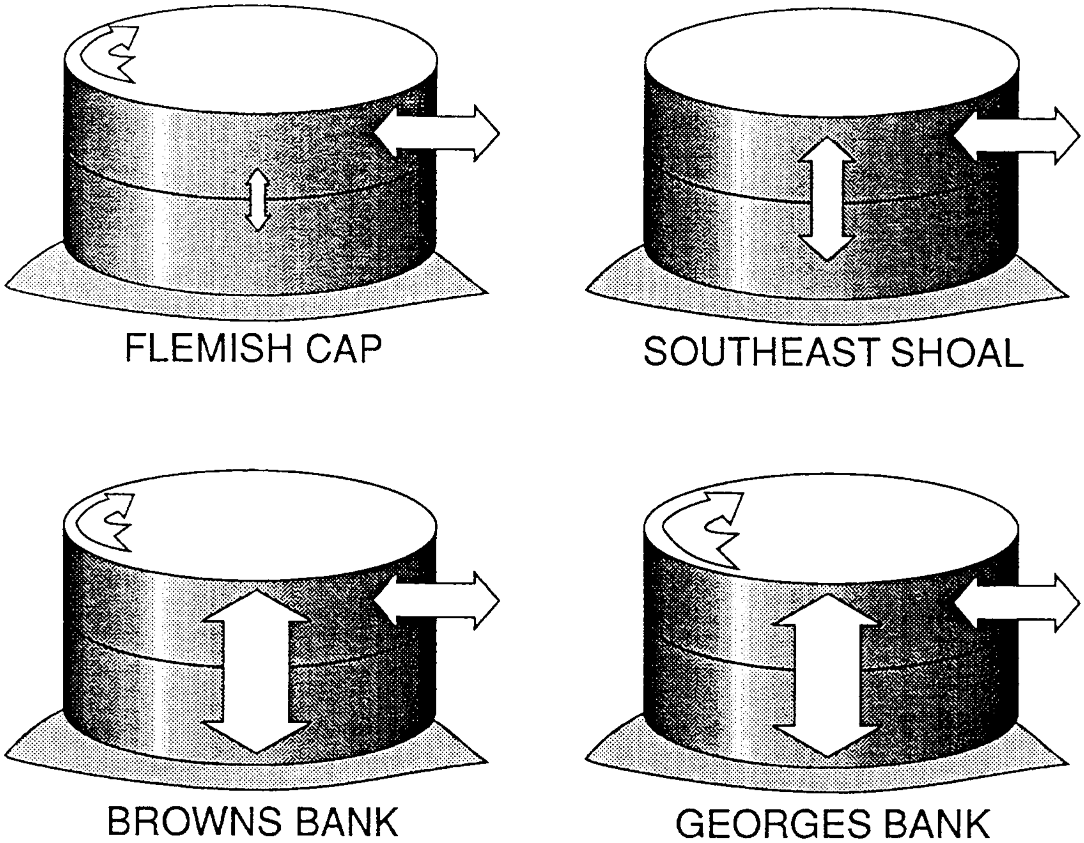

Fig. 8-6. Schematic summary of exchange rate time scales (T) for four submarine banks of eastern Canada. Arrow sizes are proportional to rate ($\propto T^{-1}$; see text).

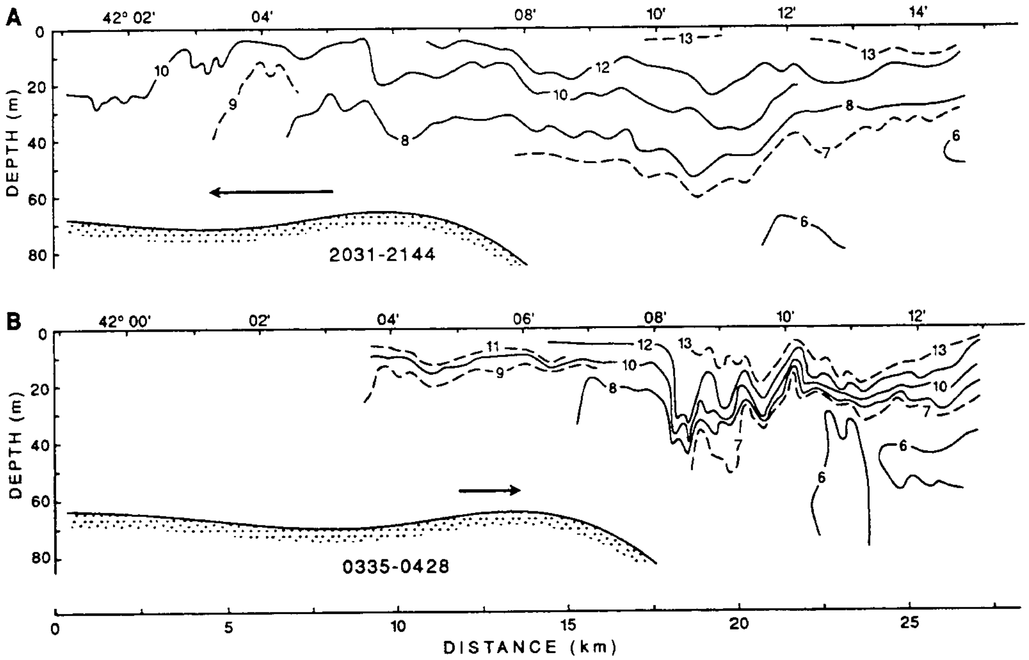

Fig. 8-7. Sequence of temperature sections on the northern flank of Georges Bank at various stages of the tide: a) on-bank flow, 2 July 1988; b) off-bank flow, 3 July 1988.

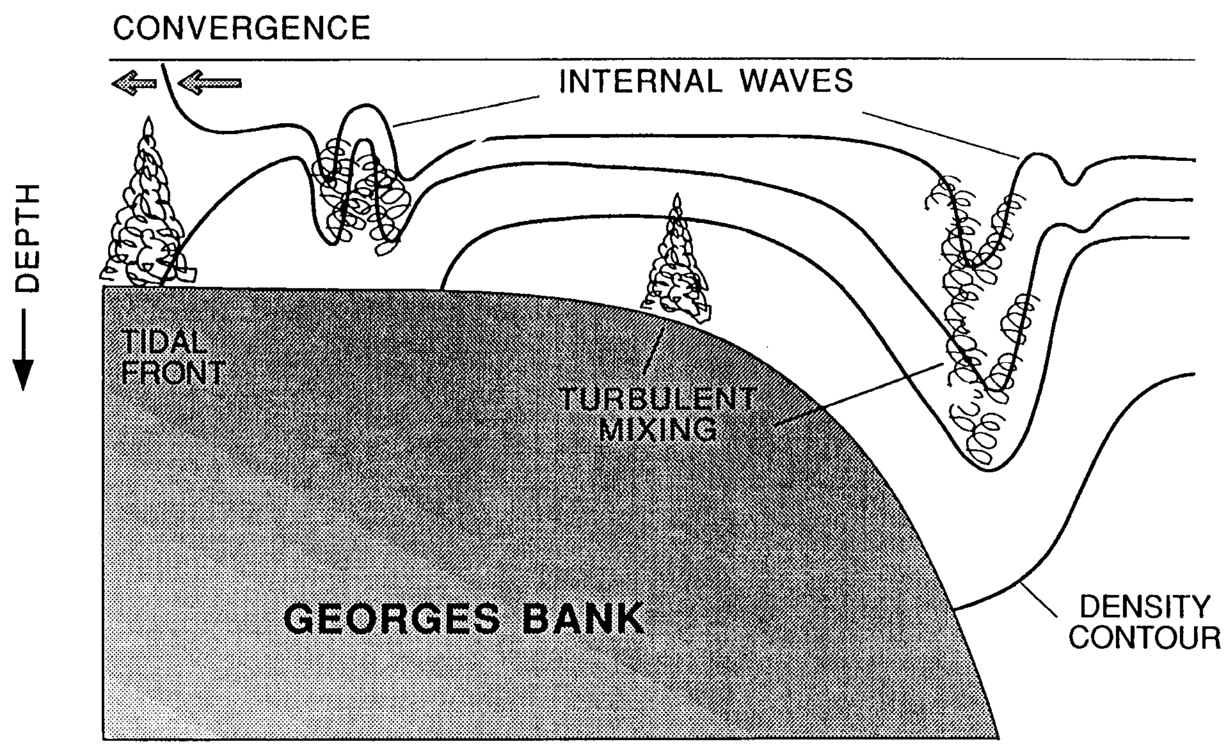

Fig. 8-8. Schematic diagram indicating the processes associated with the interaction of the tidal mixing front and shelf edge circulation on Georges Bank.

Smith, P. C. 1989a. Seasonal and interannual variability off Southwest Nova Scotia. Can. J. Fish. Aquat. Sci. 46 (Suppl. 1), 4-20.
Smith, P. C. 1989b. Circulation and dispersion on Browns Bank. Can. J. Fish. Aquat. Sci. 46, 539-559.
Smith, P. C. and F. B. Schwing. 1990. Mean circulation and variability on the continental shelves of eastern Canada. Cont. Shelf Res., in press.

8.6 Climate Variability and Fisheries in the Northwestern Atlantic

by Donald B. Olson

Recently there has been an increased interest in global changes and their effects on various components of the marine ecosystem *(cf.* Cushing, 1982; Schneider, 1989). Some of these changes on time scales of decades to millions of years are amply reflected in records kept by man or in the geologic record. An increasing awareness of how the earth's climate system works has also made us cognizant for the first time of the role man plays in determining climate. This has led to an ongoing debate as to whether or not man is setting up a serious threat to the climate system and therefore to our economic well being. The purpose here is to explore one facet of the relationship between climate change and one component of our global environment, the North Atlantic. The region and the targeted elements in the ocean ecosystem chosen reflect both the historical and geological record available in the North Atlantic and the existence of a long exploited ecosystem for which there is a reasonable set of background data on which to build a further understanding.

The influence of climate on marine populations which are also being heavily exploited by fisheries is a tough problem to quantify. It is doubtful that any attempt to assess the variations in population levels in terms of effects tied to environmental change versus fishing mortality can be successful without some further understanding of the fundamental processes involved with the dynamics of fish populations and their interaction with both the physical environment and the fishery. At the same time it is crucial to obtaining an understanding of population dynamics that both the natural and man-induced sources of population variation are considered. With this in mind it is worthwhile to consider the variations in stocks.

The variations in catch for a number of species of commercially utilized fish on Georges Bank is shown in Fig. 8-9. The extreme changes in catch reflect a combination of variations in species that fisheries target, the response of the populations to fishing pressure and variations in the environment. Fluctuations such as the peak in red hake catch in the mid-1970s can be attributed to changes in fleet deployments. Likewise the decline in cod and haddock in the late 1960s reflects fishing pressure. Survey cruises by NMFS, however, indicate that there have been major swings in year class strength which do not bear a direct relationship to fishing. The recovery of the cod and haddock for example follows a period of anomalously mild winters in the early 1970s. The effects of these winters and the transition to the harsh winters of 1977-78 show up clearly in long term weather records and in water masses throughout the Northwestern Atlantic (Talley and Raymer, 1982; Talley and McCartney, 1982). These changes are also reflected in large zooplankton standing stocks in 1973 which cannot be tied to the activities of the fishing fleets (Davis, 1987). The problem is to sort out the changes tied to climate variations, *i.e.* the physical signal itself and its manifestation in terms of the environmental needs of fish.

It is not the purpose of this portion of the report to consider approaches to the problem, but it is worth pointing out that the complexity of the issue demands a broad approach with a combination of techniques in the field, on the data archives and in both biological and physical models.

8.6.1 The North Atlantic Oscillation and related phenomena

The North Atlantic sector of the globe experiences the second highest amplitude variations in large scale interannual pressure patterns in the analysis of Wallace and Gutzler

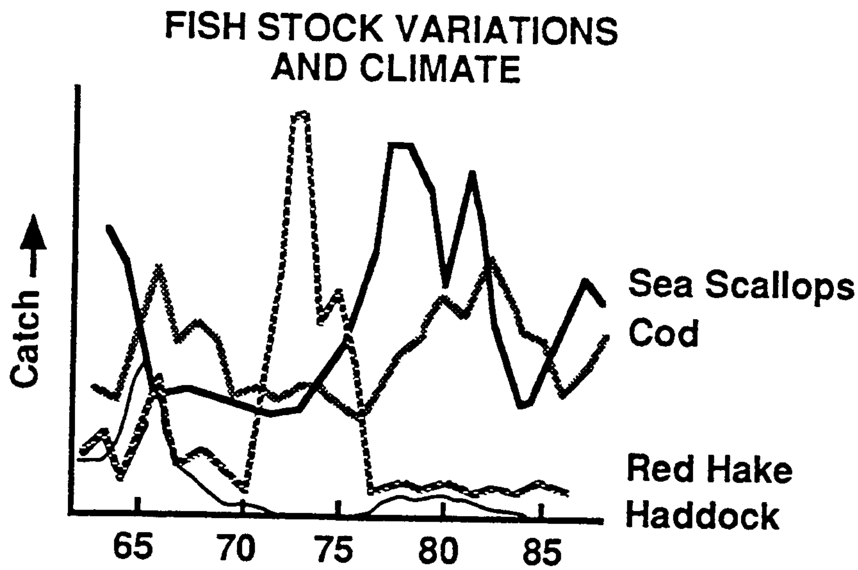

Fig. 8-9. Variations in commercial catches of economically important fisheries on Georges Bank, 1960-1989.

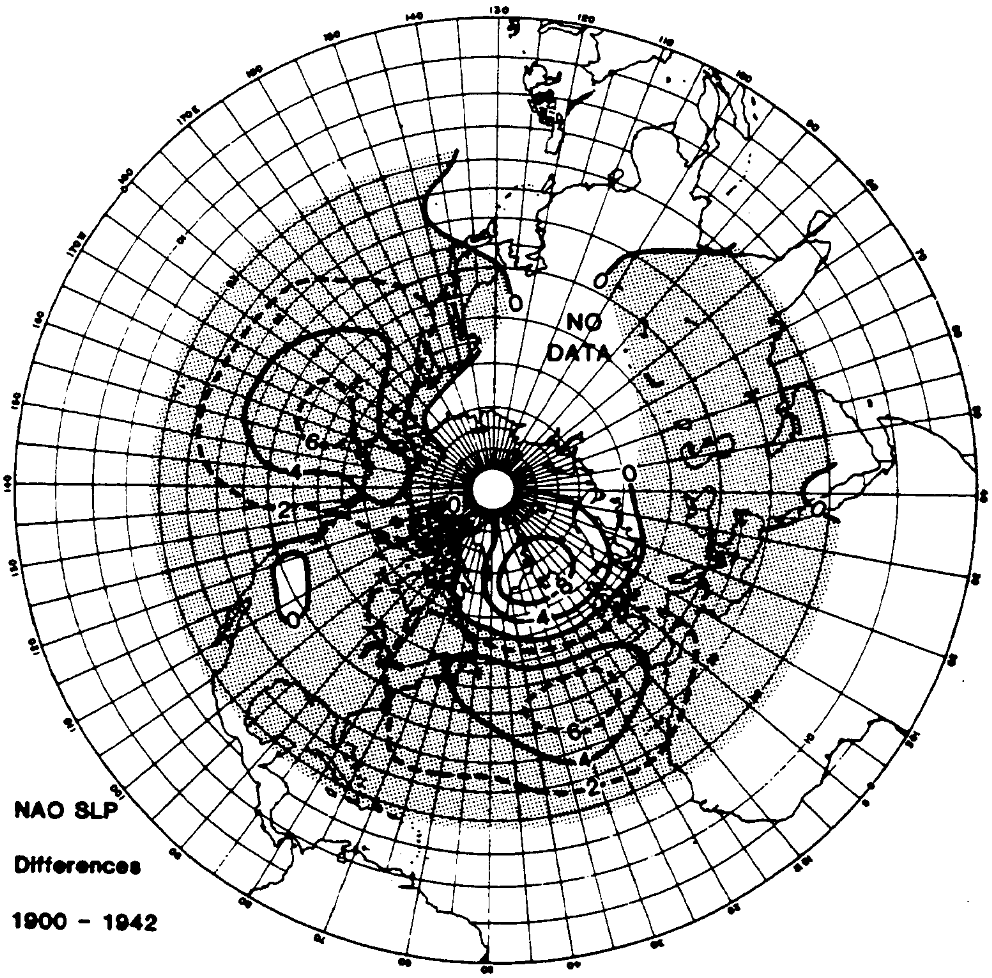

Fig. 8-10. The difference in sea-level pressure (mb) between winters from 1900 to 1942 when the NAO index is above and below normal (from Rogers, 1984).

(1981). These are somewhat more localized and oriented in more of a meridional alignment than the larger fluctuations observed as part of the El Niño/Southern Oscillation in the Pacific (ENSO, Philander, 1989). Like the Pacific Oscillation, the Atlantic variations are associated with a combination of sea surface temperature and atmospheric pressure anomaly patterns (Fig. 8-10). The variations are of longer time scale than those associated with ENSO (7.3 years, versus approximately six years for ENSO; Rogers, 1984) and have a less distinct pattern as compared to the El Niño cycle. Like ENSO they are thought to be tied to variations on much larger scales in the earth's atmosphere. In fact there is evidence that ENSO and NAO are correlated at periods of about six years although apparently not at longer periods based on the available data sets (Rogers, 1984). With the longer, less regular time scale of the North Atlantic Oscillation it is harder to differentiate it from longer term changes in the Atlantic sector.

The North Atlantic Oscillation was first described by Walker (1924) and Walker and Bliss (1932) as a see-sawing in surface pressures between the Azores and Iceland (Fig. 8-11). It is associated with fluctuations in wind strength across the entire North Atlantic and in sea surface temperature anomalies (Bjerknes, 1962; Rogers and van Loon, 1979). The slow decline in the NAO index in the late 1960s is correlated with marked changes in the 18^0C subtropical mode water at Bermuda (Talley and Raymer, 1982), the cessation of Labrador Sea Water formation (Lazier, 1981; Talley and McCartney, 1982) and a maximum in the extent of sea ice around Iceland (Lamb, 1977; Kelly *et al.*, 1987) and Newfoundland (Hill and Jones, 1990) in the late 1960s. This period in the late 1960s also saw the onset of a pronounced freshening of the sea surface which has been traced around the entire subpolar Atlantic over the decade and a half following the NAO minimum in the late 1960s (Dickson *et al.*, 1986). The overall connection between NAO, the sea ice which also involves interaction with the Arctic proper (and the solar cycle according to Hill and Jones, 1990) and the freshening of the subarctic Atlantic in the 1970-80s is still only partly understood. It is clear, however, that these changes in climate have profound effects on the marine environment and fisheries such as the cod. For example, there was a massive decline in the West Greenland cod fishery associated with the anomalous conditions around 1970 in the Labrador and Irminger Seas. In fact Koslow (1984) suggests that these conditions impacted cod stocks throughout the northwestern Atlantic. The exact relationship between climatic variables and cod stocks in this regard demands further study in order to understand the underlying mechanics behind these large scale covariations (Koslow *et al.*, 1987).

Part of the problem with isolating causal relations between large scale climate signals and local stocks involves differences in the manifestation of the NAO and other climate changes in various local regions. For example, the effect of the NAO on the Scotian shelf is quite different than what is expected off Iceland. Typically more localized analyses such as that by Thompson *et al.* (1988) of eastern Canadian sea surface temperature anomalies and their relationship to atmospheric variables isolate fluctuations on other time scales which further complicate the picture. The biotic responses, of course, are expected to change markedly throughout the range of a species like cod or zooplankters such as *Calanus finmarchicus* which is closely linked to cod throughout its range. Unraveling the complicated relationship between these organisms and climate variability demands both detailed consideration of the processes involved with their interaction and relationship to local physical conditions as w~ as attempts to glean more information for the historical data sets.

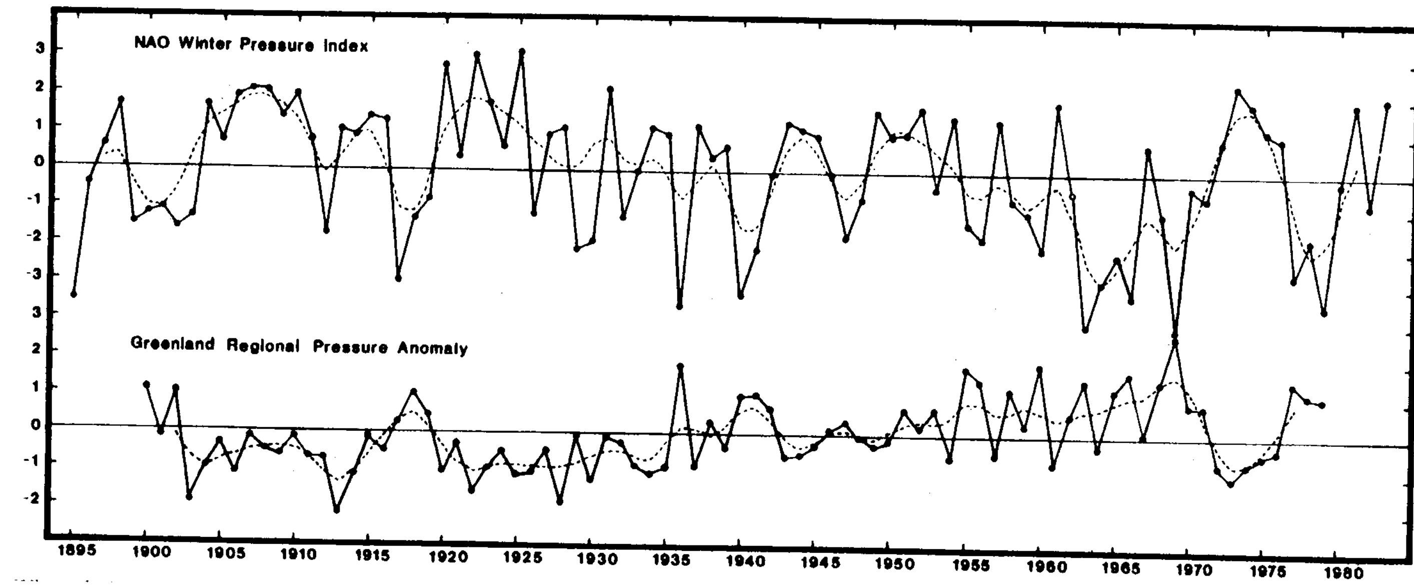

Fig. 8-11. Top: Winter index of the North Atlantic Oscillation (1895-1983) based on the mean normalized pressure difference between Ponta Delgadas, Azores and Akureyri, Iceland. Bottom: Normalized winter mean pressure anomaly for the region 60 – 70°N, 30 – 65°W from 1900 to 1979. Dashed lines represent smoothed data using a 1-4-6-4-1 low-pass filter (from Rogers, 1984).

8.6.2 Longer time scales

The effect of longer time scale climate changes is also of interest in terms of the North Atlantic ecosystem both because of the question of how the various fish stocks have evolved through time and as possible models for the impact of future climate change. The last million or so years have seen the globe proceed through a series of ice ages punctuated by warm interglacials similar to the one we are in now. At shorter time scales conditions have slipped between climate optima like that experienced approximately six thousand years ago to colder less clement periods such as the little ice age (1450-1850). The overall causal connection of the ice age cycles is thought to be the changes in the earth's orbital inclination about the sun or the so called Milankovich cycles (Ruddiman and McIntyre, 1981). This explanation requires some as yet poorly understood feedbacks from the physics of the atmosphere and ocean to account for the overall amplitude of changes associated with an ice age to interglacial transition. Likewise the smaller perturbations such as the little ice age are not well understood.

One clue to the possible dynamics of these swings in the earth's climate involves an interaction between the atmosphere-ocean system that seems to be a robust result of certain computer simulations of the system. This involves global atmosphere circulation changes and a switch between two states in the oceans' density driven or thermohaline circulation (Manabe and Stouffer, 1988). The center of these changes occurs in the far North Atlantic, which is the primary site for the formation of nearly all of the worlds deep water characteristics in our present climate state (Reid and Lynn, 1971; Gordon, 1986). At present deep waters are formed through air-sea interaction in the Norwegian, Greenland and Labrador Seas. It is known that the formation rate in these waters has varied on time scales as short as decades in the available hydrographic database (Talley and McCartney, 1982). These switches in deep water formation are tied to salinity anomalies similar to the freshening observed in recent decades in the North Atlantic (Lazier, 1980). Essentially the formation of a layer of fresh, low density waters, known as polar water on the sea surface causes a cessation of deep convection associated with cooling and salinity increases in surface salinity. The salinity changes in the deep ocean are also reflected in the salinities in the Labrador Current, which affects the coastal regime as far south as Georges Bank.

Interestingly, models such as the GFDL (Geophysical Fluid Dynamics Laboratory of NOAA) global climate model are prone to the onset of a complete cessation of deep water formation (Manabe and Stouffer, 1988). Such an alternate model state can exist with initial conditions that vary only slightly from those which set up a global ocean-atmosphere system very close to that observed today. Manabe and Stouffer (1988) suggest these two possible climate states are at least qualitatively similar to the conditions associated with variations between the little ice age and today's climate and very possibly the difference between glacial and interglacial periods. Long term trends in state of the art climate models suggest that the ocean-atmosphere system is fundamentally susceptible to climate oscillations (Bryan, 1986).

The changes in conditions evident from direct observations, the geological record and model simulations all suggest large shifts in fisheries potential within the North Atlantic ecosystem. At the ice age extreme the habitat for cod was probably greatly compressed in latitudinal extent and viable local space because of the combination of sea surface temperature and salinity changes and the hundred meter drop in sea level that put areas such as Georges Bank and much of the Scotian Shelf above sea level. The fairly abrupt changes between glacial and interglacial periods with the accompanying fresh water surges through the Mississippi and St. Lawrence Rivers (Broecker *et al*, 1989), and sea level rise represent large short time scale swings in demersal habitat and probably eventually a wide expansion of the species such as cod to fill the expanding niches. The time scales for these changes are such that they sit between the time required for speciation and the shorter time frame adaptations in physiology and behavior through which a species can acclimate itself to global change.

An approach to the longer time scale issues in North Atlantic climate change requires a better understanding of the present ecosystem and its response to variations in physical forcing and an exploitation of models as well as a study of the full historical and geological record. Therefore, advances on the longer term question of the evolution of the ecosystem will be made through process oriented investigations aimed at shorter time frame questions. There should also be some consideration of the longer term aspects with a focus on the crucial multidisciplinary tools required for progress on reconstructing transitions associated with ice age cycles and anomalous periods such as the little ice age.

8.6.3 References

Bjerknes, J. 1962. Synoptic survey of the interaction of sea and atmosphere in the North Atlantic. Geofysiske Publik., 24, 115-146.

Broecker, W. S., M. Andree, W. Wolfli, H. Oeschger, G. Bonani, J. Kennett, and D. Peteet 1988. The chronology of the last deglaciation: implications to the cause of the Younger Dryas event. Paleooceanography, 3, 1-19.

Bryan, F. O.1986. High latitude salinity effects and interhemispheric thermohaline circulation. Nature, 323, 301-304.

Cushing, D. H. 1982. Climate and Fisheries. Academic Press, London, 373 pp.

Davis, C. S., 1987. Zooplankton life cyclies. In: Georges Rank, R.H. Backus, ed., MIT Press, Cambridge, 256-267.

Dickson, R. R., J. Meincke, S.-A. Malmberg and A. J. Lee, 1986. The "Great Salinity Anomaly" in the northern North Atlantic 1968-1982. Prog. Oceanogr., 20, 103-151.

Gordon, A. L., 1986. Interocean exchange of thermocline water. J. Geophys. Res., 91, 5037-5046.

Hill, B. T. and S. J. Jones, 1990. The Newfoundland Ice extent and the solar cycle from 1860 to 1988. J. Geophys. Res., 95, 5385-5394.

Kelly, P. M., C. M. Goodess, and B. S. G. Cherry. The interpretation of the Icelandic sea ice record. J. Geophys. Res., 92, 10835-10843.

Koslow, J. A., 1984. Recruitment patterns in Northwest Atlantic fish stocks. Canadian J. Fish Aquatic Sci., 41, 1722-1729.

Koslow, J. A., K.R. Thompson and W. Silvert 1987. Recruitment to northwest Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeqiefinus*) stocks: Influence of stock size and climate. Can. J. Fish. Aquatic Sci., 44, 26-39.

Lamb, H. H., 1977. Climate, present, past and future. Volume 2. Methuen, London.

Lazier, J. R. N., 1980. Oceanographic conditions at Ocean Weather Ship Bravo, 1964-1974. Atmosphere-Ocean, 18, 227-238.

Manabe, S. and R. J. Stouffer, 1988. Two stable equilibria of a coupled ocean-atmosphere model. J. Climate, bf Vol. 1, 841-866.

Philander, G.S. 1990. El Niño and La Niña, and the southern oscillation, Academic Press, San Diego, 293 pp.

Rogers, J. C., 1984. The association between North Atlantic oscillation and the southern oscillation in the Northern hemisphere. Mon. Weather Rev., October, 1984, 1999-2015.

Rogers, and H. van Loon 1979. The seasaw in winter temperatures between Greenland and northern Europe. Part II: Some oceanic and atmospheric effects in middle and high latitudes. Mon. Wea. Res., 107, 509-519.

Ruddiman, W.F. and A. McIntyre, 1981. Oceanic mechanisms for amplification of the 23,000-year ice volume cycle. Science, 212, 617-627.

Schneider, S. H. 1989. Global Warming. Are we entering the Greenhouse Century? Sierra Club Books. San Francisco.

Talley, L. D. and M. S. McCartney, 1982. Distribution and circulation of Labrador Sea Water. J. Phys. Oceanogr., 12, 1189-1205.

Talley L. D. and M. E. Raymer, 1982. Eighteen degree water variability. J. Mar. Res., 40, 757-775.

Thompson, K. R., R. H. Loucks and R. W. Trites, 1988. Sea surface temperture variability in the shelf-slope region of the Northwest Atlantic. Atmosphere Ocean, 26, 282-298.

Walker, G. T., 1924. Correlations in seasonal variations of weather, IX. Mem. Ind. Meteor. Dept., 24, 275-332.

Walker, G. T. and E. W. Bliss, 1932. World weather. V. Mem. Roy. Meteor. Soc., Vol. 4, 53-84.

Wallace, J. M. and D. S. Gutzler 1981. Teleconnections in the geopotential height field during the Northern Hemisphere winter. Mon. Wea. Rev., 109, 784-812.

9 WORKING GROUP REPORTS

9.1 Fish Working Group Report

Chairman: Steve Kerr

Rapporteur: Jake Rice

The Fish Working group used a Draft Proposal for a study on Georges Bank as a starting point. The general objective of the proposal, as presented by Ed Cohen of NMFS, was to relate changes in cod and haddock larvae to temporal variability of vertical stratification on the Southern Flank of Georges Bank. Major components of the study proposal included:

- Moored oceanographic instruments to measure the development and dynamics of vertical stratification.
- Sampling of cod and haddock larvae (and zooplankton of similar size) using MOCNESS and hydroacoustics.
- Measurement of growth and condition of larvae.
- Target position is 80 m isobath.
- Target time period should include May.
- Study should cover periods of stormy and "quiet" weather.

The Working Group concurred all components of the study were appropriate, and the survey design was sound, to the extent it was presented. A number of suggestions were made to expand the scope and scale of the study, consistent with objectives of GLOBEC and CCC. Specific augmentations include:

- Study and sampling to relate the duration and intensity of stratification to:
  (1) length of the food chain
  (2) flux of particulate matter from surface to bottom. Both would enhance the trophic context of the study.
- Increased modeling of the physical oceanography, focusing particularly on:
  (1) dynamics of the South Slope (esp. advection).
  (2) more forcing functions (esp. storm events).
- More paleoecological studies including:
  (1) quantification of fish remnants (scales, otoliths, etc.)
  (2) stable isotope ratios; etc.
- Possible additional site on Georges Bank, where the physics differ in known ways.
- Include horizontal and tidal mixing dynamics with the vertical stratification dynamics.
- Comparative studies on other banks where the proximity of stratified and mixed waters is different. (It was suggested Georges Bank may be atypical, with the upper layer nutrient levels augmented from adjacent mixed waters.)

The discussion of Cohen's proposal evolved into a more general discussion. From the wide-ranging comments several general suggestions emerged. These should outline general areas of priority research, and guide development of additional specific proposals in many contexts, including both GLOBEC and CCC.

It was acknowledged that to evaluate marine aspects of global change we require a much more in-depth picture of the physics of all banks, to establish a background for any other work. the physical studies should focus on several factors, including:

- Mechanisms of retention and export on the banks.
- Sites of retention and export on the banks.
- The role and frequency of episodic events (storms).
- Features of transport, including how much, where, and when within the year.

The Working Group concurred that it was important to consider the effect of global change on the total energy in the ecosystem (a concept discussed by Louis Legendre, among others, recently). Questions within this context would include:

- What are the dissipative mechanisms in the system?
- What are the concentrating mechanisms in the system?
- How will those mechanisms change in magnitude?
- How will those mechanisms change in position?

No specific studies were proposed within this total energy framework, but the framework should be considered carefully in planning any global change studies in marine systems.

The Working Group suggested researchers consider any study of marine consequences of climate change in the context of another set of questions. One should ask if global change will produce:

- The same events as in recent history, but in different places in the bank/shelf, etc.
- The same events as in recent history, but at different times within the annual cycle.
- The same types of events, but of greater or lesser magnitude.
- Different events.

The Working Group then had a long discussion of the gaps in understanding of the effects of global change on adult fish. Although discussions commonly settle quickly into studies of early life history and recruitment processes, adults may be affected in many ways, and most processes are poorly understood, poorly quantified, and poorly modeled. It was noted that work planned by OPEN will address many of these problems, but additional work is appropriate. Among the foci for future directed research are:

- Studies of stock structure, to delineate the populations to be studied. Studies on Georges Bank should be a priority. Many of the new molecular and biochemical techniques should be explored. These may provide many insights beyond basic questions of stock structure.
- Studies of the direct effects of temperature on many biological processes, such as growth rate, seasonal energy budgets, and stage duration of life history stages.
- Studies of overwintering energetics are especially needed. It is important to separate the environmental and heritable components of growth rate for stocks, given the noteworthy differences in growth rate observed for many fish stocks.
- Studies of how global change may alter food and feeding patterns. The prey spectrum may change, and should be quantified. Growth efficiency varies with type of food. This must be quantified for various stocks, and the balance of prey of different

quality needs to be considered in global change models. Research should address the question of whether changes in net productivity will keep up with the changes in physiological requirements.

- Research is needed to quantify the "growth window" (the period of rapid feeding and growth in most cod stocks in summer), and how it will be extended and moved in time by global change.
- Much knowledge needs to be systematized into models. Development of a full annual energy budget of cod is needed urgently.
- Commercial fisheries have marked effects on the population dynamics of many stocks, including all cod and haddock stocks. These effects must be included in meaningful models, but many consequences of fishing pressures on fish biology are poorly known.
- Research is needed to determine exactly what features (presumably physical, but not necessarily only physical) characterize spawning sites of the species of interest. Research is then needed to determine the mechanisms used by adults to find these spawning sites; the mechanisms and/or cues used by adults to aggregate the sites; and the retention mechanisms for other stages which may be present at the sites.
- Research is also needed on the basic temperature preferences and tolerances of cod (and other fish) and the behavioral mechanisms used to select and maintain position in water masses of particular characteristics. Features which must be considered include absolute vs. relative temperature selection, and importance of temperature profile vs. simply bottom temperature (the usual variable considered in studies). Features of the water masses other than temperature should be reviewed, including but not restricted to salinity.

The Working Group acknowledged that there are many excellent data sets on fish populations; many extending for decades, some for centuries. These data sets are often collected for specific purpose, usually stock assessments, and are greatly underutilized for other purposes, including global change impacts. Major analysis projects should be initiated to make more use of these historic resources. Candidate projects include:

- The degree to which Sequential Population Analyses smooth yearclass variation. This has been shown to occur, but to unspecified degrees, for most stocks. If year-class variation is smoothed by SPA, individual population estimates will be poor data for examining linkages between population and environmental attributes.
- What is the true measure of spawning output (spawning biomass? egg production?) and how is it related to recruitment levels?
- How far can one hindcast the physics and biology from existing data sets of catches and temperature records which may be long, but of uneven or unknown quality?
- The research vessel surveys for groundfish have been conducted for decades on every bank from New York Bight to Northern Labrador and Greenland. Methods are quite comparable among most surveys, and individual surveys are usually highly consistent. These data are invaluable, and should be analyzed much more comprehensively. In particular, they should be used to investigate how the pattern of aggregation varies with time, stock size and oceanographic conditions, and much more extensive use should be made of the oceanographic data collected on most of these surveys. Rarely are more than bottom temperatures analyzed, although profiles are often collected. Even bottom temperatures are usually examined as only absolute temperature, and the regime from which the fish select sites is rarely considered. The

Working Group RECOMMENDS that a Working Group be established with scientists from the entire Atlantic coast, to ensure that appropriate and comprehensive analyses of these data are conducted, and the analyses be done with proper statistical tools consistently for data from New England to Greenland.
- Many additional historical data sets of fish populations and oceanographic attributes exist. Data "archaeology" should be done to evaluate the quality of these data, and make good data sets available to the scientific community.
- Much has been learned from the small amount of work done on marine paleoecological cores. More of this work should be done.

The Working Group concurred that bottom substrate was important to many (probably all) life history stages of fish, as it is to benthos. Substrate characteristics are also poorly known for most areas. Research is urgently needed for to quantify substrate attributes on meaningful spatial scales. Then studies are needed to establish and quantify the linkages of the substrate attributes to each life history stage of fish. This quantification is important in the global change context both as a covariate (so data can be interpreted in meaningful ways), and because substrate characteristics may be altered by global change processes (altered erosion, deposition and sedimentation regimes).

The Working Group also reviewed technological needs from the fish study perspective. Many deficiencies were noted in both hardware and software tools. Among the requirements are:

Hardware:

- Fast, affordable tools for biogeochemical analyses of cores.
- Tools for rapid quantitative analyses of plankton samples and hydroacoustic signals.
- Image analyses systems for many purposes, especially for sorting, identifying and quantifying plankton samples.
- More research and development on all aspects of hydroacoustics. Determining absolute abundance, and automated species identification from hydroacoustic signals are urgent needs.

Software:

- Better use of quantitative experimental design theory and practice in research projects.
- More software for processing of the huge amounts of data collectable with hydroacoustics.
- Statistical tools are inadequate for relating the multidimensional patterns in the biology and physics data sets. Processes are nonlinear, have thresholds, plateaus, asymmetries, and many other characteristics which are handled very poorly by commonly used regression-based statistical tools.
- Uncertainty is handled very poorly by most quantitative tools in both fisheries and physical oceanography. This must be improved before any model predictions can be subjected to meaningful quantitative tests.

The Working Group concluded with a second wide-ranging overview discussion. Three other general points emerged, the first two with relevance to the entire GLOBEC/CCC community. We need much more efficient methods to mobilize the existing data in every discipline, and produce data products which will be useful to other disciplines, as well as the specialists in one field. We need much more efficient ways of getting experts from diverse disciplines to come together often, and to work together. Finally the group agreed it would be necessary, at some point, to quantify the predators on, and prey of, fish larvae, juveniles, and adults; and the population dynamics consequences of the predator-prey interactions. That is not going to be an easily tractable problem.

As the Working Group adjourned, it agreed to RECOMMEND to the GLOBEC Steering Committee that it develop many of the general observations in this report into specific recommendations for Working Groups or other fora to ensure experts come together to proceed further with the work outlined in this report.

9.2 Benthos Working Group Report

Chairman: Charles Peterson
Rapporteur: Robert Mohn

(1) There was a consensus that processes affecting the larval life stage up to and including the time of settlement represent the largest gap in our understanding of population dynamics and quantitative demography of benthic invertebrates.
(2) Principal attention should be focused on the larval (meroplanktonic) life stages.
(3) The Working Group was pessimistic about the chances of being able to follow a cohort of scallop larvae in time and space sufficiently closely to draw inferences about what controls survivorship.
(4) We debated over the rationale for choosing study species: although the sea scallop can be justified by the existence of a historical data base and ongoing prerogatives for continuing fisheries assessments and research, as well as an OPEN focus, it would be wise to choose a species on the grounds of selecting the best study system to address the problem. In this instance, that might be a highly localized, synchronous, predictably heavy spawner whose larvae were orange and naturally fluoresced. A proposal that discovered such a beast and proposed it as the focus of study would have much merit.
(5) The best use of support to study the impacts of physical processes, direct and indirect, on larval ecology of benthic invertebrates would be to build a set of fundamental contrasts that could allow some extrapolation and prediction. Specifically, a) holoplankton vs. meroplankton; b) feeding vs. non-feeding larvae; c) phytoplanktivorous vs. zooplanktivorous larvae; d) long vs. short planktonic period (6 vs. 3 weeks); e) spawning season (spring vs. fall); f) strong vs. weak swimmers.
(6) Field observations on how these types (from #5 above) compare in their responses to physical features and processes should be complemented by experimentation *in situ*, on shipboard, or in the laboratory to: a) test behavioral responses of larvae to changing stimuli; b) test for food limitations; c) address effects of predators.
(7) Scallop larvae should be included in this group (#6) and a modest effort devoted to a population dynamics study of sea scallops, dovetailing with the studies of scallop settlement and early juvenile survival in OPEN.
(8) Larval ecology field studies should be co-ordinated with the zoo-plankton and ichthyoplankton studies to set an appropriate sampling design as dictated by physical oceanographic considerations.
(9) Specific physical processes and conditions of likely importance to population dynamics and likely to vary as a function of climate change should be explicitly identified. Explicit sampling, both physical and biological, with specific hypotheses, should be conducted, with emphasis on features and processes such as a) fronts of different types; b) stratification - mixing; c) advective regime and its forcing; d) tides; e) storms; f) wind field; g) temperature change; h) fresh water input; i) mediating variables of primary production, competitors, predators.
(10) Critical need for technology development or device to quantify larvae of a few species by species (using perhaps immunology or some other biotechnological tool)
(11) Equipment need for automatic larval sampler (fixed mooring)
(12) Additional effort needed on benthic habitat (physical and biological) associated with juvenile cod, focusing on prey of cod, whether they are limited, etc.

(13) In this connection, the Working Group recommends a study of how other groundfish (especially elasmobranchs) affect cod dynamics, including interactions mediated by their joint influences on benthic prey

(14) Much interest exists among benthic biologists of Atlantic nations (especially US, Canada, France) in determining how benthic boundary layer dynamics influence growth and production of benthic animals, especially commercially important shellfish. If physical dynamics (bottom boundary currents, shear stresses, sediment dynamics, etc.) could be somehow related to global change with a sensible model, a major GLOBEC program could be generated addressing this issue.

9.3 Zooplankton

Chairman: Charles H. Greene
Rapporteur: Stephen Bollens

9.3.1 Context

GLOBEC will attempt to understand how physical processes affect the dynamics of animal populations in the ocean. Such an understanding is essential to predicting the consequences of changing physical processes on animal populations in the context of global change.

9.3.2 Target species

Although there are numerous zooplankton species worthy of intensive study on Georges Bank, *Calanus finmarchicus* was chosen as the target species for zooplankton investigations during the GLOBEC field program. This species was chosen for the following reasons:

(1) It dominates the zooplankton biomass on Georges Bank during the winter/spring;
(2) Congeners often dominate the zooplankton biomass in other boreal and cold-water temperate ecosystems during the winter/spring;
(3) It is an important prey item for the larval and pelagic juvenile stages of commercially important cod, haddock, and herring;
(4) More physiological and ecological studies are available for the genus *Calanus* than for any other zooplanktonic taxon;
(5) Reasonably good historical data sets are available for *Calanus* on Georges Bank (however, there is some confusion with regard to *C. finmarchicus* and *C. glacialis* in these historical data sets).

9.3.3 Field program objectives

The primary objectives of the field program are the following:

(1) To examine the demographic processes of birth, growth, and mortality of *Calanus* in the context of physical transport processes on Georges Bank and
(2) To examine the exchange processes between Georges Bank and adjacent deep waters (Gulf of Maine, Slope Waters) with regard to *Calanus'* population ecology on the Bank.

9.3.4 Field program approaches

The field program envisioned by the group will consist of three basic elements:

(1) survey cruises,
(2) process-oriented cruises, and
(3) biological/physical moorings.

Where possible, attempts will be made to coordinate these efforts with the OPEN and other relevant field programs. It was suggested that cruises should be scheduled primarily in the first and third years of the program, with moorings operating throughout the duration of the program. The reasoning underlying this approach was that it would enable the research community to plan appropriate studies in year three based on analyses of data from cruises in year one and moorings in years one and two.

9.3.5 Survey cruises

Survey cruises will cover a grid extending over the whole Bank out to approximately the 100 m isobath. In addition, several cruise tracks out to the deep basins of the Gulf of Maine and the slope waters to the south will be conducted to study exchange processes and other factors regulating *Calanus'* winter/spring excursions onto Georges Bank.

Data sets to be collected on survey cruises might include the following:

- Vertical distribution, abundance, and physiological condition of *Calanus*
  - (1) stage distribution
  - (2) size (length, mass) distribution
  - (3) physiological and molecular genetic indicators *(e.g.,* lipid content, gonad development, RNA/DNA ratio, gut fluorescence, digestive enzymes, allozymes, mitochondrial DNA)
- Vertical distribution and abundance of food
  - (1) phytoplankton
  - (2) microzooplankton
- Vertical distribution and abundance of predators
  - (1) invertebrate predators
  - (2) fish predators
- Physical properties - Vertical profiles of
  - (1) salinity
  - (2) temperature
  - (3) light transmittance
  - (4) downwelling
  - (5) light
  - (6) current velocities

Six survey cruises will be conducted monthly from January until June. It was suggested that each will require 2-3 weeks of ship time to complete. It was further suggested that NOAA might be able to provide the necessary ship time for this component of the field program.

9.3.6 Process-oriented cruises

Additional cruises will be carried out to conduct process-oriented studies associated with *Calanus'* population ecology. Cruise tracks will be determined on the basis of early survey cruise results. Processes to be studied on these cruises might include the following:

- Egg production rates
  - shipboard incubations

egg traps

- Development, growth rates:
  shipboard incubations;
  Lagrangian "drift" studies
- Mortality, loss rates:
  shipboard predator-prey experiments;
  Lagrangian "drift" studies
- Physical dispersion - Lagrangian drifters

Four or five process-oriented cruises will be conducted between January and June. It was suggested that each will require about 3 weeks of ship time to complete. It was further suggested that UNOLS should provide the necessary ship time for this component of the field program.

9.3.7 Biological/Physical Moorings

Five biological/physical mooring sites were tentatively chosen for the Georges Bank field program (Fig. 6-1). Four mooring sites will be located on Georges Bank and one in the Gulf of Maine. The four sites on the Bank include one on the western edge adjacent to the Great South Channel, one on the northeastern corner, one on the southeastern corner, and one in the center. The central mooring will include one acoustic Doppler current profiler (ADCP) and a variety of hydrographic, bio-optical, and bioacoustical sensors (bio-sensors); the other three Georges Bank moorings will include five ADCPs and the biosensors. The Gulf of Maine mooring will be situated in Georges Basin. It will include an ADCP and the bio-sensors. Moorings will be deployed in the autumn of 1992 and maintained for three years. It is anticipated that moorings might be relocated or new ones brought on line as the field program progresses.

9.4 Population Dynamics Working Group Report

Chairman: David H. Cushing
Rapporteur: Pierre Pepin

At the meeting, our information from the primary groups was given informally by the members who happened to be present. With the written reports, the objectives of the three primary groups are stated more clearly. I now write the sort of conclusion we might have come to had our objectives been more clearly stated. I deal with the three primary groups and write a short synthesis.

9.4.1 Fish

Objective To study the changes in growth and numbers of cod and haddock larvae along the 80-100m isobath in May with respect to the vertical stratification. A cohort of larvae will be followed from the spawning ground and will be sampled at frequent intervals.

Method The larvae will be sampled in the whole water column and at frequent intervals of depth. Their growth will be estimated by changes in length, weight and by examination of the daily growth rings on the otolith (if possible). Such studies will be executed in the mixed water column before stratification and above and below the thermocline after it has become established. At the same time, numbers will be sampled above and below the thermocline to estimate survival under conditions of rich and poor food.

The fish larvae feed on *Pseudocalanus* and later on *Calanus.* The gut contents of the larvae and their gut evacuation rates should be measured. *Calanus* can be sampled at all stages with nets, but *Pseudocalanus* should probably be sampled by pumps or fairly large water bottles (John Nichols of the Lowestoft Laboratory has a paper in press on the mesh selection of plankton nets). It would be desirable to estimate the production of larval food so that larval growth can be matched to the quantity of food eaten.

The mortality of fish larvae will be estimated by Lagrangian drift experiments and by the decline in numbers produced. The real point here is that the latter could be successful if the sampling were very concentrated in space and time. In other words a cruise is not used to produce one observation on numbers, but as many as possible. It would also be desirable to estimate the changes in survival in the mixed water before stratification and below and above the thermocline after it has become established. Finally, we need to know the predators and their effect on the mortality or what are the components of loss, predation, advection and diffusion. I shall deal with the need for physical measurements more explicitly below.

9.4.2 Zooplankton

Objective The zooplankton group will study *Calanus finmarchicus* from January to June along the 80-100m isobath, in terms of birth, growth and death in the context of physical transport processes on Georges Bank. Particular attention will be paid to sizes, stages and genetic and physiological indicators in the vertical distribution.

Method Each of the monthly cruises should be arranged so that weekly samples of the population can be taken. The vertical distribution of calanids and food will be studied with respect to the onset of stratification. Growth should be studied to include the molting process and we should improve the present accent on exponential growth and on the use of the von Bertalanffy equation. Again, growth should be studied in the mixed water before stratification and both above and below the thermocline. The fecundity of the winter spawners should be studied in situ as well as experimentally. In addition to the proposals given, the rates of mortality should be studied in the evolution of the cohort and the rates obtained should be linked to the numbers of predators. This requires that the predators be properly identified.

9.4.3 Benthos

Objective The group will study the larval ecology of six contrasting groups, particularly in their response to physical features and processes.

Method Benthic spawners (but not scallops) occupy fixed positions and the diffusion of larvae from that area can be described with respect to physical processes. The problem is that larvae from a small patch will spread quickly and become lost. But those from a large patch could be followed till settlement and losses by diffusion and other physical processes to the settled patch could be estimated. The problem is to find the six species with large spawning areas.

Synthesis Let the zooplankton proposal be the core of the program and the other two primary groups fit into that scheme. Then the physical problems are twofold:

(1) To estimate the loss of calanids and fish larvae along their drift from their spawning ground, by advection and diffusion. At the same time the proportion retained might be estimated. Such loss rates due to physical causes should be studied with respect to the analogous loss rates due to predation.

(2) To estimate the growth of calanids and fish larvae in the mixed water before stratification and later above and below the thermocline. Such studies should be linked to the food available, *Pseudocalanus, Calanus* for the fish larvae and phytoplankton for *Calanus.* The onset of stratification should be described physically with a view to the construction of a general model.

What is the link with climatic change? It is assumed that the changes in recruitment to the stocks of cod, haddock and of *Calanus* are rooted in the early stages of the life history. Then we can only understand the links between recruitment and climatic change, if the population parameters in those early stages are described and understood.

There are many proposed studies not dealt with, which however will proceed. We have only picked those which bear on the population parameters which may in the future reveal the effect of climatic change on the cod, haddock, *Calanus* and some unspecified benthic organisms.

9.5 Physiological Rates Working Group Report

Chairman: Lewis Incze
Rapporteur: Patrick Walsh

9.5.1 Background

The objective of GLOBEC is to understand the influences of physical processes on population dynamics. These influences are mediated directly at the level of the individual by dispersion and by physiological and behavioral responses of the organism to environmental conditions and change. It was the charge of this working group to suggest those rates and responses most central to the achievement of GLOBEC's goals.

9.5.2 Criteria

In selecting physiological and behavioral processes to be emphasized, the following criteria were used.

Identify physiological and behavioral properties which:

- are sensitive to physical conditions and/or change;
- are indicative of the state of the individual; and
- will yield good returns for the level of effort invested in methodological developments.

Emphasize methods which:

- can be applied to small sample sizes, ultimately, to the individual;
- can provide for rapid sample processing, enabling quick turn around and large sample numbers; and can be taken to sea.

9.5.3 Priorities

Topics which fit the above criteria are listed below. Along with some are examples of potentially useful techniques which might be applied. The examples are tentative and are offered to stimulate thought. Recommendations for further consideration of techniques are given at the end of this section. Development of new techniques are especially needed for topics 1-4.

1. Measures of Physiological Condition. These include:

- General performance capabilities (e.g., locomotion);
- Egg production rates;
- Entrance to "diapause";
- Morbidity/low physiological capability.

Biochemical or molecular "proxies" for the above are desirable. For example, if an activity of a key metabolic enzyme can be calibrated with an organism's nutritional background or locomotory capability in the laboratory, then assays for the enzyme performed in the field could be used as an index of condition, instead of attempting to perform complex shipboard experiments. Proxies for egg production rates and for assessing "diapause" in copepod stages (e.g., C_{IV} or C_V of *Calanus finmarchicus)* are needed for the same reason and would have the same advantages. Levels of hormones or indicator molecules (e.g., yolk proteins), are possible candidates for these needs. Diapause is placed in quotes because it probably requires clearer definition for the copepods. The final entry is suggested because specific "low performance" indicator(s) should add to the precision of evaluating physiological condition in nature. To wit, a multiple enzyme approach (e.g., contrasting a and d) is thought to be better than one using a single enzyme only. Non-biochemical techniques, e.g., video monitoring *in situ,* would be useful for a number of applications and certainly would be essential for behavioral applications.

2. Measures of Growth Rates, Development Rates and Age. RNA/ DNA ratios have been applied with success to larval fish and are being developed for larval lobsters. Increases in sensitivity and ease of use of the assay should be encouraged, with the goal of analyzing single organisms of even smaller size (e.g., the larvae of benthic invertebrates). Assessment of developmental rate is a particular problem for crustaceans; the presence of enzymes associated with molting or other hormonal indices may prove useful in population studies. There are presently effective, though time-consuming, methods for aging larval fishes and bivalves. There is room for improvement, especially further automation, of sample processing and analysis for these organisms. There is virtually no known method that can be used with copepods. Past efforts with lipofuscin in fish have not yielded useful methods (Mullin and Brooks, 1988). Advances in biochemical techniques in recent years may warrant a revisitation of this problem from a different perspective.

3. Feeding Rates and Diet. Current methods are time-consuming considering the large number of observations needed to meet GLOBEC objectives for field studies. The development of instruments to observe or record feeding activity *in situ* would be extremely valuable. This would enable independent and undisturbed observations of a variety of organisms over time and with varying conditions. Methods which assess the consequences of feeding (e.g., a short- term grazing chamber or trap that captures fecal pellets) may be one solution. Knowledge of diet is essential to improving our understanding of ecosystem functions and responses. A variety of methods are available to assess dietary components *(e.g.,* immunochemistry, molecular biology, fatty acid composition). These presently could be used to assess simply presence or absence; however, attempts could be made to improve the facility of assays and to extend methods to enable quantification of items. Added benefits of these biochemical/molecular approaches might be in taxonomy, for instance with the complicated *Pseudocalanus* spp. problem. Another application may be in rapid sample sorting and identification. Expanded use of these techniques will prove invaluable in predation studies at higher trophic levels as well.

4. Mortality Rates for Populations. Innovations are needed. The traditional method has been to assess changes in abundance of organisms over time after accounting for dispersion and new individuals recruited during the intervening period. Measures of physiological condition (performance/morbidity) and knowledge of predators and predation rates should increase confidence in estimates of population mortality rates. That is, empirical and mechanistic estimates should be coupled.

5. Bioenergetic/Metabolic Functions. These are essential inputs to mechanistic or deterministic population models. They are undertaken in the study of most marine organisms and are parts of many ongoing studies. Comprehensive measurements and models should be encouraged with the objective of predicting physiological states from physical parameters.

6. Behavioral Preferences. Certain behaviors of planktonic, settling and post-settlement stages need to be studied to predict organism preferenda and responses to physical conditions and change. Vertical distribution and benthic site selection are among the behaviors of interest. Potential consequences of behavioral responses include growth, feeding and predation. Such things as temperature, turbulence, food, predators, and substrate type are among the environmental variables of concern.

9.5.4 Conclusions

1. Zooplankton Research This community has for years recognized the need for improved methods for some of the topics outlined above and has recognized the potential value of some of the possible solutions listed. Development of applications in this field has lagged behind the developing technology, however. GLOBEC must address this deficiency, at least for some of the most important rates. This will not only be critical for our own project goals, but will have tremendous benefits to the marine science field in general. We must recognize that some applications are needed immediately and will probably, at least initially, require "quick and dirty" approaches. Regardless, the long-term perspective should not be overlooked as a needed investment in biological oceanography.

2. Biological Oceanography Most biological oceanographers do not have a good working knowledge of the developing techniques in biochemistry and molecular biology that may benefit them. To address this, GLOBEC should take the following two steps.

- Convene a workshop of biochemists/molecular biologists/geneticists with a small group of biological oceanographers to discuss the most promising techniques for oceanographic applications. The above goals and both short and long time-frames should be considered. A list of methods and areas for development should result.
- After the above, consider supporting a classroom short-course of techniques and ideas. The course would be advertised and open to the community at large. The format of such a course might be prescribed by the above workshop participants.

These two actions should put biological oceanographers in a much better position to forge collaborations and proposals to work with appropriate biochemical/molecular scientists on certain GLOBEC problems.

References

Mullin, M. M. and E. R. Brooks. 1988. Extractable lipofuscin in larval marine fish. Fish. Bull. U.~. 86: 407-415.

9.6 Field Sampling/Technology Working Group Report

Chairman: Rick Pieper
Rapporteur: Ed Cohen

A key aspect of the discussions of the Field Sampling/Technology Working Group was the importance of recognizing that after an initial period of intensive ship based survey work *(i.e.,* for sea truth) time series data from moored instruments could largely replace ship surveys. There are data to suggest that time series from moored arrays will maintain the ability to detect and assess population changes while being much less intensive of both capital and labor than large scale ship surveys. It was felt that moored instruments could provide both short term high resolution data and longer time scale records indicative of global change.

The organization of the sampling and technology section followed largely from the deliberations of the zooplankton group. The zooplankton group's plan for proposed research is composed of Mesoscale Surveys, Process Studies and Moored Instruments for time series measurements. The areas discussed by covered technology (extant, almost ready and necessary but non-existent) for surveys, rates and moorings.

9.6.1 Mesoscale surveys

Available gear for assessing the distribution and abundance of zooplankton and fish include MOCNESS, bug counter, acoustic (multifrequency, dual beam and acoustic doppler current profilers (ADCP)), silhouette photography and image analysis, and sonar for fish schools. Further development of optical systems for assessing distribution and abundance and feeding interactions *(e.g.,* "critter cam") was highlighted as a fruitful area for further development.

The group felt that additional development of biotechnology for marine science was necessary. A primary area of interest was biotechnology related to assessing feeding rates and identifying food items. Another area for biotechnological applications is the use of genetic markers in stock structure and in studying "survivors" in recruitment studies. Physical oceanographic instrumentation of interest for mesoscale surveys included acoustic Doppler current profilers (ADCP) and CTD arrays in conjunction with fluorometers, transmissometers, light and other optical sensors.

9.6.2 Moorings

Most of the discussion centered on technology related to moorings, because of the great potential for moorings in time series measurements. The types of instruments envisioned encompassed hydrographic, biooptical, bioacoustic, and passive and active biological samplers.

Existing instruments include CTDs with fluorometers and transmissometers, the moored dual beam echosounder (BIOSPAR), which has been tested in a lake, and ADCPs.

In the "almost ready" category the group considered the usefulness of bioacoustic instruments including multifrequency acoustics, a "bug counter", low frequency acoustics for fish schools, multi-element split beam acoustics and broad band acoustics. Some of these instruments already exist but are not yet available for deployment on a mooring. Optical instrumentation and video image analysis are two areas where significant gains could be realized. Another area of interest were active samplers on moorings. This could include a programmable plankton pump and tidally driven samplers for plankton and moored egg samplers.

An area of potentially great usefulness is the development of 3D acoustic imaging (which could be deployed on a mooring or as part of a survey or process study). A system called "Fish TV" (FTV) is in the early stages of development.

9.6.3 Process Studies

There was very little instrumentation specific to process cruises, *i.e.*, most of the instruments have already been mentioned in conjunction with surveys and moorings. There are, however, areas where new technology and methods are sorely needed, particularly with respect to rate measurements, e.g., egg production, development, growth and mortality of all stages. There is also the necessity for the development of Lagrangian drifters. Particularly acute is the need for "smart drifters" that can be programmed to mimic the diel vertical migration of fish larvae or zooplankton. The development of MOCNESS systems which include acoustics, optics and "bug counters" is also an area for further development.

The Working Group felt that satellite and other remote sensing methods (e.g., AVHRR and CZCS) should be an integral part of any GLOBEC field program. The possibility of using side scan sonar and submersibles for investigations of the benthic boundary layer and benthic pelagic coupling is desirable.

Benthic specialists on the Working Group made a special request for new technology using fluorescent or other tags for real time identification and enumeration of meroplankton.

10 LIST OF ACRONYMS

ACCP	Atlantic Climate Change Program
ADCP	Acoustic Doppler Current Profiler
AVHRR	Advanced Very High Resolution
BIONESS	Biological Net and Environmental Sampling System
BIO SPAR	Moored Dual Beam Echosounder
CCC	Cod and Climate Change
CoOP	Coastal Ocean Processes
CPUE	Catch Per Unit Effort
CTD	Conductivity, Temperature, Depth probe
CUD	Conservation and Utilization Division
CZCS	Coastal Zone Color Scanner
DOE	Department of Energy
ENSO	El Niño Southern Oscillation
FEP	Fisheries Ecology Program
FTV	Fish TV
FY	Fiscal Year
GFDL	Geophysical Fluid Dynamics Laboratory
GLOBEC	GLOBal ocean ECosystem dynamics
ICES	International Council for the Exploration of the Sea
JGOFS	Joint Global Ocean Flux Study
MOCNESS	Multiple Open and Closing Net and Environmental Sensing System
NAFO	North Atlantic Fisheries Organization
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCSP	Northern Cod Science Program
NEFC	Northeast Fisheries Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
ONR	Office of Naval Research
OPEN	Ocean Production Enhancement Network
RFP	Request For Proposal
SCOR	Scientific Committee on Oceanographic Research
SLP	Sea Level Pressure
SPA	Sequential Population Analysis
SSB	Spawning Stock Biomass
SST	Sea Surface Temperature
SWNS	Southwest Nova Scotia
TAC	Total Allocated Catch
UNOLS	University National Oceanographic Laboratory System
VPA	Virtual Population Analysis
WOCE	World Ocean Circulation Experiment

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