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Final Report of the 2000 Annual Meeting of the Fisheries Oceanography Committee Including the Report of the Workshop on the Cod Recruitment Dilemma

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Northwest Atlantic Fisheries Center
St. John's, Newfoundland

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Executive Summary of the 2000 FOC Annual Meeting

The Fisheries Oceanography Committee (FOC) of the Department of Fisheries and Oceans (DFO) met in St. John's, Newfoundland at the Northwest Atlantic Fisheries Center on 22-25 February 2000. The Committee reviewed environmental conditions in the Northwest Atlantic during 1999, convened a workshop on the Cod Recruitment Dilemma, reviewed additional papers on physical and biological oceanography and on changes in cod diets, and conducted its annual business meeting.

1. **Physical Environment in 1999**: Eight papers were reviewed on the meteorological and physical oceanographic conditions in 1999. Air temperature warmed relative to 1998 throughout most of the northwest Atlantic, reaching record high values in the Gulf of St. Lawrence, on the Scotian Shelf and over eastern Newfoundland. Sea ice coverage and duration were below average in most areas. Water temperatures from southern Labrador to the Grand Bank and off southern Newfoundland were generally above normal values.This was reflected in below-average volumes of the cold intermediate layer (CIL) and warmer-than-average bottom waters off Newfoundland, especially on the Grand Bank where bottom temperatures were 1-3°C above average. A substantial warming and thinning of the CIL occurred in the Gulf of St. Lawrence in 1999. The CIL core temperature index increased to its warmest value since 1985, CIL thickness decreased by about 50% compared to 1998, and the area of sub-zero bottom water on the Magdalen Shallows declined from the high 1998 value to near zero. Warm Slope Water replaced the cold Labrador Slope Water that had flooded into Emerald and Georges Basins in 1998 and had covered the bottom over much of the southwestern Scotian Shelf in 1998. Temperatures deep in Emerald Basin increased by 2-3°C in 1999. The waters below 50 m on the northeastern Scotian Shelf continued to warm in 1999 reaching above-average temperatures for the first time in about 15 years. Very warm surface temperatures occurred over the Scotian Shelf and Gulf of Maine, with anomalies of several degrees in many months. Stratification remained high over the Scotian Shelf.

2. **Biological Environment in 1998:** Eight presentations on the biological and chemical oceanographic conditions in 1999 were reviewed. The spring phytoplankton bloom occurred earlier in 1999 than in 1998 in most areas. Phytoplankton abundance on the Grand Bank was high in the fall of 1999. Along the Bonavista Bay transect, sampled since 1993, total copepod abundance peaked in 1998 while overall zooplankton biomass peaked in 1999. The late summer pelagic fish survey of the Newfoundland Shelf and Grand Bank indicated a steady increase in zooplankton biomass from 1994 to 1997 with continued high levels in 1998 and 1999. Nekton biomass increased steadily from 1995 to 1999 in this area. In 1999, abundances of pelagic 0-group Atlantic cod, American plaice, redfish and sandlance all increased to the highest levels seen in the 1994-1999 time series. In the St. Lawrence Estuary and northwestern Gulf, the spring phytoplankton bloom in 1999 was the earliest in the 1995-1999 time series and phytoplankton biomass was substantially higher than in earlier years. Densities of both krill and mesozooplankton in this area in 1999 were the second lowest in the 1994-1999 time series, slightly below the 1998 levels and well below the high 1994 values. On the Scotian Shelf, bottom water nutrient concentrations were lower in 1998 than in 1999, consistent with the incursion of Labrador Slope Water onto the Shelf in 1998.

However, there was no evidence that this incursion affected the distribution or quantity of plankton on the Shelf. Continuous Plankton Recorder (CPR) and ocean colour data both indicate that phytoplankton biomass in 1998 was higher than in earlier periods (1961-1975, 1978-1986). The CPR data indicate that abundances of copepods and krill on the eastern Scotian Shelf has been low in recent years, though krill abundance in 1998 rose to near the longterm mean.

3. A workshop on the **Cod Recruitment Dilemma** was convened during the meeting. Cod in most populations in the Northwest Atlantic declined to low levels of abundance in the early 1990s. Recovery from these population collapses has been very slow despite fishery closures. In contrast, many of these populations recovered rapidly from declines to similar levels of abundance in the mid 1970s despite continued fishing. The goal of the workshop was to understand the reasons for the slow recoveries in the 1990s. Over 25 presentations were reviewed during the workshop. Time series of spawning stock biomass, recruitment, growth and mortality were presented for each stock, along with analyses of effects of ecosystem factors (e.g., climatic conditions, prey and predator abundance) and spawning stock characteriestics on recruitment success. Conclusions differed between stocks and are outlined in the attached executive summary of the workshop proceedings.

4. Four presentations were reviewed in the **general environmental session**: three on physical or biological oceangraphy and one on recent changes in cod diets. The oceanography papers included (1) an analysis of sea surface temperatures derived from satellite data, (2) a description of interannual variability in chlorophyll fields of the Atlantic Zone based on satellite data, and (3) egg and larval distributions of cod and haddock from Cape Hatteras to the Laurentian Channel. The paper on cod diets described the disappearance of euphausiids from the diet of cod in the southern Gulf of St. Lawrence in the 1990s.

5. Reports of the **FOC working groups** were presented. In 1999/2000, the **Cod Growth Working Group** focussed on preparations for the upcoming ICES/GLOBEC workshop on cod growth (May 2000) and explored possibilities for laboratory studies on cod growth. It was agreed that after the workshop the WG will have met all its goals and will disband. The **Environmental Indices Working Group** has completed its objectives and will disband after publishing its work as a technical report. Parallel work on biological indices will be undertaken by the AZMP. The **Cod Distribution Working Group** was unable to conduct further work in 1999/2000 and was asked to continue this work during the coming year. A new working group on **Incorporating Environmental Information into Stock Assessments** was formed with Ken Drinkwater as its chair.

6. The **biological/chemical overviews** were discussed. The amount of information presented in the overviews has increased greatly as the Atlantic Zonal Monitoring Program (AZMP) has come onstream. A need for standardization among Regions was raised but it was agreed that this was an issue that needed to be decided upon within the AZMP. Linkages between the AZMP and the FOC were again discussed. It was re-affirmed that the environmental overviews produced by the AZMP need to be reviewed by the FOC.

7. The **2001 Annual Meeting** will be held at the Gulf Fisheries Centre in Moncton during the second last week in March. The theme session will be on recruitment and productivity of invertebrate populations.

Executive Summary of the Cod Recruitment Workshop, March 2000

A workshop on the Cod Recruitment Dilemma was convened during the meeting. Cod in most populations in the Northwest Atlantic declined to low levels of abundance in late 1980s and early 1990s and failed to recover quickly after moratoria were imposed. The goal of the workshop was to understand the reasons for the slow recovery in the 1990s compared to the rapid recovery from previous declines in the 1970s. Over 25 presentations were reviewed during the workshop. Time series of spawning stock biomass, recruitment, growth and mortality were presented for each stock, along with analyses of effects of ecosystem factors (e.g., climatic conditions, prey and predator abundance) and spawning stock characteristics on recruitment success.

Conclusions differed between stocks but it quickly became apparent that the lack of recovery is more than just a recruitment rate issue. Recruitment rate is defined as the level of recruitment given the observed levels of spawning stock biomass (i.e., the number of recruits divided by the spawning stock biomass that produced them). Recruitment rate is lower than normal for some stocks (3NO, 3Ps, 4VsW, and 4X). However, for the three other stocks examined (2J3KL, 3Pn4RS, and 4T), recruitment rate is not low and hence cannot account for the slow recovery. A high natural mortality of adult cod (calculated from research surveys) impedes recovery in some stocks (3Pn4RS, 4T, and 4VsW). For some stocks, loss of spawning components and/or the reduced area occupied by spawners may also be preventing recovery (primarily 2J3KL and 4VsW but also 3NO and 3Pn4RS). A decline in growth rate has resulted in decreased growth production for most stocks, impeding their recovery (2J3KL, 3NO, 3Pn4RS, 4T, and 4VsW). For most stocks, changes in structure of the spawning stock due to the intensive fishing of the late 1980s / early 1990s (low weighted mean age of spawners, low age diversity, small body size) contribute to the problem. Given the collapsed age structure and spawning stock biomass of these stocks and the restricted spawning areas, we now are in a unique phase of the history of these stocks. Moreover for many stocks, and in particular 2J3KL and 4VsW, intensive fishing eliminated spawning components and most of the spawning biomass.

Scientists do not know if and when the abundance levels of the past will come back but for many of the stocks it is clear that until spawning components and the spatial structure of spawning are re-established, recruitment comparable to historical levels is not likely to occur. Any fishing that crops the little surplus production that the stocks are now yielding may well prevent any rebuilding to historical levels.

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1. Introduction

The Fisheries Oceanography Committee (FOC) of the Department of Fisheries and Oceans (DFO) met in St. John’s, Newfoundland, at the Northwest Atlantic Fisheries Center on 22-25 February, 2000, to (1) review the environmental conditions in the Northwest Atlantic during 1999, (2) review other papers on the environment or fisheries-environment linkages, and (3) conduct the annual FOC business meeting and review progress of the working groups of the FOC. A workshop on the Cod Recruitment Dilemma, the failure of depressed cod stocks in the Northwest Atlantic to recover despite restricted fishing mortality, was also convened during the meeting. This report provides a summary of the working papers presented at the meeting, the discussions during the meeting and the recommendations following from these discussions. The report of the workshop on the Cod Recruitment Dilemma is also included as a section of this report. The agenda, and lists of working papers and meeting participants, appear in the Appendices.

2. FOC Core-Membership

While participation in the activities of the FOC are open to all, the Committee formally consists of a number of core-members whose responsibilities are to disseminate information in their respective laboratories and to provide a leadership role within the committee. At the time of 2000 annual meeting, the FOC core-members were:

Name	Region	Location
John Anderson	Newfoundland Region	NAFC
Denis D'Amours	DFO Headquarters	Ottawa
Martin Castonguay	Laurentian Region	IML
Eugene Colbourne	Newfoundland Region	NAFC
Ken Drinkwater	Maritimes Region	BIO
Ken Frank	Maritimes Region	BIO
Denis Gilbert	Laurentian Region	IML
Glen Harrison	Maritimes Region	BIO
Savi Narayanan	MEDS, DFO Headquarters	Ottawa
Patrick Ouellet	Laurentian Region	IML
Fred Page	Maritimes Region	SABS
Dave Reddin	Newfoundland Region	NAFC
Doug Swain, Chairman	Maritimes Region	Moncton
John Tremblay	Maritimes Region	BIO

3. 1999 Environmental Overviews

As part of the FOC mandate, the Committee provides an annual review of environmental conditions in the Northwest Atlantic. A total of 16 papers were reviewed, nine on the physical environment and seven on the biological environment. Each environmental overview paper was assigned a reviewer to improve the quality of the manuscripts by providing detailed comments, ensuring editorial correctness and including possible suggestions for next year's overview papers. Reviewers delivered their comments to the senior authors before the end of the meeting or made arrangements to provide them shortly thereafter. A physical environmental "scorecard" was developed and is included below (Table 1).

*3.1 **Meteorological and Sea Ice Conditions** (K. Drinkwater et al.)*

Annual mean air temperatures throughout most of the northwest Atlantic warmed relative to 1998 setting record high values in the region from southern Labrador to Cape Cod (Fig. 1). The maximum air temperature anomalies and the largest increases relative to 1998 were in the Gulf of St. Lawrence, on the Scotian Shelf and over eastern Newfoundland. Seasonally, air temperatures in most areas of the northwest Atlantic were above normal in 10 out of the 12 months of 1999. The only exception to the warm air temperatures was on the West Greenland side of the Labrador Sea.

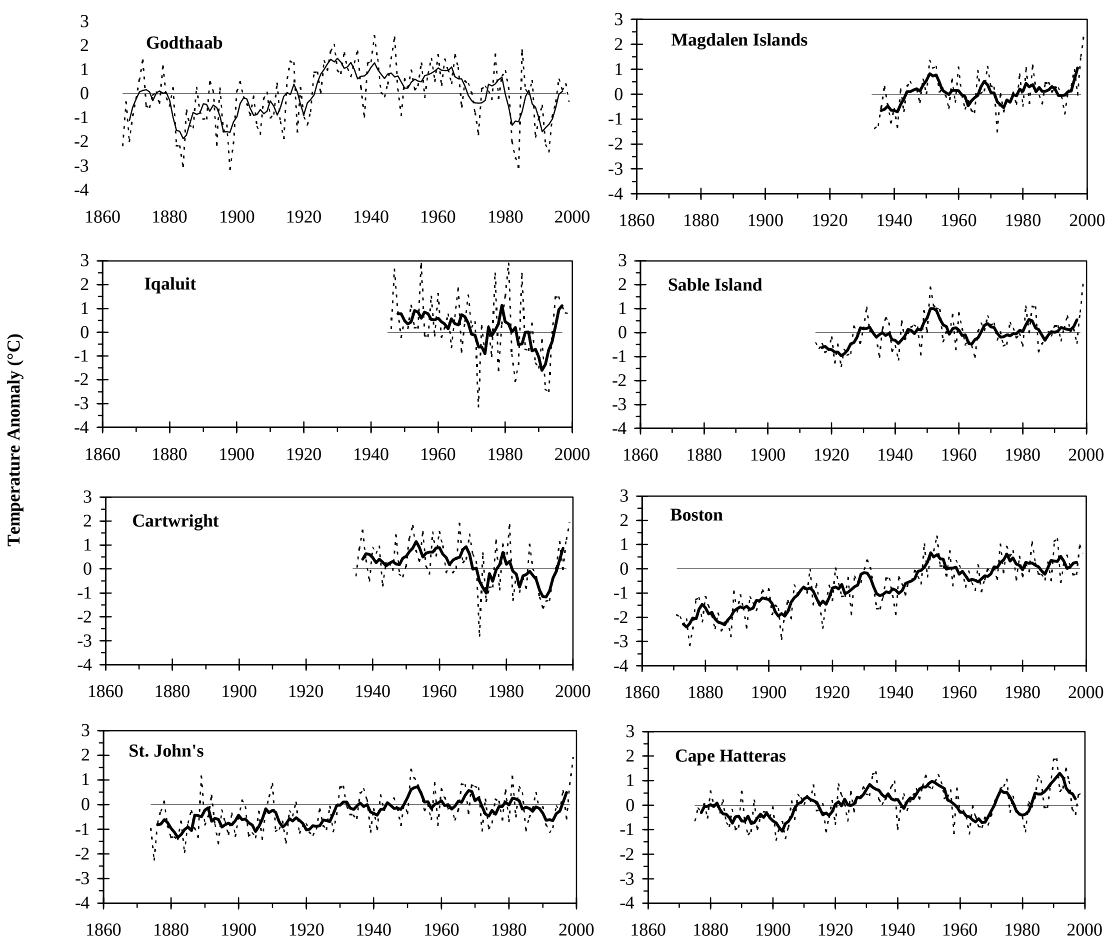

Fig. 1. Annual (dashed) and 5-yr running means (solid) of air temperature anomalies relative to 1961-1990 means at selected sites.

The North Atlantic Oscillation (NAO) index for 1999 was well above normal, reversing the trend of below normal and near normal values of the previous three years (Fig. 2). The index in 1999 was similar to levels observed in the early 1990s. This indicates that the large-scale atmospheric circulation, including the Icelandic Low, intensified in 1999. The sea ice on the southern Labrador and Newfoundland shelves generally appeared on schedule but left early, resulting in a shorter duration of ice than usual. The ice coverage in these areas during 1999 was lower than average but similar to 1998 (Fig. 3). The number of icebergs reaching the Grand Banks in 1999 was only 22, well down from the 1384 icebergs observed in 1998. The small number of bergs in 1999 is consistent with the reduced ice cover later in the season and the generally warmer-than-normal air temperatures. In the Gulf of St. Lawrence, the sea-ice also appeared more or less on schedule. Although there was a tendency to disappear earlier-than-normal, there was still a significant portion of the Gulf where the date of last presence was later than usual. Little to no ice reached the Scotian Shelf proper and the areal coverage of ice in the Sydney Bight area off eastern Cape Breton was much less than normal.

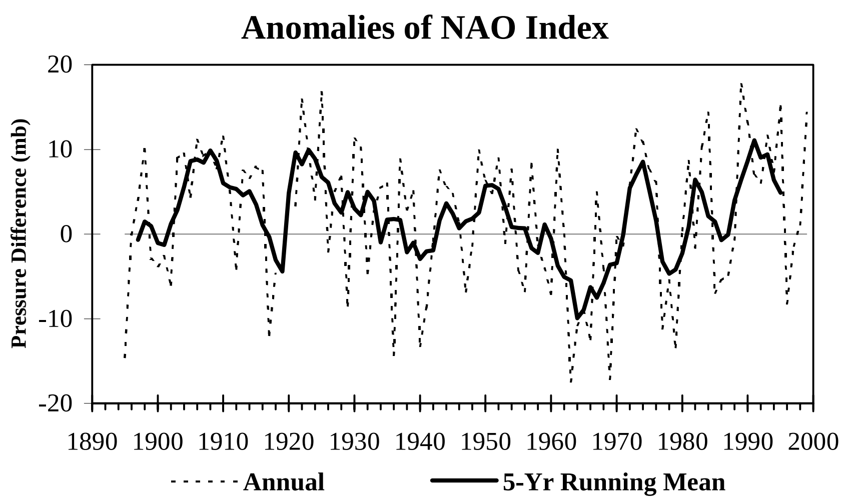

Fig. 2. Annual (dashed) and 5-yr running means (solid) of anomalies of the North Atlantic Oscillation (NAO) index relative to the 1961-90 mean.

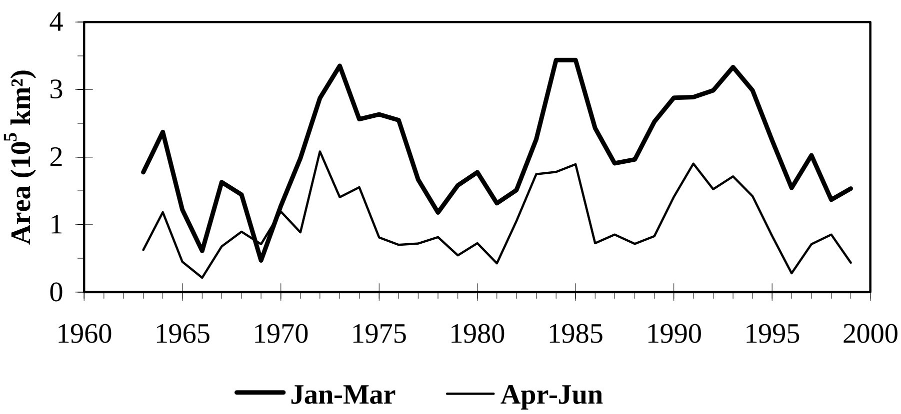

Fig. 3. Average ice area during January-March (time of ice advance) and April-June (time of ice retreat) off Newfoundland and southern Labrador between 45°N and 55°N.

*3.2 **Physical Oceanographic Conditions***

3.2.1 <u>Newfoundland/Southern Labrador</u> (E. Colbourne)

The low temperatures and salinities established in the waters of the Northeast Newfoundland Shelf in the late 1980s and early 1990s moderated in the mid 1990s. Water temperatures were above normal in 1996 and near normal in 1997 and 1998. Ocean temperatures were above normal over most areas in 1999. At Station 27, the hydrographic monitoring site off St. John's, temperatures were 0.25° to 1°C above normal over most of the water column during the winter months. Temperatures increased to over 2°C above normal at the surface by mid-summer. Fall temperatures over the upper 100 m at Station 27 were below normal by about 0.5°C as a result of a colder-than-normal temperature anomaly associated with the Labrador Current. Bottom temperatures were 0.25° to 0.5°C above normal throughout the year. The depth-averaged annual temperature at Station 27 was above the longterm mean in 1999 (Fig. 4). Annual depth-averaged salinity was below normal at Station 27 in 1999, as a result of above normal values during winter months but below normal values throughout the remainder of the year.

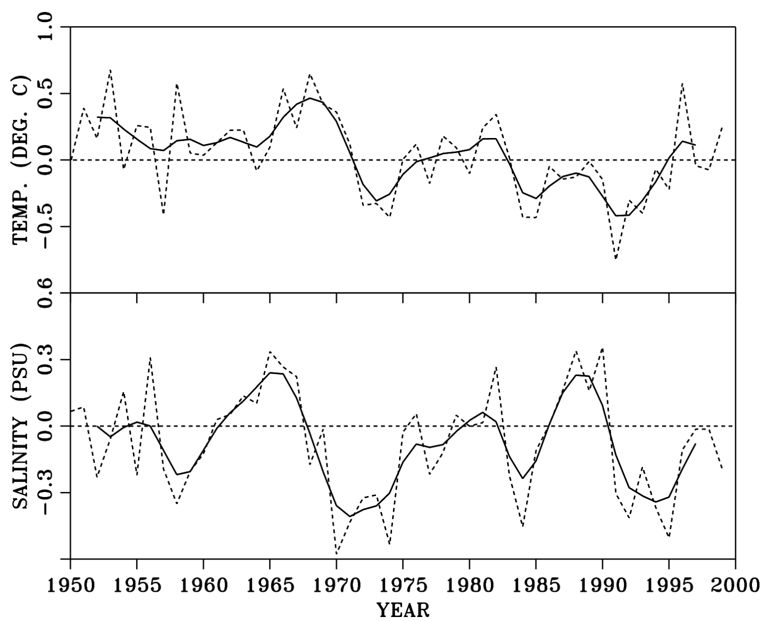

Fig. 4. Vertically-averaged annual temperature anomalies (0-176 m) and summer (Jul-Sep} salinity anomalies (0-50 m) at Station 27. Heavy lines are 3-yr running means.

The volume of the cold intermediate layer (CIL), defined as waters at temperatures below 0°C, over the Shelf from southern Labrador to the northern Grand Bank was below normal again in 1999 (Fig. 5), reflecting the warming of these waters in recent years. Bottom temperatures were above normal over most areas in 1999. On the Grand Bank, bottom temperatures in spring and fall were 1-3°C above the longterm average (Fig. 6).

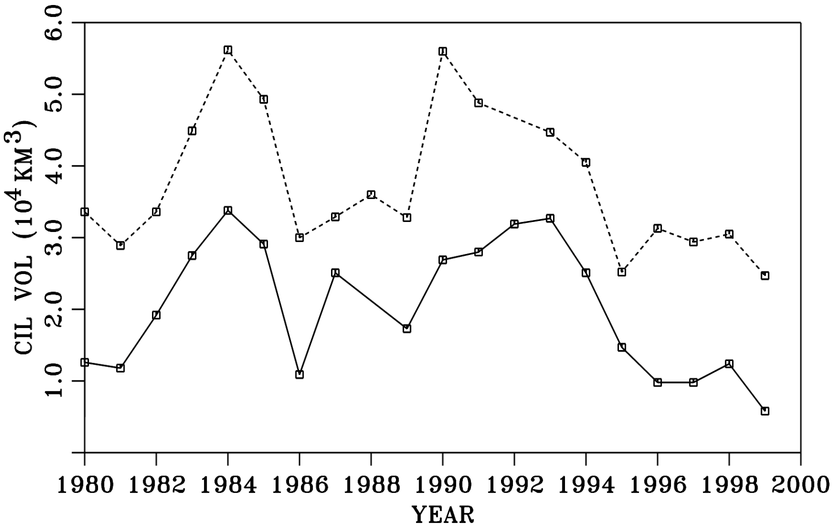

Fig. 5. Summer (dashed line) and fall (solid line) CIL volume over NAFO div. 2J3KL.

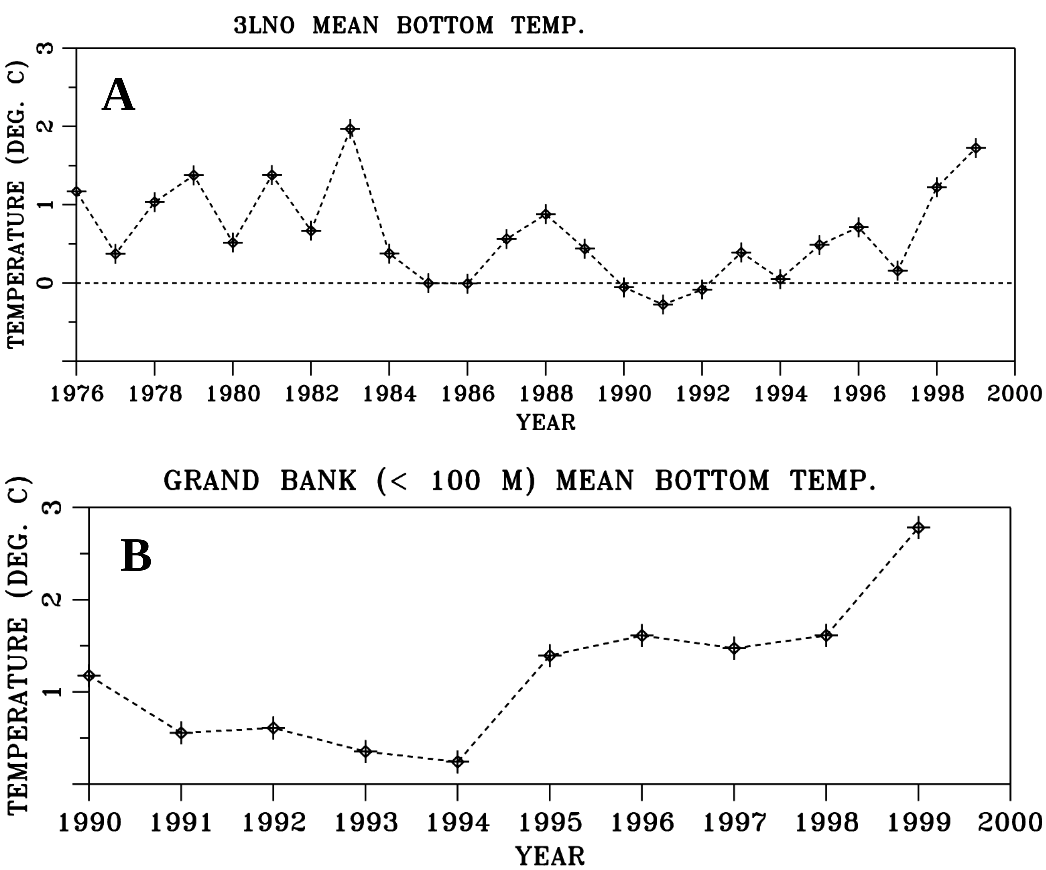

Fig. 6. Mean bottom temperatures over NAFO div. 3LNO strata with depths ≤ 100m during (A) spring and (B) fall.

Bottom temperatures on the banks off southern Newfoundland were relatively cold in the mid to late 1980s and early 1990s (Fig. 7), resulting in large areas of subzero bottom waters (Fig. 8). Conditions moderated in the mid 1990s, with near average bottom temperatures and little subzero bottom water over the banks in 1996. Bottom waters cooled again in 1997 but returned to near average temperatures with little subzero bottom water in 1998. Temperatures continued to warm during 1999 and were above normal over most of the water column, including near bottom. No subzero bottom water occurred on these banks in 1999.

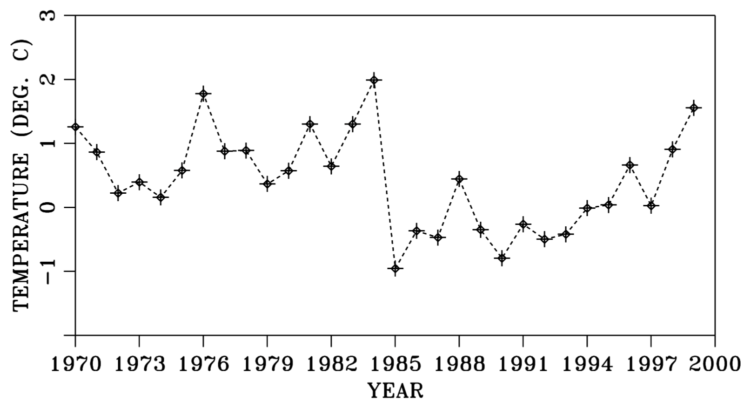

Fig. 7. Mean bottom temperature of Burgeo, St. Pierre and Green Banks.

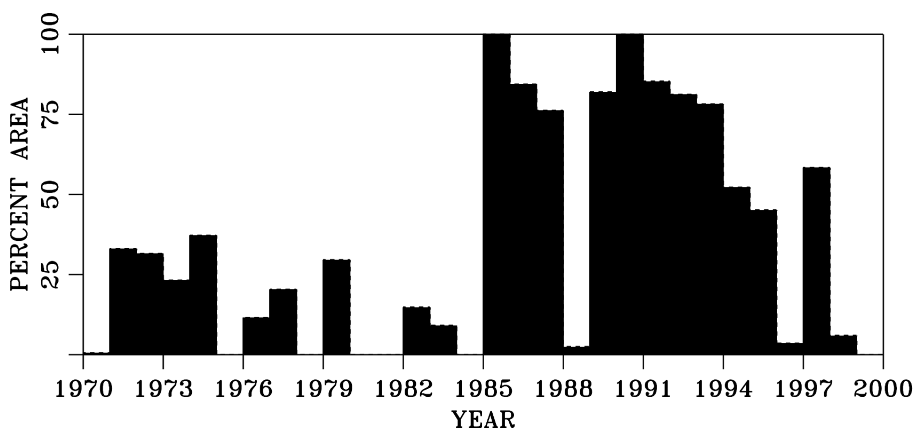

Fig. 8. Area of subzero bottom water on Burgeo, St. Pierre and Green Banks.

3.2.2 <u>Gulf of St. Lawrence</u> (J. Plourde et al.)

A substantial warming and thinning of the CIL occurred in the Gulf of St. Lawrence in 1999. This contrasts sharply with the situation in 1998, when the CIL cooled and thickened despite mild winter conditions. Though still slightly below the longterm mean, the CIL core temperature index increased by about 0.6°C to its warmest value since 1985 (Fig. 9). CIL thickness decreased by over 20 m (about 50%) in 1999 compared to 1998. On the Magdalen Shallows, the areas with bottom waters <0°C and <1°C decreased by 98% and 32% respectively in 1999 compared to 1998, reaching the lowest values seen since 1988 (Fig. 10). In deeper waters, temperatures warmed slightly (100-200 m) or changed little (200-300 m) relative to 1998, and were slightly above (100-200 m) or near normal (200-300 m) in 1999.

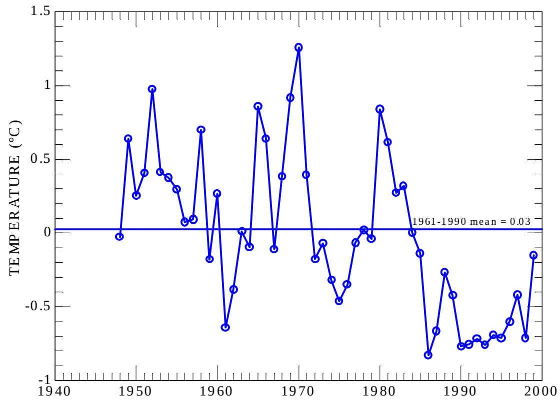

Fig. 9. Composite index of CIL core temperature anomaly (°C) in the Gulf of St. Lawrence (1961-1990 mean = 0.03°C).

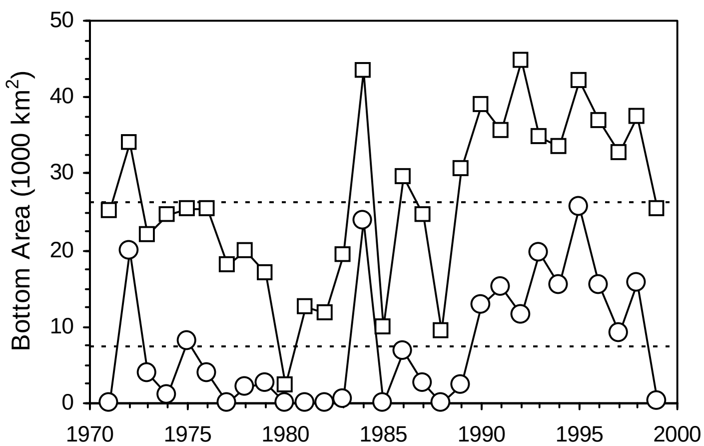

Fig. 10. Bottom area with T < 0°C (circles) and T < 1°C (squares) in September in the southern Gulf of St. Lawrence. The horizontal lines represent the 1971-1999 averages.

3.2.3 <u>Scotian Shelf/Gulf of Maine</u> (K. Drinkwater et al., Losier et al., Page et al.)

Several significant changes in the physical oceanography of the Scotian Shelf and Gulf of Maine took place in 1999. The first was the replacement of cold Labrador Slope Water along the outer edge of the Scotian Shelf by Warm Slope Water. The latter warm waters subsequently penetrated onto the shelf through channels and gullies in 1999 to displace the cold slope water that had entered the deep basins, such as Emerald and Georges basins, and covered much of the bottom of the southwestern Scotian Shelf during 1998 (Fig. 11). Temperatures in deep Emerald Basin increased by 2°-3°C in 1999 over 1998 values. The second significant event was on the northeastern Scotian Shelf, where waters below 50 m continued their gradually warming that began in the mid-1990s

(Fig. 12) such that significant portions are now above normal for the first time in approximately 15 years. The presence of these cold waters was believed to be due to a combination of advection from the Gulf of St. Lawrence and off the Newfoundland Shelf and *in situ* cooling during the winter. The third change was the very warm surface layer waters that developed over the region. Anomalies of several degrees were observed in many months. This is related to the record air temperatures observed in 1999. Finally, there was continued high stratification in the upper water column (between surface and 50 m) throughout the Scotian Shelf.. This high stratification was not observed in the Gulf of Maine, however.

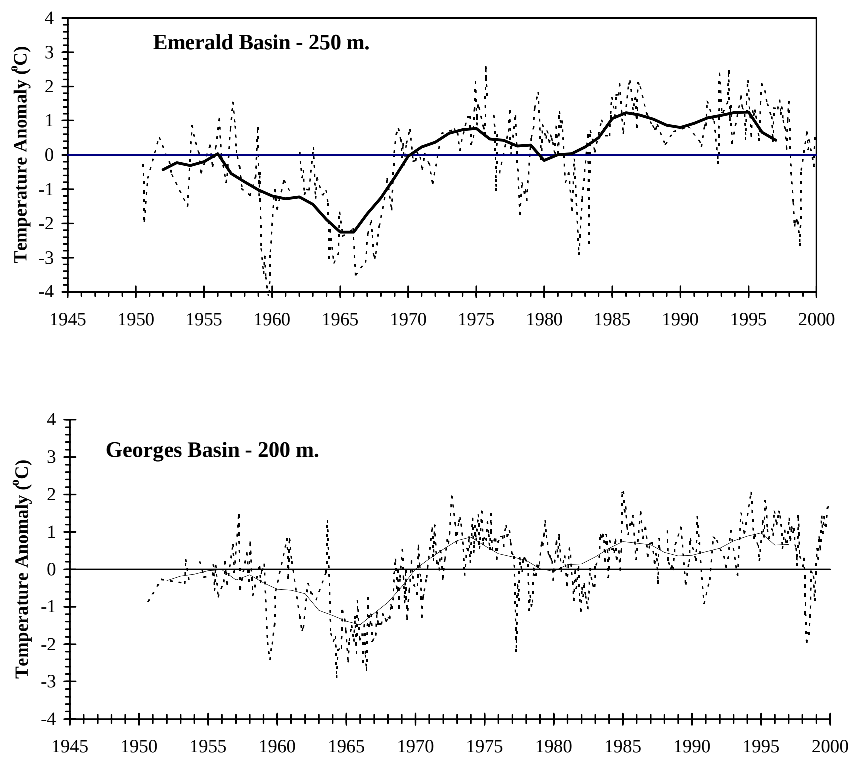

Fig. 11. Temperature anomalies (relative to the 1961-1990 mean) at 250 m in Emerald Basin and at 200 m in Georges Basin. Dashed lines show monthly mean anomalies and solid lines the 5-yr running mean of the estimated annual anomalies.

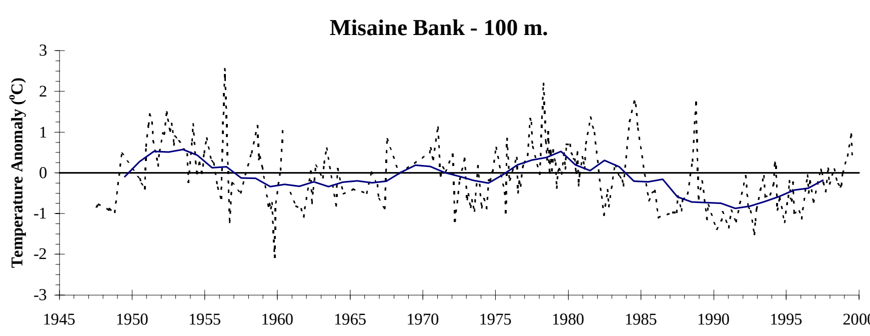

Fig. 12. Monthly mean temperature anomalies (dashed line) and 5-yr running mean of the estimated annual anomalies (solid line) at 100 m for Misaine Bank.

Near-bottom temperatures were near or above normal over most of the Scotian Shelf during the July 1999 groundfish survey (Fig. 13), with no bottom water below about 2°C. This contrasts sharply with results for the July 1998 survey, when near-bottom temperatures were below normal over most of the Shelf, particularly over the southwestern Shelf. Near-surface temperatures were above normal during the July 1999 survey, particularly over the northeastern Scotian Shelf where stratified means reached historical highs. Salinities recorded during the July 1999 survey was near normal levels over most of the Scotian Shelf at the surface, at 50 m and near the bottom.

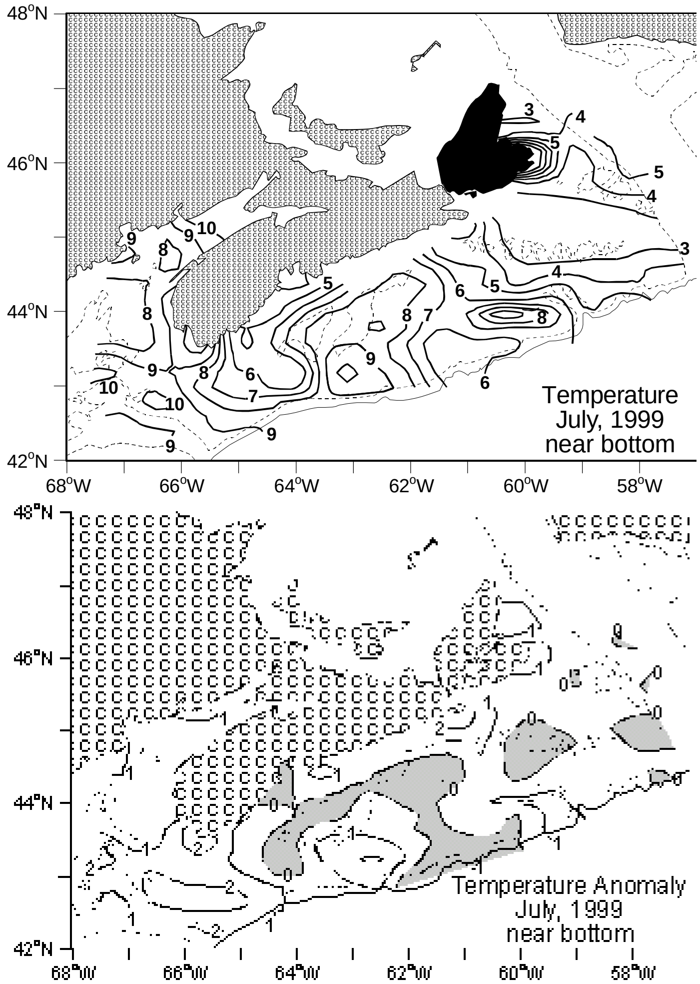

Fig. 13. Near-bottom temperature and temperature anomalies during the July 1999 groundfish survey. Negative anomalies are shaded.

Temperatures at the Prince 5 monitoring station in the Bay of Fundy were above the longterm (1961-1990) means at all depths during all months in 1999 except for January. Salinities were below the longterm means from January until April-May and above the longterm means from May through December.

Table 1. Environmental scorecard for 1998. Conditions for 1998 are shown as anomalies in standard deviations from the longterm average and are compared to 1997 and the previous 5 yr. Shading indicates conditions that were unusually cold/fresh or warm/salty. GSL = Gulf of St. Lawrence.

Index	Area	1998	Cold Fresh	Warm Salty	Relative To 1998	Relative to 1994-1998
NAO		1.46			Up	Up
Annual Air Temperature	Labrador	1.84			Up	Up
	Newfoundland	3.01			Up	Up
	Gulf of St. Lawrence	3.95			Up	Up
	Scotian Shelf	3.84			Up	Up
	Gulf of Maine	1.18			Down	Up
Sea Ice	Nfld/Lab (Area)	-0.95			Down	Down
	Scotian Shelf (Area)	-1.33			Down	Down
Near-bottom Temperature	Nfld – Grand Bank	2.62			Up	Up
	Station 27	0.78			Up	Up
	St. Pierre Bank	2.08			Up	Up
	Magdalen Sh. area T<0	0.91			Down	Down
	Misaine Bank - 100 m	0.70			Up	Up
	Emerald Basin - 250 m	0.19			Up	Down
	Georges Basin – 200 m	1.21			Up	Same
	Bay of Fundy P5 – 90 m	1.91			Up	Up
CIL	Nfld Bonavista Bay (Area)	-0.71			Down	Down
	GSL (Min. Temp. 1948-99)	-0.26			Up	Up
Integrated Temperature	Station 27	0.89			Up	Up
	Cabot Strait (200-300 m)	0.85			Up	Up
	GSL 0-30 m	0.89			Up	Up
	GSL 30-100 m	-0.24			Up	Up
	GSL 100-200 m	0.90			Up	Up
	GSL 200-300 m	0.49			Same	No Trend
Surface Temperature	Station 27	0.96			Up	Up
	Halifax	-0.01			Down	Up
	Bay of Fundy – St. Andrews	2.23			Up	Up
	Gulf of Maine – Boothbay	2.73			Up	Up
Salinity	Station 27	-0.74			Down	Same
	Prince 5 (90 m)	1.03			Up	Up

3.2.4 Physical Environment Scorecard

Following the practice instituted at the 1998 FOC meeting, a physical oceanographic "scorecard" was constructed to summarize changes in the many standard environmental indices (Table 1). Following suggestions made at the 1998 meeting, quantitative information was incorporated by indicating, where possible, the strength of the 1998 anomaly in terms of its standard deviation from the longterm average. Conditions were generally warmer than the longterm averages throughout the Atlantic zone.

3.2.5 Questions and Discussion

The low number of icebergs reaching the Grand Banks in 1999 was discussed. The index is the number of icebergs occurring south of 48° latitude. The low number in 1999 could be due to fewer icebergs being produced or due to fewer reaching this latitude. The index tends to be related to the amount of sea ice (which protects icebergs from wave erosion, etc.).

The ice area time series was discussed. This index is based on the estimated area within the ice edge rather than an estimate of the actual ice area (i.e., ice-free areas within the ice edge would be included in the index). Variation in ice thickness is not incorporated in the index, though variation in ice breakup and heat loss may be related to ice thickness.

A question was raised regarding the positive anomalies in surface temperatures off Newfoundland – what are the implications of these warm temperatures to stratification? It was noted that stratification depends mainly on variation in salinity and that stratification has not changed much in this area over the years.

The very warm bottom temperatures on the Grand Bank in 1999 were discussed. It was suggested that these temperatures appear to be warmer than those preferred by some species such as capelin and cod. *It was recommended that data from the groundfish survey should be examined to determine whether these very warm waters may be influencing groundfish distribution.*

It was noted that Station 27 temperature anomalies did not appear to be related to air temperature, and that these may be related to ice melt. However, this cannot be confirmed because no data on ice thickness are available to calculate heat loss due to ice.

It was noted that data on oxygen concentration was not included in the physical overview for the Gulf of St. Lawrence for 1999. It was confirmed that profiles of dissolved oxygen continue to be collected. A recommendation that data on oxygen should be included in the overview was made.

3.3 ***Chemical and Biological Oceanographic Conditions***

3.3.1 *Newfoundland/Southern Labrador* *(P. Pepin & G. Maillet, E. Dalley et al.)*

Seasonal and interannual variation in the concentrations of chlorophyll *a*, nitrates, phosphates, silicates and major zooplankton taxa were described for Station 27 and standard oceanographic transects on the Newfoundland Shelf, comparing conditions during 1998 and 1999 with those for the 1993-1997 period. Chlorophyll levels appeared to be below average in the spring and summer of 1998, while deep nutrient concentrations appeared to increase throughout the year, levelling off in late summer when they were above the 1993-1997 average. In 1999, chlorophyll concentrations were below recent averages during spring and summer on the Northeast Newfoundland Shelf but above average during summer on the Grand Bank. There appears to have been a substantial depletion of nitrates in deep waters during the spring, perhaps explaining the relatively low concentrations found in deep waters in the fall of 1999 on the Grand Bank and the Northeast Newfoundland Shelf. Phytoplankton concentrations were high on the Grand Bank in November of 1999, suggesting a fall bloom in the area; diatom abundance increased substantially at that time. The summer zooplankton community appeared to undergo substantial changes during the 1996-1998 period, associated with increases in the abundance of small copepods and corresponding decreases in species diversity. Preliminary results for 1999 indicate that large copepods, which make up most of the biomass, have increased in both relative and absolute abundance.

Plankton and nekton abundance and distribution were described for late summer 1999 based on a pelagic fish survey covering an area from southern Labrador to the southern Grand Bank. Results for 1999 were compared to results for 1994 to 1998. Geographic variation was generally greater than annual variation and was associated with latitudinal or inshore/offshore clines. Though lower than the high 1997 value, total zooplankton biomass remained relatively high in 1999 compared to the 1994-1996 values (Fig. 14). Capelin larvae were relatively abundant and widespread in 1999 but did not extend to the southern Labrador coast as they did in 1998. Mean total nekton biomass (including jellyfish) was significantly higher in 1998 and 1999 than earlier years (Fig. 14). Capelin (age 1+) and sand lance continued to dominate total nekton, but redfish increased to rank third in overall abundance, increasing by 2 orders of magnitude since 1998 and 3 since 1997. Arctic cod, which decreased in abundance in early years, maintained a relatively low, stable abundance over the past 3–4 years (Fig. 15). Mean catch of pelagic capelin ranked highest in 1999, but was significantly higher than 1998 and 1995 only. The mean catch rate of pelagic 0-group Atlantic cod increased for the third year in succession (Fig. 15). It was significantly higher in 1999 as a result of increases in the inshore particularly, but also on the northern Grand Bank. Hake catch rates were 2 orders of magnitude higher than 1998, and catch rates of American plaice were highest in 1999 (Fig. 15). Six northern taxa that had decreased sharply in abundance in 1998 all increased over 1998 but remained relatively low in comparison to 1994 – 1997 levels. Of twenty measures of the nekton community examined in 1999 all but two ranked higher (6 significantly) than 1998 indicating a growing nekton community.

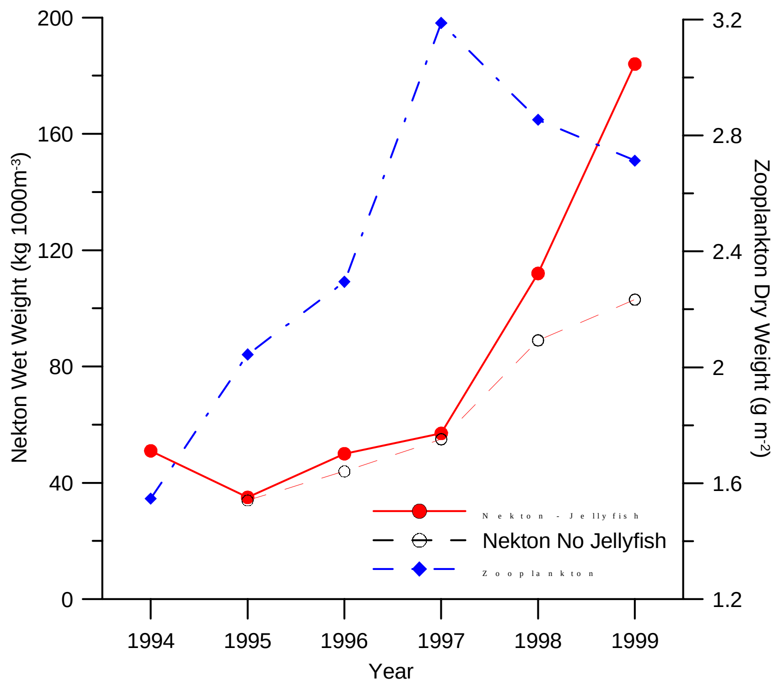

Fig. 14. Total zooplankton and nekton biomass measured during pelagic 0-group surveys of the Grand Bank and Northeast Newfoundland Shelf in 1994-1999.

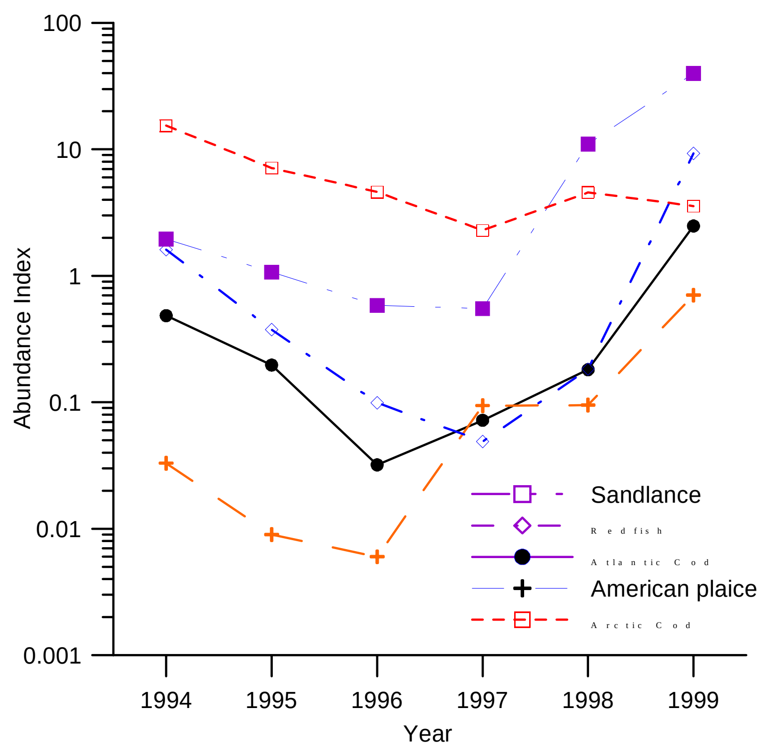

Fig. 15. Abundance indices of five common fish species in the nekton on the Grand Bank and Northeast Newfoundland Shelf, derived from the pelagic 0-group surveys of NAFO Divisions 2J3KLNO, 1994 –1999.

3.3.2 Gulf of St. Lawrence (M. Starr et al., M. Harvey et al.)

Phytoplankton biomass has been monitored at three fixed stations on the St. Lawrence Estuary and the northwest Gulf of St. Lawrence since 1995. At the Rimouski station in the lower Estuary, the primary bloom started several weeks earlier than usual in both 1998 and 1999 (Fig. 16), possibly due to the warmer than normal temperatures in winter and spring in these years. Bloom duration in 1999 was twice as long as in 1998 and 1996 but similar to the 1997 and 1995 durations. Average phytoplankton biomass in 1999 was substantially higher than in earlier years (Fig. 17). Biomass levels were also generally higher in the Gaspé Current station in 1999 than in earlier years, particularly during the intense spring bloom in 1999. Although phytoplankton concentrations at the Anticosti Gyre station were not notably different in 1999 compared to earlier years, the seasonal evolution of nutrients indicated that new spring production was much higher in 1999 than in 1997 and 1998. In summary, phytoplankton production in the Estuary and northwestern Gulf appears to have been greater in 1999 than in recent years.

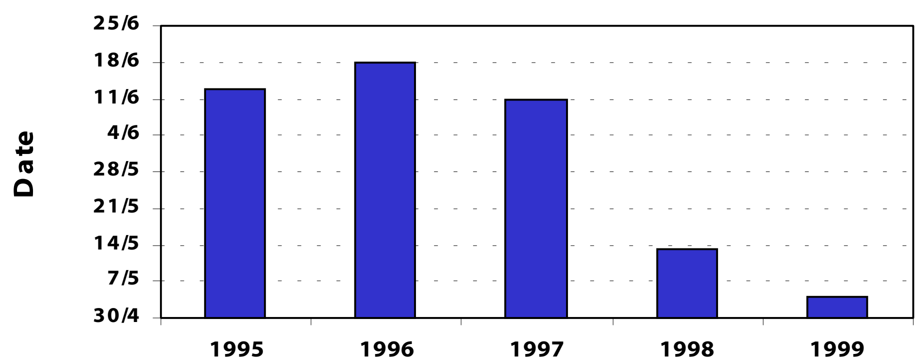

Fig. 16. Onset of the primary phytoplankton bloom in the lower St. Lawrence Estuary. Onset was defined as the first sampling day when chlorophyll a levels exceeded 100 mg per cubic meter.

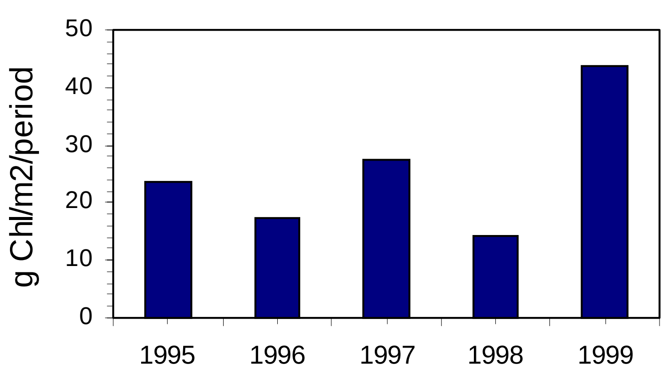

Fig. 17. Phytoplankton biomass at the Rimouski station in the lower St. Lawrence Estuary (integrated chlorophyll a, May-August).

A zooplankton survey has been conducted in the lower St. Lawrence Estuary and the northwest Gulf of St. Lawrence in September each year since 1994. The estimated average wet biomass of both mesozooplankton and krill were greatest in 1994 (209.2 and 38.1 t·km^{-2}, respectively) and lowest in 1996 (106.5 and 7.2 t·km^{-2}, respectively). For both components of the zooplankton, mean biomass in 1999 was comparable to the low 1996 level, slightly lower than the 1995, 1997 and 1998 levels and much (two to five times) lower than the 1994 level (Fig. 18).

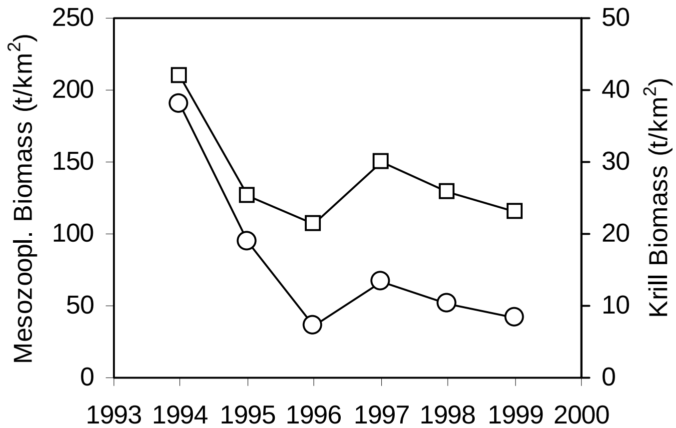

Fig. 18. Total biomass (tww·km^{-2}) of mesozooplankton (□) and krill (○) for the lower St. Lawrence estuary and northwest GSL from 1994-1999.

Seasonal variability in zooplankton abundance and biomass in 1999 was examined at two Zonal Monitoring stations, one in the Anticosti Gyre and one in the Gaspé Current. Copepods dominated the zooplankton communities at both sites. Small copepods (*Oithona similis, Oncea borealis*) were dominant on all sampling dates at both stations except in the Gaspé Current in July and August, when larger species were more abundant. As in 1998, mean biomass in 1999 was much higher in the Anticosti Gyre (212.0 g ww·m^{-2}) than in the Gaspé Current (41.2 g ww·m^{-2}), probably due to the greater abundance of *Calanus hyperboreus* in the Anticosti Gyre and the greater depth of this station (337 vs 165 m). Mean abundances of copepod eggs, nauplii and juveniles were all 1.5-2 times higher in the Anticosti Gyre than in the Gaspé Current. Total *Calanus* abundance (representing about 80% of the zooplankton biomass) in 1999 was greater in the Anticosti Gyre than in the Gaspé Current during all sampling periods except May and June. Abundance of *Metridia longa*, an arctic species that may be a good indicator of environmental change, averaged four times higher in the Anticosti Gyre than in the Gaspé Current, with a strong peak in abundance in September and October. In 1999, the total number of species varied between 33 and 42 at the Anticosti Gyre station and 23 and 31 at the Gaspé Current station.The annual mean values of the Shannon-Wiener diversity index were 1.04 in the Anticosti Gyre and 0.86 in the Gaspé Current.

3.3.3. Scotian Shelf (G. Harrison et al., D. Sameoto)

Seasonal patterns and regional differences were described in chemical and biological oceanographic variables on the Scotian Shelf and Magdalen Shallows in 1998 and 1999. Nutrient concentrations in bottom waters over the central Scotian Shelf were lower in 1998 than in 1999, consistent with the hydrographic evidence of a significant incursion of Labrador Slope Water onto the shelf in 1998. Phytoplankton biomass was variable but concentrations were generally higher in spring than in fall in 1998 and 1999. Satellite ocean colour data indicated that the spring and fall phytoplankton blooms occurred earlier in 1999 than in 1998. Zooplankton biomass was highly variable and no geographic or seasonal patterns in distribution were apparent. There was no evidence that the 1998 Labrador Slope Water incursion affected the distribution or quantity of plankton on the Scotian Shelf.

Phytoplankton biomass levels on the Halifax and Louisbourg transects were higher in 1998 than in 1997 in spring but similar between the two years in fall. Biomass levels in 1998 were similar to the longterm (1974-1998) means along these transects. Satellite ocean colour data indicated the occurrence of a large-scale winter bloom in 1998 in addition to the spring bloom. Comparison to earlier ocean colour data (1978-1986) indicated that phytoplankton biomass levels appeared to be somewhat higher in 1998 than in the earlier period. This is consistent with Continuous Plankton Recorder (CPR) data which indicate a large increase in diatom and dinoflagellate abundance on the eastern Scotian Shelf in the 1990s compared to the 1961-1975 period (Fig. 19).

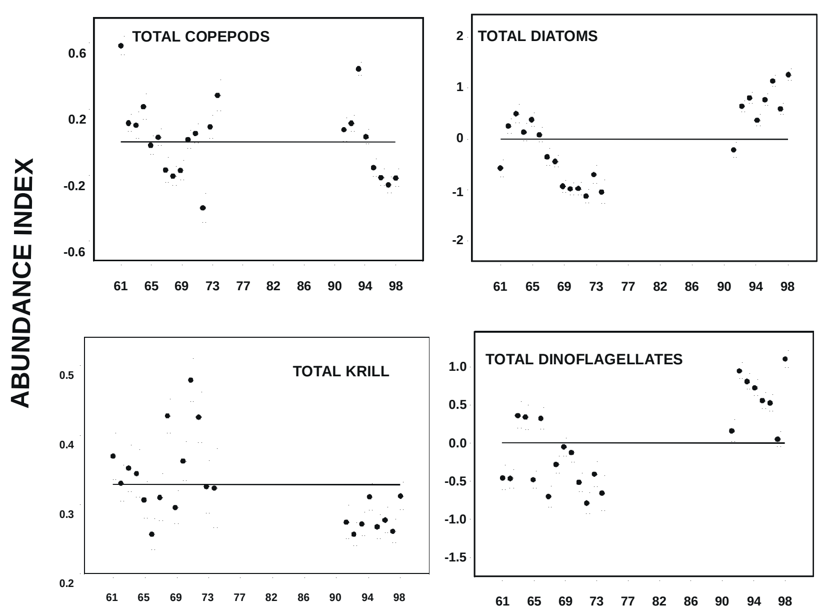

Fig. 19. Continuous Plankton Recorder indices of phytoplankton (diatom and dinoflagellate), copepod and krill abundance on the eastern Scotian Shelf.

In contrast to phytoplankton, the CPR data indicated that krill (euphausiids) abundance on the eastern Scotian Shelf tended to be low in the 1990s compared to the 1961-1975 period (Fig. 19). The CPR abundance index for copepods, including the early stages of *Calanus finmarchicus*, also declined to low levels in recent years on the eastern Scotian Shelf (Fig. 19). The 1998 levels of *C. finmarchicus* in the Emerald Basin were similar to the 1997 levels but below the longterm (1984-1997) mean. Acoustic indices for krill suggested a slight increase on the Louisbourg transect and in Emerald Basin in 1998 compared to 1997.

3.3.4 Questions and Discussion

Several general issues were discussed regarding the biological overviews:

1. Display consistency: It was suggested that there is a need to present data in the same ways for the different regions. Such standardization would facilitate comparisons between regions. On the other hand, it was argued that the important variables or issues may vary from region to region. It was decided that this needed to be discussed and decided upon by the scientists preparing the biological overviews and should be worked out within the Atlantic Zonal Monitoring Program (AZMP). It was noted that standardized procedures are already being established within the AZMP.

2. Analytical elements: Similarly, there is a need to decide on which indices to calculate and report on (e.g., diversity indices, measures of community structure, etc.). Again, it was decided that this was a matter to be discussed within the approriate AZMP committee.

3. Can an environmental scorecard be developed for the biological and chemical oceanography? The physical scorecard includes columns comparing current values to the longterm mean (in units of SDs), recent years and the previous year. The first column will be unavailable for the biological data for many years (since monitoring has only recently begun for most variables). The second and third columns are available for some areas and indices, but not for others (for which this is the first year of data). It was decided that a biological scorecard would be developed, initially making comparisons between years.

4. Regional and zonal SSRs – it was discussed whether these could be prepared. The point was made that for some areas this was the first year of data, so there was little point in preparing an SSR in these cases (as there was nothing to compare the results to – it would be like presenting a physical SSR saying that temperature was, say 10C, with no idea of whether 10C was hot, cold or average). It was decided that regional SSRs would be prepared where possible, and the group would try to develop a scorecard for the 2001 meeting. Regional biological/chemical SSRs will be reviewed at the 2001 meeting. A zonal SSR will be prepared after the meeting and circulated to FOC members for approval.

The roles of the AZMP and FOC regarding review of the environmental overviews was discussed. It was felt that these should be standardized among regions as much as possible by the AZMP in preparation for presentation to the FOC. However, the annual overviews needed to be reviewed fully by the FOC. There should also be time for discussion and synthesis of the material at the FOC meeting. The annual meeting provided a rare opportunity to look for similarities and differences among regions, and for connections between the physical, chemical and biological processes. It was noted that the amount of chemical and biological information presented at the meeting had increased greatly this year, as the AZMP came on stream. Thus, there will be a need for more time to devote to the environmental overviews at future meetings, in order to allow for a full debate, discsussion and synthesis. It was decided that at least 1.5 days would be needed at the next meeting for the environmental overviews.

There was some discussion of the forum for dissemination of the AZMP results. Possibilities were CSAS Research Documents, “Stock” Status Reports (SSRs), or a “glossy” brochure. As noted above, it was agreed that regional SSRs would be produced, as well as a zonal SSR in 2001. It was also agreed that the details of the work should be documented in Research Documents. There was some support for a glossy brochure to showcase the work, but it was concluded that this was a decision for the AZMP.

The timing of the meeting was discussed. The biological data require considerable processing and it is difficult to prepare the biological overviews in time for a February meeting. In some cases, data were not received until the week before the meeting, and in other cases data were not yet available. The February timing for the meeting was originally intended to provide environmental overviews prior to the spring groundfish assessment meeting. Groundfish RAP meetings are now held throughout the year. In 2000, the Gulf groundfish RAP meeting was held in the same week as the FOC meeting, and the Laurentian groundfish RAP, initially scheduled for the same week as the FOC meeting, was moved to the week before the FOC meeting. Thus the original justification for a late February meeting no longer applies and consideration could be given to a later meeting date.

Groundtruthing of satellite data was discussed. Maritimes Region is attempting to groundtruth these data throughout the Atlantic zone. They would like to receive near-surface chlorophyll and temperature data collected in daytime along monitoring sections (with location and time of collection). Data from the groundfish surveys would also be useful. Near-surface was defined as the upper 10-m, though surface values are preferred.

In summary, this discussion led to the following recommendations/conclusions:

1. Regional presentations should be standardized as far as possible with respect to analytical elements and their display. The details need to be worked out within the AZMP.
2. The annual environmental overviews prepared by the AZMP should be reviewed by the FOC.

3. More time needs to be set aside at the annual meeting of the FOC for review, discussion and synthesis of the environmental overviews.
4. Regional SSRs on chemical and biological oceanography should be produced. A zonal SSR should be produced after the 2001 meeting.
5. A scorecard on biological and chemical oceanograohy should be developed.

4. General environmental Session

Each year the FOC receives several papers that are not directly related to the annual environmental overviews or the major theme session. This year the committee reviewed 4 presentations in this category.

K. Drinkwater presented a paper by B. Petrie and C. Mason on sea surface temperatures from satellite measurements between January 1998 and November 1999. Throughout most coastal regions of the Canadian Atlantic sea surface temperatures were at or near their highest values since 1981. An empirical orthogonal function (EOF) analysis identified two orthogonal modes that accounted for 70% of the overall temperature variance. This EOF analysis suggested that climate in this area has been changing mainly in two spatial patterns, one located in northern areas and a second in the southern part of the zone.

T. Platt made a presentation on interannual variability in chlorophyll fields of the Atlantic Zone based on satellite data. These data revealed major and widespread differerences between years in the timing of the spring bloom. Timing of the bloom was early in 1999. Peak phytoplankton abundance appeared to have been greater in 1999 than in 1998 for most areas. The more synoptic view of phytoplankton in the Northwest Atlantic derived from these satellite data provided an important complement to monitoring programs along sections and at fixed stations.

D. Swain presented a paper by M. Hanson describing dramatic changes in the importance of euphausiids in the diet of cod in the southern Gulf of St. Lawrence. Cod stomachs were sampled from the western area of the southern Gulf in September in 18 years between 1959 and 1987 and in each year from 1990 to 1995. Euphausiids comprised 5-40 % of the diet of cod (by weight in 19 years, % occurrence in 1 year) in all years sampled between 1959-1987 (about 15-40% in 12 of the 18 years). Euphausiids were absent from the cod diet in 1990-1993 and 1995 and comprised only about 5% of the diet in 1994. These results indicate a striking decline in either the abundance or availability of euphausiids in the southern Gulf in the 1990s. During the discussion it was noted that a decline in the importance of euphausiids had also been noted in the diet of northern Gulf cod in recent years. It was suggested that predators like cod may provide a useful sampling tool for information about ecosystem components that we are unable to monitor well using more traditional sampling techniques.

F. Page made a presentation on composite egg and larval distributions of cod and haddock from Cape Hatteras to the Laurentian Channel. This was an information item to indicate that these data were being worked up and would soon be available.

5. Workshop on the Cod Recruitment Dilemma

A workshop on the Cod Recruitment Dilemma was held during the 2000 annual meeting. This section contains the report of this workshop, prepared by the workshop chair, Dr. Martin Castonguay, and the workshop steering committee. Note that table and figure numbering in this section is independent of that used elsewhere in this document.

Introduction

A moratorium on fishing was imposed on most Atlantic cod (*Gadus morhua*) stocks following a period of intensive exploitation in the 1980s and early 1990s. The prevailing perception when the moratorium was put in place was that stocks would quickly rebound after a few years. However it has now been six to eight years and this has not yet happened. We see a slow rebuilding in some stocks while some stocks have not rebuilt or worse have kept on decreasing. As fishery closures are prolonged, there is increasing frustration in the fishing industry who wonders why are stocks not coming back faster.

In contrast to this lack of recovery from recent declines, these cod populations recovered quickly from declines to low abundance in the mid 1970s. The earlier period of decline and rapid recovery was characterized by rapid growth rates and strong recruitment while the recent collapse and slow recovery has been a period of slower growth and weaker recruitment.

As a result of the lack of recovery, the Fisheries Resource Conservation Council (FRCC) requested the Department of Fisheries and Oceans to examine the cod recruitment problem. In its 1997 report, the FRCC stated that "Recruitment is a major issue which must be addressed as a priority. Work has to be done to understand the various factors affecting stock renewal." In March 1998 and 1999 letters to the Minister of Fisheries and Oceans defining research priorities, the FRCC termed the widespread perception that stocks were not rebuilding as anticipated a "dilemma". In these letters, the FRCC recommended that the information be consolidated and presented into a report in a language accessible to a wide audience. The report would present a consolidated description of the state of knowledge with respect to recruitment, listing various hypotheses, knowledge gaps, and further research to be conducted.

DFO's Fisheries Oceanography Committee (FOC) was asked to conduct a workshop on the cod recruitment dilemma and to write a report on the workshop. The FOC nominated a steering committee among its core members to organize the workshop: Drs. Martin Castonguay (chair) and Patrick Ouellet (Institut Maurice-Lamontagne, Mont-Joli), Dr. Doug Swain (Gulf Fisheries Centre, Moncton), Dr. Jake Rice (Head Office, Ottawa), Dr. John Anderson (Northwest Atlantic Fisheries Centre, St. John's), and Drs. Ken Drinkwater and Ken Frank (Bedford Institute of Oceanography, Dartmouth). The steering committee identified key questions that needed to be addressed at the Workshop:

- Is there a recruitment dilemma? Has recruitment been unusually low in the 1990s, or has it been at the level expected from the low spawning stock biomasses? Have recovery rates of the depleted cod populations been unusually slow given estimates of their intrinsic rates of natural increase? Has apparent pre-recruit survival been unusually low in the 1990s, or was it unusually high during the rapid recovery of the late 1970s and early 1980s?

- Can variation in cod recruitment success or pre-recruit survival be related to variation in their abiotic or biotic environment (e.g., climatic variation, predator-prey relationships, ecosystem changes, regime shifts)? Are there environmental or ecosystem differences between the 1990s and late 1970s/early 1980s that may explain the dramatic difference in apparent pre-recruit survival between these two periods? Are there links (either positive or negative) between the recruitment of cod and recruitment success of other fishes or invertebrates?

- Is spawning stock biomass alone an adequate measure of reproductive potential? Can variation in recruitment success be related to variation in the quality of spawners (e.g., age and size distribution of spawners, fish condition, temporal or spatial distribution of spawning)? Were cod stocks in better shape demographically to recover from the decline in abundance in the mid 1970s versus the early 1990s?

Three outside guests were invited to the Workshop: Dr. Mike Heath from the Marine Lab in Aberdeen, Scotland, Dr. Tara Marshall from the Institute of Marine Research in Bergen, Norway, and Dr. Mike Fogarty, from the National Marine Fisheries Service in Woods Hole, MA. Three FRCC members also attended the Workshop: Mr. Fred Woodman, Mr. Bruce Chapman, and Dr. George Rose. Total attendance at the Workshop was about 50 people, mostly from DFO, but also from MUN.

The workshop was divided into four sessions (see Appendix I). The first session, called “Is there a dilemma?”, started with a presentation of hypotheses to account for current levels of recruitment. Following this, DFO scientists from the four regions of eastern Canada (Newfoundland, Maritimes, Gulf, and Laurentian) presented background information on recruitment rate (hereafter defined as the level of recruitment given the observed levels of spawning stock biomass) and on total mortality of adult cod for the seven stocks under consideration (2J3KL, 3NO, 3Ps, 3Pn4RS, 4T, 4VsW, and 4X). Information on total mortality is especially revealing when fisheries are closed since it represents natural mortality. The second session termed “Ecosystems effects on recruitment” examined various physical and biological factors influencing recent recruitment patterns of cod stocks. The third session, “Population effects on recruitment”, focused on relationships between food, growth, and reproduction of individual cod, total egg production by the stock, and recruitment. One hour of discussion followed each session with the invited experts serving as rapporteurs for each session.

On the last day of the workshop, rapporteurs each presented their report. This closing fourth session also included a presentation by the Chairperson of tables prepared by the Steering Committee on stock by stock key factors affecting recovery of cod stocks. Factors considered were (1) loss of substocks or of spawning areas, (2) recruitment rate, (3) adult mortality rates, and (4) size-at-age. The tables were an attempt to achieve consensus on the reasons for current recruitment trends of the various cod stocks. They were prepared on the basis of the evidence heard during the first three sessions of the Workshop.

The Workshop is seen as a step in an iterative process to help us further our understanding of the factors affecting the recovery of cod stocks to historical levels of abundance.

Hypotheses

Dr. John Anderson reviewed some of the central tenets of population dynamic theory that play a critical role in understanding the response of populations to exploitation and factors affecting recovery from a depleted status. The stability and resilience of a harvested population depends on feedback mechanisms that govern the response to exploitation. *Compensatory* feedback is required for a stable equilibrium; sustainable harvesting is not possible without some form of compensation. Example of compensatory processes include increases in age-specific growth and/or maturation and decrease in natural mortality at low population sizes. These are negative feedback mechanisms.

Other forms of feedback mechanisms can be destabilizing. For example, positive feedback resulting in *depensation* can result in unstable population equilibrium points and threshold levels below which a stock will decline to extinction. For example, if mating or fertilisation success is adversely affected a low population size so that the rate of recruitment is reduced, an unstable lower equilibrium point exists. The issue of whether depensatory mechanisms occur in northern cod has been the focus of recent studies.

It was also noted that various changes in the abiotic and biotic environment will affect recruitment success. These changes, broadly classified as Ecosystem Mechanisms (including changes in temperature, food supply, oceanographic mechanisms, predation rates etc.) have the potential to affect substantially the rate of recovery.

Dr. Ken Frank noted that the list of hypotheses of factors affecting recovery of cod stocks should include the issue of substock structure and the potential loss of substocks, affecting the total productivity of the stock(s).

Below is a summary of hypotheses to explain current levels of recruitment of cod stocks. “Recruitment” is defined here as the production of juvenile fish into the spawning population.

Depensatory Mechanisms:

1. **Allee Effect:** too few spawners to successfully reproduce. Could include disruption of ‘normal’ migration patterns.

- Density of adult cod is so low that natural spawning has been disrupted (i.e. over dispersed within home range).
- Historical migration patterns of adult cod have been disrupted such that spawning occurs outside the historical range.

2. **Poor Parental Condition Resulting in Low Spawner Success:** Includes: degree of egg hydration; sperm motility; fertilization success, …
    - Maternal condition is too low to maintain historical fecundity levels.
    - Parental condition is too low to maintain historical spawning success rates (lower egg viability and sperm motility).
3. **Number of Substocks has Declined; Simplification of Population Structure.**
4. **Reduction of Spawning Season due to Collapse in Age and Size Structures.**

Compensatory Mechanisms:

1. **Density Dependent Survival:**
    - At low population sizes, there has been an increase in age specific growth rates resulting in larger sizes at age and lower mortality.
    - At low population sizes, there is a greater availability of preferred habitats resulting in lower juvenile mortality.
    - At low populations sizes, there has been a reduced age at maturity resulting in earlier “recruitment” into the spawning population and, therefore, in lower pre-recruit mortality.

Ecosystem Mechanisms:

1. **Low Egg and Larval Survival Resulting from Poor Environment:** Includes temperatures, food supply for larvae; dispersal (member/vagrant) mechanisms.
    - Cold (warm) temperatures result in consistently low levels of recruitment.
    - Low (high) salinity result in consistently low levels of recruitment.
    - Anomalous T-S conditions result in transient levels of high mortality (e.g., Great Salinity Anomaly)
    - The availability of preferred prey types has declined resulting in low levels of larval survival.
    - Ocean circulation patterns have changed from historical patterns, resulting in a greater degree of egg and larval dispersal from the home range.
    - Poor environmental conditions have resulted in spawners migrating from historical home range (stock area).
    - The predator field has changed, resulting in high levels of egg and larval mortality.
    - Increases in the abundance of historical predators has resulted in high levels of egg and larval mortality.

2. **Low Survival During Pre-Recruit Demersal Phase:** Poor feeding for juveniles (condition); loss of preferred habitat (could include temperature as well as substrates); increase in predators (include seals, seabirds, whales, cannibalism, piscivorous fish, etc…);

- The availability of preferred prey types has declined resulting in low levels of juvenile survival.
- The predator field has changed, resulting in high levels of juvenile mortality.
- Increases in the abundance of historical predators has resulted in high levels of juvenile mortality.
- There has been a significant loss in the availability of preferred habitats for juvenile cod, due to fishing.
- There has been a significant loss in the availability of preferred habitats for juvenile cod, due to a changed environment.

Session I: Is there a dilemma?

This session's title is less trivial than it seems. There is a dilemma, which is that the recruitment is low according to the interpretation of the FRCC. The reason for putting the session title as a question mark is that Steering Committee felt it was not clear that recruitment had been unusually low in the 1990s given the low spawning stock biomass and the intrinsic rates of natural increase of cod stocks. Examining recruitment rate (abundance at age 3 divided by the spawning stock biomass that produced each year-class) across stocks was especially useful in this regard as it provided information on the level of recruitment given current levels of spawning biomass.

DFO scientists from the four regions presented background information on recruitment rate and on total mortality of adult cod for the seven stocks. This information is summarized here to put the recruitment problem of each stock in its proper context.

Northern cod (2J3KL), Grank Bank cod (3NO), and St. Pierre Bank cod (3Ps)

Data for spawning stock biomass (SSB) (Fig. 1) and recruitment (Fig. 2) were obtained from the most recent assessment documents available from the Canadian Stock Assessment Secretariat (CSAS). SSB and recruitment declined steeply in the 1990s for 2J3KL and 3NO but not for 3Ps. An index of cod recruitment rate (Figs. 3 to 5) was estimated as the abundance of cod at age 3 divided by the spawning stock biomass that produced each year-class (R/SSB). Recruitment rates of the three stocks are quite variable and no clear trend is present. Data were taken from the most recent Sequential population analysis (SPA) models, although neither the northern cod (2J3KL) or St. Pierre Bank (3Ps) models were considered acceptable in the recent assessments (Lilly et al. 1998, Stansbury et al. 1999, Brattey et al. 1999, 2000). Therefore, data since the 1990 year-class for the northern cod and since the 1993 year-class in the St. Pierre Bank stock are uncertain. Similarly, recruitment rate was estimated from the annual research vessel (RV) surveys. For RV data, abundance was the standardized catch rate per tow, while the RV spawning stock biomass was estimated as the multiple of the standardized catch rate, the proportion mature (%) and the weight (t). Total instantaneous mortality (Z) was estimated from research vessel surveys (Figs. 6 to 8). This analysis indicates for 2J3KL and 3NO cod a period of high mortality (>0.8) in the early 1990s followed by a gradual decline after fisheries were shut down. In contrast, no trend in mortality is apparent for 3Ps cod.

Northern Gulf of St. Lawrence cod (3Pn4RS)

SSB and recruitment data were extracted from the most recent assessment of the stock, the February 2000 assessment (DFO 2000) (Fig. 9). Maximum SSB and recruitment were reached in the early 1980s and were followed by a gradual decline. Recruitment rate (defined as above), calculated from these data rose steeply in the 1990s (Fig. 9). The method used here to estimate total mortality of adults (Z) is described by Chouinard et al. (1999) (Fig. 9). It consists of estimating Z for moving 4-yr windows using a modified catch curve analysis. An analysis of covariance is calculated with *ln* survey catch rate as the dependent variable, year-class as the class variable and age (ages 6-11 for the Gadus and 5-10 for the Needler) as a covariate whose slope represents Z. SPA estimates of F, averaged over ages 6-11 for the same 4-yr blocks, are also included to provide an indication of variation in fishing mortality. Z has remained high (0.5) after the fishery was shut down on this stock in 1994. Weights at age are also presented in Fig. 9, which indicate a downward trend from the early 1980s to the early 1990s, followed by a recent increase.

Southern Gulf of St. Lawrence cod (4TVn)

SSB and recruitment data were drawn from the most recent assessment of the stock. SSB had declined to a low level by the mid-1970s (Fig. 10A). Strong recruitment from the mid-1970s to the mid-1980s (Fig. 10B) contributed to a rapid increase in SSB to high levels throughout most of the 1980s. SSB declined precipitously in the late 1980s and early 1990s, and has remained at a low level since then (Fig. 10A). Recruitment rate (R/SSB) rose sharply to remarkably high levels in the mid 1970s and then declined to lower levels in the mid-1980s (Fig. 10C). By the late 1980s, recruitment rate had returned to the levels that had persisted from the 1950s to the early 1970s (Fig. 10C). SPA results suggest that recruitment rate has risen to relatively high levels in recent years, though this is not indicated by the survey catch rates (Fig. 10C). Rates of total mortality (Z) and fishing mortality (F) were calculated for ages 7-11 yr, as described above for 3Pn4RS cod. Both F and Z rose sharply to high levels in the late 1980s and then declined sharply in the early 1990s when the fishery was closed (Fig. 10D). However, Z remained relatively high (0.4-0.6) after the fishery closure, suggesting a high level of adult natural mortality in recent years. Weight at age declined sharply in the late 1970s and early 1980s, and has remained at a low level since the mid-1980s (Fig. 10E).

Eastern and Western Scotian Shelf, 4VsW and 4X

Trends in SSB, recruitment, and recruitment rates for Eastern Scotian Shelf cod (4VsW) (Fig. 11) and for Western Scotian Shelf cod (4X) (Fig. 12) were based on July research vessel survey data and a SPA. These three population indicators have been declining or low over the decade for 4VsW cod but show only large interannual variability for 4X cod. Trends in size at age for 4VsW cod by sub-area and Z estimates for ages 4-8 were from the July research vessel survey data (Fig. 13). For 4X cod, trends in condition, size-at-age, and total mortality Z estimates for ages 3-7 from the July research vessel survey data are presented (Fig. 14). Z of 4VsW cod has been increasing over the past two decades while it has been fluctuating without trends in 4X cod. Size at age has been declining over the past two decades in 4VsW cod while it has remained stable in 4X cod (Fig. 14).

Recruitment, mortality, and growth

Several major themes emerged in the discussions concerning the status of cod stocks in Atlantic Canada. First, there does appear to be some level of synchrony in recruitment in the stocks with the highest level of coherence occurring in adjacent stocks. These patterns do suggest the possible role of large scale environmental forcing in the status of cod stocks. Second, a general pattern of decreasing mean weights-at-age and condition factors is evident, suggesting changes in prey availability or other factors. Evidence for increases in natural mortality rates were highlighted and these changes have often been integrated into assessments. Finally, concerns were raised that some substocks have been eliminated and that this is a major factor in the overall lowered levels of productivity of many of the stocks.

Changes in temperature patterns have been noted which may be affecting the dynamics of these stocks. Other aspects of large-scale physical forcing were discussed including changes in the North Atlantic Oscillation which has generally been in a positive phase since the late 1960's. The overall observations concerning recruitment are consistent with common features in each of the stocks. An overall decrease in spawning stock biomass is of course one such feature. However, environmental factors affecting survival cannot be discounted and these changes can act synergistically to affect the response of the cod stocks to exploitation and also affect the rate of recovery. Fishing and natural mortality were both very high in the years that preceded fisheries closures (about 1.0 to 1.5). After fisheries were closed, natural mortality was roughly double the value of 0.2 usually assumed.

The issue of changes in size-at-age is important because it affects both the overall population biomass and the reproductive output of the population (through the linkage between body size and fecundity). If prey availability has changed, altering growth, the overall level of productivity of the stocks decreases and the intrinsic rate of increase also declines, affecting the projected time frames for recovery. Size-selective harvesting practices may modify the age and size structure of a stock by selectively removing fast growing fish, which may result in slower apparent growth rates. Size-selective fishing may also have resulted in a genetic selection against fast-growing fish. The extent to which both types of size-selective processes may have affected observed trends in size-at-age of cod stocks is not known.

Changes in natural mortality rates used in assessments, generally a shift in the range from M=0.2 to 0.4 (usually) in the mid-1980s, have been explored in several analyses. The role of small pelagic fish and marine mammals have been investigated based on known predation relationships. The incorporation of changes in the natural mortality rates in SPAs however in some cases results in undesirable residual patterns. The overall role of potential shifts in natural mortality rates requires further investigation. This factor too affects overall levels of productivity and has important implications for the projected rate of recovery.

Loss of substocks

The question of loss of substocks generated considerable discussion not only during the first session but throughout the Workshop. The key recruitment-related question in relation to substock structure is whether the stock as a whole can achieve historic maximum rates of recruitment with the modern spatial configuration of spawning. An important issue to be resolved is whether former spawning grounds have been eliminated or whether small residual groups remain in the historically important spawning areas. The issue of detectability is particularly important in this regard.

A good part of the discussion of the role of sub-stock structure on recruitment was focused on northern cod (WP29, WP30, WP34, WP35). Here, the most significant impact of the final, devastating bout of exploitation in the late 1980s, appears to have been to eliminate a high proportion of the spatial structure of the spawning stock. Most of the outer shelf components of the spawning distribution were eradicated, leaving a residual coastal component. Clear evidence for erosion of substock structure of 4VsW cod was also presented. It is suspected that exploitation has reduced sub-stock structure for some of the other stocks as well, although the evidence may not be as clear (see Table 1).

Optimum patterns of stock and recruitment for a particular cod stock must be an evolutionary adaptation to growth and mortality conditions in a given ecosystem. The pre-exploited spatial structure of cod stocks probably evolved following the re-colonisation of sub-Arctic continental shelves at the end of the last ice age. It is clear that this evolutionarily adapted state has been significantly altered in some stocks by the intensive exploitation of the late 20th century, such that the current spatial configuration of reproduction may be far from optimal. The genetic basis for sub-regional spatial structuring of fish stocks is not well understood.

Session II: Environmental Effects

During Session II on Environmental Effects a total of 11 presentations were made, 7 with working papers, and one additional paper was tabled. Most fell under three main issues: environmental correlates; changes in distribution and abundance; and early life stage models.

Environmental Correlates

Several presentations during the workshop described analyses of spawning stock biomass (SSB) and recruitment (R) data in relation to environmental indices. These involved searching for correlations between R, R/SSB, or residuals of R from some fitted stock-recruitment model, and aspects of the environment. In the southern Gulf of St Lawrence the analyses showed that the period of exceptional recruitment to the cod stock between 1973 and 1984 coincided with the collapse of pelagic fish stocks in the region (herring and mackerel) (WP33). The hypothesis implied by these results is that the relaxation of piscivorous predation on early life stages was responsible for increased survival and recruitment. There are strong parallels between this conclusion and the results of studies in the Baltic Sea, where there is a similar interaction between cod and sprat. However, the situation was less clear for Scotian Shelf cod stocks (WP31), where a strong inverse relationship between residuals from a Ricker stock-recruitment relationship and the abundance of *Calanus finmarchicus* stages was revealed. This counter-intuitive result suggests that in this case *Calanus* abundance *per se* is not the fundamental driver of cod recruitment, but may act as a proxy for whatever processes are actually promoting recruitment.

Correlations between physical environmental indices and recruitment or survival were generally low or weak. In the southern Gulf of St. Lawrence (WP33) no significant correlations were found. In the northern Gulf (3Pn4RS; WP32) pre-recruit survival was found to improve with later sea-ice disappearance and longer ice seasons. The mechanism underlying this relationship is not understood and is counter to the empirical evidence of negative effects of cold water temperature on egg development and survival. For cod and haddock on the Scotian Shelf (WP 31), temperature correlations with recruitment and survival were positive and statistically significant but weak. Other environmental correlates included nitrates and the position of the Gulf Stream and the Shelf/Slope front but in these cases the correlation coefficients were also weak, although significant. Higher nitrates result in higher recruitment and survival that may indicate higher primary production and eventually food for the fish. The frontal positions were negatively correlated with recruitment and survival indicating that when the fronts are further offshore recruitment improves.

There was little evidence of correlations between the large-scale atmospheric circulation patterns as represented by the North Atlantic Oscillation (NAO) index and recruitment to most cod stocks in the region. However, comparison of the available recruitment time series showed that all stocks in the region except the southern Gulf of St Lawrence showed synchronously increasing recruitment between 1960 and 1970, coinciding with the century minimum in the values of the NAO. Cod stocks in the northeast Atlantic have also shown the same pattern. This synchrony suggests that cod recruitment may in some way be driven by the ocean basin scale climate system, even if we are unable to identify specifically the processes involved.

It was argued that the search for linear correlative relationships between environmental factors and recruitment, survival, or residuals from some stock-recruitment relationship, might be a fruitless endeavour in many cases. The reason is that the factors involved in the processes influencing recruitment are not expected to act linearly or continuously over their full dynamic range, nor over the range of spawning biomass values for any given stock. The existence of compensatory processes in stock-recruitment dynamics implies that environmental factors will act differently at high and low stock sizes. At low stock sizes, environmental factors which influence the density independent recruitment rate will dominate, while at high stock sizes, factors that unleash recruitment from density dependent control will dominate. Hence, we should not expect to find correlative relationships. Synchronous recruitment events occurring in several stocks over ocean basin scales are, however, strong evidence of environmental control, even if continuous relationships with climate indices are lacking for the individual stocks. In spite of the difficulties, exploratory correlation analysis helps to focus attention on particular issues or processes while confirmatory correlation analysis can be used to test specific hypotheses.

During the discussions there was a debate on whether recruitment rate (R/SSB) or recruitment (R) should be used in these analyses. Some participants thought that only R should be used because it is uncertain whether relationships are due to changes in R or changes in SSB if R/SSB is used. Others argued that the point of these analyses was to test for possible effects of ecosystem factors on early survival, so the dependent variable should be an index of early survival, e.g. R/SSB. They argued that the use of recruitment rate rather than total recruitment controls for variation in SSB. In fact, many of the analyses used residuals from a stock-recruitment relationship or included the ecosystem factors as covariates in such a relationship. It was argued that this has the advantage of incorporating (controlling for) compensatory or density-dependent effects on recruitment. There was no consensus on this issue.

Changes in abundance and distribution

Several papers discussed abundance and distribution of juvenile to adult cod as well as associated predator and prey species based upon acoustic, pelagic juvenile fish and groundfish surveys conducted on the southern Labrador shelf to the Grand Banks. There was a sharp decrease in the abundance of spawning cod from 1994 – 1996 that translated into a decline in the estimated number of eggs spawned (WP 29). This in turn was mirrored in an observed reduction in both the distribution and abundance of pelagic juvenile cod. Coincident with the decline in Atlantic cod and shift southward during the first half of the 1990s there was a general southeastward movement by both capelin and Arctic cod (WP 47). These potentially prey upon cod eggs and larvae but are also prey for adult cod. Since 1996 the abundance of juvenile cod has risen, mostly as a result of high catches inshore and on the northern Grand Bank (WP 30). In 1999, condition factor increased, growth rates were higher, larval hatching dates were earlier and duration was shorter. A relatively large year-class was measured on the southern Grand Bank for the second year in succession. Also, in the past two years, capelin and Arctic cod appear to be returning to distributions seen in the late-1980s (WP 34). The recent changes to juvenile Atlantic cod were interpreted as possibly a positive response to a warmer ocean environment (WP 30) while increases in adult cod in the inshore were attributed to high abundance of capelin (WP 34). Although it was suggested that the return of the cod offshore may not occur until capelin appears in large numbers there (WP 34), some workshop participants felt scaling up from a small inshore area to the larger region offshore may not be justified.

Adult cod in 2J3KL appear to be faring better inshore (higher densities; larger, older fish) than cod in the offshore (WP 35). In addition, there has been recent interest in distinguishing and managing individual components within the 2J3KL cod stock complex, with a quota established for inshore waters in 1999. There was rich spatial structure in this management unit (2J3KL) with different ages being located in different areas. Also, evidence suggested separate stock components in 2J, 3K and 3L. If a management regime with two or more components or substocks is to be considered, then it will be important to create separate recruitment indices for the various components.

This led to much discussion on the importance of stock structure on the recovery of the northern cod. It was felt that recovery of the 2J3KL stock might not occur until the various substocks recover.

Early Life Stage (ELS) Models

Two presentations described ELS models. The first by M. Heath focussed on haddock in the North Sea. Using a numerical circulation model, eggs and larvae are advected as passive particles from known spawning sites. The larval durations and the growth rates are temperature dependent while mortality is assumed to be a function of growth alone. As the haddock reach their settling stage, their survival is dependent upon being over or near proper bottom types. Also, mortality in the settlement stage becomes density dependent such that if there is overcrowding in the settlement areas then mortality will increase. Survival to the juvenile stage thus depends heavily upon the circulation patterns which are largely wind driven (to transport them from the spawning sites to settlement areas) and upon the temperature (which affects growth and therefore mortality rates). The second presentation was by D. Brickman on the Browns Bank haddock stock. Haddock spawn on Browns Bank and in some years most are transported into the Bay of Fundy while in other years they are mostly retained on the Bank. Those that are advected into the Bay tend to grow faster and have higher survival than those that remain on the Bank. Thus the drift path of the larvae has an important effect upon both body size and recruitment levels of Browns Bank haddock. A similar model to that described for the North Sea haddock was used although it was not carried through to the density dependent settlement stage. The eggs and larval were advected by the seasonal mean circulation pattern. Hindcasting of the ratio advected into the Bay to those retained on the Bank matched reasonably well with estimates based on observed size. The model was extended to include temperature dependent growth and mortality rates of the larvae and run for several different years that had different wind patterns (circulation) and temperatures (growth and mortality). Recruitment estimates and the model estimates of survival to the end of the larval stage were highly correlated. Future studies will examine more years and better representation of the temperature fields. These studies provide methods to incorporate physical effects of circulation and temperature on recruitment and also provide the spatial context that is generally missing in most recruitment studies. The workshop participants saw the use of such models as very promising and encouraged their continued development.

Other Presentations

Two other presentations were made that did not fall into the above categories. The first was a review of the recent activities of the ICES Working Group on Recruitment Process. Of particular interest was the formation of a study group on the incorporation of process (including environmental) information into the stock-recruitment models. Under the chairmanship of Dr. Carl O'Brien of the UK, they met for the first time in November 1999. Their report, which considers several aspects of the problems relating environment to recruitment, is published on the ICES web page (http:/www.ices.dk/reports/occ/2000/). The second presentation examined the mortality rates of larval fish, and in particular roles of predation and dispersion.

Session III: Population effects on recruitment

Several papers on reproductive biology of cod and its relation to recruitment rate were presented during Session III. The importance of variation in the characteristics of the spawning stock in determining stock reproductive potential was emphasized in WP42. This WP stressed the need to collect the basic biological data required to estimate reproductive potential (e.g., fecundity, condition, egg size and viability) and to incorporate this information into stock assessments and management. WP39 described the extensive work underway in Norway investigating the links between food, growth and reproduction of individuals, total egg production by the stock and recruitment. Variation in condition was an important source of variation in reproductive potential of NE Arctic cod, and a bioenergetic index of stock reproductive potential (total lipid energy) showed a strong positive relationship with estimated recruitment (even though spawner biomass did not). The importance of nutritional status to reproductive potential and the rate of population increase was described for northern Gulf of St. Lawrence cod in WP 40. Fecundity was significantly lower in females in poor condition, particularly those of smaller size. Condition of northern Gulf cod declined significantly in the early 1990s, resulting in reduced egg production which may have contributed to the lack of recovery in this stock. WP45 presented evidence for mass atresia (resorption of oocytes) among cod in an overwintering concentration in Smith Sound, Newfoundland. Atresia was associated with poor condition and skipped spawning by cod in poor condition was suggested to be a possible factor contributing to low spawning success in northern cod. WP41 described the importance of the timing and location of spawning to recruitment success of cod in coastal regions of Newfoundland. Late spawning resulted in faster development (due to warmer water) and reduced probability of being swept offshore. WP46 described trends in recruitment of age-0 cod in Newman Sound, Bonavista Bay from 1995 to 1999, estimated by beach seining surveys. Recruitment has been an order of magnitude higher in recent years than in the earlier years. Recent years of high recruitment were characterized by two distinct pulses of cod settlement, with only the later pulse evident in the earlier years of low recruitment. WP43 described trends in recruitment, SSB, and characteristics of the spawning stock (weighted mean age, proportion of first-time spawners, proportion of females, age of maturity) for 2J3KL, 3NO and 3Ps cod and for 3LNO American plaice. Age of maturity has declined in all the stocks, mean age declined substantially in 3LNO plaice, 2J3KL cod and 3Ps cod, and the proportion of first-time spawners has increased in recent years. WP44 tested effects of spawning stock characteristics (age and size structure) on the recruitment rate of southern Gulf of St. Lawrence cod. There was no tendency for high recruitment rates to be associated with an older or more diverse age structure of the spawning stock, or with a spawning stock composed of larger fish in better condition. This suggests that effects of characteristics of the spawning stock on recruitment success of southern Gulf cod are overshadowed by other sources of variation in recruitment rate, or that the indices used do not adequately describe variation in the reproductive potential of spawners.

A firm foundation of empirical observations fosters the development of detailed statistical models. These models, in turn, lead to new theoretical insights. If data are limiting or non-existent (e.g., fecundity data), then the models which are developed to describe population effects on recruitment can be very misleading. Investigating population effects on recruitment requires more detailed information than is typically available for most stocks. This necessitates collecting new data or revisiting historical data. To stimulate the acquisition of new data the following ideas were proposed: using underutilized data (e.g., Russian data on northern cod), using rapid techniques for fecundity determination, explore the use of proxy variables to represent more difficult to measure variables (e.g., condition or lipid energy to represent total egg production), exploit non-traditional sources of information (e.g., oil:meal ratios from industrial sources), develop links with industry to monitor condition, maturity and fecundity, develop links with aquaculture industry to develop techniques for measuring egg quantity and quality, develop links with international scientists (e.g., through participation in joint projects). The field of population effects on recruitment is developing very rapidly due to new insights into the dynamics of cod reproduction. In the near future more information on these topics will be made available from the activities of the NAFO Working Group on Reproductive Potential. It will be useful to identify the type of data that should be collected routinely so that future fisheries scientists will have a broader range of biological information at their disposal for addressing recruitment variation.

Discussion focused on the practical difficulties faced by managers who must make real-time decisions based on limited data and imperfect knowledge. Options for doing this included a scorecard approach whereby key processes are identified and represented by biological/physical variables that are routinely monitored. The effects of these variables on the variable of interest (e.g., recruitment) is tracked in a qualitative (good/bad) or semi-quantitative fashion. Using a semi-quantitative approach is, in practice, a difficult sell. There is accumulating evidence that condition of spawners has a significant impact on recruitment. This information could easily be incorporated into the assessment although changes would be required so that it would impact advice (choose lower quotas when condition is low). Describing variation in condition requires an understanding of seasonal cycles in energy acquisition. This is, in part, dependent on food. It is unfortunate that for most stocks information about feeding is so limited. Egg surveys are one means of directly measuring total egg abundance. From a technical perspective, it is easier to sample eggs when they are in the ovary. Consequently, monitoring fecundity and abundance and maturity stage of spawners is the more expedient way of establishing total egg production. However, egg surveys do provide very valuable information about the temporal and spatial fate of eggs that can be coupled with particle tracking models. Surveys of early pelagic juveniles are very useful indicators of year-class strength for several cod stocks (Iceland, Faroe Islands). Future assessment methods should make greater use of maturity information such that the rate at which immature fish are harvested relative to mature fish is clearly specified.

Session IV: Discussion and Conclusions

There was considerable discussion on how recruitment rate was calculated for different stocks, particularly 4T and 2J3KL. Most of the questions seemed to be resolved.

It was noted that in some cases the current SPA (sequential population analysis) model was not accepted and should not be used. In addition, it was acknowledged that there is uncertainty in SPA-based estimates of recent recruitment rates due to possible retrospective patterns. Therefore, research vessel survey data was deemed most relevant in terms of assessing recent trends in R/SSB.

Drs Mike Fogarty and Mike Heath questioned the value of calculating the recruitment rate, R/SSB. They noted that most of these stocks appear to show strongly compensatory recruitment rates, so that recruitment rate declines as SSB increases. Thus, one needs to consider the level of spawning stock biomass (SSB) when interpreting recruitment rate. Dr. Mike Fogarty suggested that it would be better to estimate the Ricker parameter α. They suggested that using R/SSB, as was being done in the workshop, was assuming that it equalled a constant, rather than declining as SSB increased.

Dr. Doug Swain disagreed with the above interpretation. He acknowledged that one would expect R/SSB to be highest at small SSB due to compensatory mechanisms, declining as SSB increased, and agreed that one would need to fit a stock-recruitment relationship to make long-term predictions about recovery rates (due to declining R/SSB as SSB increased). However, he maintained that R/SSB provided a useful indication of the recruitment rate in a particular year. He noted that there was a perception that recruitment rate was unusually low (the opposite of what one would expect at low SSB if recruitment rate was compensatory). Dr. Swain rightly pointed out that the key question that the Steering Committee identified for the workshop was whether current recruitment rates were unusually low, and that estimates of the actual R/SSB in recent years were needed to answer this question. He maintained that fitting a stock-recruitment over an extended time period would not provide a simple answer to this specific question, though Dr. Mike Fogarty suggested that different relationships could be fit for different periods. Dr. Jake Rice commented that R/SSB was an indication that spawners are still producing young fish. Dr. Mike Heath concluded that they would have to agree to disagree.

Most of the discussion following the invited experts presentations focused on an attempt to achieve consensus on the situation for each stock, starting with the stocks for which the answer seemed to be the most straightforward. The chairperson, Dr. Martin Castonguay, presented tables prepared by the Steering Committee on stock by stock key factors affecting recovery. Factors considered were (1) loss of substocks or in the area occupied by spawners, (2) recruitment rate, (3) adult natural mortality rates, and (4) growth (size-at-age). The tables were prepared on the basis of the evidence heard during the first three sessions of the Workshop. Of note, only the second factor deemed important with respect to the recovery of cod stocks concerned directly the recruitment issue, which indicates that the recovery issue is a larger problem than just recruitment. The natural mortality topic was the theme of a DFO High Priority program whose outcome was summarized at this workshop (see extended abstract of WP 25 in this report) while the growth topic was the subject of a previous FOC theme session. Considerable discussion and debate ensued this stock by stock presentation that led to refinements of the tables. A consensus-derived table stemming from that discussion is presented in Table 1, which summarizes factors affecting recovery for each stock. The time period referred to in the Table is the 1990s. The following section presents a stock by stock discussion of these factors with a review of the hypotheses presented in the introduction to explain current levels of recruitment as they apply to each stock.

Newfoundland stocks: 2J3KL, 3NO, and 3Ps

If we address this question from the workshop perspective of R, SSB and R/SSB then the overall conclusion is that things look poor for 3NO cod, may be looking up for 2J3KL cod but have a long way to go, and the 3Ps stock did not collapse so “recovery” per se is not an issue; although the apparent low survival (i.e. recruitment rate) and low levels of R in recent years indicates that things might be slowing down for 3Ps.

It seems problematic to address the recruitment dilemma question from the perspective of growth, age of maturity and parental condition. George Lilly has analysed these data for 2J3KL and 3Ps cod and concluded it is not possible to determine changes in body condition and individual growth due to possible aliasing in the observations (Lilly 1998a, 1998b). This alias, he points out, results from a single fixed sampling time for populations that change the timing of their seasonal physiological cycle in relation to spawning and feeding. However, age at maturity has declined in all three cod stocks and there has been some evidence that condition was lower during the 1990’s, although this may be increasing in recent years. Finally, the collapsed age structure in 2J3KL and 3NO cod must be regarded as detrimental to population growth.

If we address this question from the perspective of mortality estimated from RV data, then things are finally improving for 2J3KL and 3NO cod in that the common slopes of mortality across ages 3-7 years and four survey years are now $< 0.2\ y^{-1}$. The RV data from the 3Ps survey are so erratic that no conclusions can be drawn. There is a related question of mortality, which can be addressed using the “Shelton” method of estimating RV mortality for individual year-classes on a bi-annual basis. Using this method for the 2J3KL cod, current mortalities are greater than the 1980’s but are much less than late 1980’s and early 1990’s. In addition, the trend in these bi-annual mortalities has been to decrease in magnitude since about 1991 – 1992. Results for Shelton’s Z’s are less clear for 3NO cod, where, since 1996, mortalities on cod ages 3-6 years appear to be reduced. It would probably be prudent to examine mortality for each stock using the Shelton method of estimating Z.

If we address this question from the perspective of the environment, then it is clear that the environment has played a role in recruitment rate of cod in the Newfoundland region. Environmental conditions were generally warm and good in the 1950’s and 1960’s, generally deteriorated through the 1970’s and 1980’s to the very cold and poor conditions of the late 1980’s and early 1990’s. In recent years, since about 1994 – 1996, conditions have been improving. So the prospects for survival, at least for 2J3KL and 3NO cod, are looking up in the future; but who wants to predict? The relation of survival with environment for 3Ps cod has broken down since the mid-1980’s.

If we address the question from the perspective of the 0-group survey, unique to 2J3KL and 3NO cod, then year-class strength declined from 1994-1996 for 2J3KL cod but has been improving since then. In particular, the 1999 year-class is one to two orders of magnitude greater than anything we have seen in the 1990's. However, the production of juvenile cod continues to originate almost exclusively from the inshore area along the NE coast of Newfoundland. There continues to be almost no spawning fish offshore and no pelagic juveniles. We will return to the inshore component of the 2J3KL cod below. The 3NO cod produced virtually no juvenile cod until the 1998 year-class, which was relatively very large. In 1999, a second relatively strong year-class was measured although less than the 1998. The production of juvenile cod in 3NO appears to be linked with a warming of bottom waters in spring and possibly a migration of adult cod into the area from the adjacent 3Ps zone. So, by 1998 in 3NO cod and by 1999 in 2J3KL cod, year-class abundance was up significantly.

If we address the question from the perspective of stock components, then it is clear that the offshore spawning components for 2J3KL cod are essentially gone. Inshore, spawning components remain along the NE coast of Newfoundland but are essentially absent from southern Labrador. The size, or SSB, of these components remains essentially unknown except for the concentration in Smith Sound, Trinity Bay which has typically been measured as 15,000 to 22,000 t total biomass, where most of this would be spawning biomass. Inshore, the current estimate is that there might be 55,000 t of cod in 3K and northern 3L but it is not possible to estimate in southern 3L due to mixing from 3Ps. In 3NO, there is no indication of spawning components, or substocks, based on previous studies. However, if there were substocks these may have been lost with the collapse of the SSB. In 3Ps, there are inshore and offshore components. Given the relatively large SSB currently in 3Ps, it is doubtful that there has been any significant loss of substocks. However, migration into and out of the 3Ps stock area remains a concern.

Results from a life history model by Hutchings (1999) suggest that changes in mortality rates on immature and mature cod had the biggest effect on the rate of population increase (*r*), compared to changes in age at maturity and individual growth rate. For example, an increase in mortality on mature cod from 0.20 to 0.45 y^{-1}, in the absence of changes to weights at age and to pre-reproductive mortality, reduced population growth rate from 14-18% to 8-10% y^{-1}. Here, we have presented evidence for the three Newfoundland cod stocks that recruitment rate has been low during the 1990's. We have also demonstrated that mortality rates have been relatively high for 3-7 year old cod during the 1990's as well, and only recently have these declined. Therefore, the major factor affecting recovery of the three Newfoundland stocks may be the relatively high mortality rates being experienced by both juvenile and adults. The recent trend in reduced mortality rates for age 3-7 year old cod in 2J3KL and 3NO is encouraging. However, it appears that mortality rates in age 0-3 year old cod remains high for 3Ps and 3NO stocks. Finally, the increased abundance of pelagic 0-group cod in 2J3KL and 3NO is encouraging as it indicates the production of cod has increased. However, if mortality rates remain high during the demersal juvenile stage then recovery in these stocks may remain low.

Caveats relative to conclusions for Newfoundland stocks

The inshore area along the northeast coast of Newfoundland remains very problematic to the assessment of the 2J3KL cod stock. Currently, it is the only area in which significant concentrations of adult cod have been reported. Historically, the inshore zone was the primary nursery area for the stock. As fish aged beyond 2 years, they were increasingly found within the offshore area demonstrating an ontogenetic migration in the autumn (Dalley and Anderson 1997, Anderson and Gregory 2000). This means our estimates of R/SSB in recent years are suspect because we should expect juvenile cod age 3 to migrate into the offshore zone during the autumn and, therefore, to be captured by the RV survey. However, the survey estimates almost no SSB in recent years (<0.25% historical mean). Therefore, it is likely that cod spawned inshore are migrating onto the offshore and this has resulted in the large R/SSB values in recent years. If true, then the outlook for the offshore component of 2J3KL remains bleak.

The lack of any reasonable estimate of either R or SSB for this stock from the inshore means that most predictions (i.e. outlooks) for the stock remain largely in the realm of best guesses. The only reliable measure we have is the 0-group survey that has indicated conditions are improving. However, no one knows at this point whether or not these juvenile fish will show up in significant numbers at age 3, and older.

The co-occurrence of both adults and juveniles within the inshore area all year raises concerns regarding cannibalism. Anderson and Gregory (2000) demonstrated that cannibalism increased with broader distributions of 1 and 2 year old cod into the offshore overwintering areas of the Northern cod. Currently, there is no seasonal inshore – offshore migration. However, this cannibalism issue, like most others, remains undressed scientifically.

Historically, migrations between 3Ps and 3NO occurred and these varied over time. Re-stocking of 3NO from 3Ps remains a likely possibility. The increasing trend in bottom temperatures and the general ameliorating environmental conditions are encouraging, especially when matched with the increased abundance of juvenile fish from the 1998 and 1999 year-classes.

Currently, a tagging program being carried out by Dr. John Brattey has demonstrated that there is a significant seasonal migration of cod from Placentia Bay (3Ps) northwards along the coast into the Conception Bay and Trinity Bay areas (3L). The degree to which this migration occurs in spring before or after spawning remains open to question. Again, re-stocking at least the inshore 3L portion of the 2J3KL stock area remains a possibility. Moreover the highly variable RV data indicate that the 3Ps survey is a very poor indicator of abundance. Positive mortalities, for example, indicate that cohort size would have increased from one year to the next, suggestive of immigration into the stock area.

Linking Hypotheses to recruitment for Newfoundland cod

Under Depensatory Mechanisms, there is indirect evidence that all four mechanisms may have occurred in the Northern cod stock (2J3KL) and the southern

Grand Bank cod stock (3NO) (Lilly et al. 1999; Stansbury et al. 1999; Anderson and Dalley 2000). There is no evidence of depensation in the 3Ps stock. It should be noted that sampling programs are generally poorly designed to detect depensation.

Under Compensatory Mechanisms: Density Dependent Survival, there is no indication that growth rates have increased significantly. Contrary to expectations, mortality has increased in the absence of fishing for 2J3KL and 3NO cod. All three cod stocks have shown a significant decrease in the age of maturity. So, it appears this is the only way these cod stocks have been able to compensate. Here we should note the lack of seasonal data with which we can properly determine if individual growth and condition has varied for the NF cod stocks. There is no information on habitat availability or how this might have changed to effect mortality.

Under Ecosystem Mechanisms, Low Egg and Larval Survival, there is evidence that the environment was poor in the late 1980’s and early 1990’s and this may have lead to low survival of eggs and larvae (this was not examined at the Workshop). A similar environmental period occurred briefly in 1970 and 1971, known as the Great Salinity Anomaly, and this was associated with low survival (there are primary publications on this, for reference). As far as understanding what mechanisms might have operated, as outlined in the hypotheses, we have very little idea. The study presented by Anderson and Rose (see abstract of WP 29) demonstrated that reduced abundance of pelagic juveniles resulted from both a reduction in the number of spawners offshore 1994-1996 and high egg and larval mortality in 1996.

Under Ecosystem Mechanisms, Demersal Phase, there is evidence of low R/SSB for all three stocks that might relate to low survival as 1 and 2 year old cod. The seal issue is a big one for the 2J3KL cod, as the diet data and consumption models indicate the predation impact is on 1 and 2 year old cod and that approximately 88,000 t may be consumed each year. The increase in the seal population and the lack of seasonal migrations of cod between inshore and offshore areas may indicate that the predator field has changed. But there are no direct studies on this, during winter, when the effect might be greatest. Again, this was not examined at the Workshop.

Northern Gulf, 3Pn4RS cod

Spawning stock biomass of northern Gulf of St. Lawrence cod gradually declined to a minimum in 1994 and has slowly recovered since. Recruitment has been weak through the 1990s. Recruitment rate has risen in the 1990s, which could indicate a compensatory response of the stock to low abundance levels (Castonguay 2000). Hence the slow recovery of the stock cannot be accounted for by low recruitment given the observed low level of spawning stock biomass. Total mortality of adult cod calculated from survey data has been around 0.5 from 1994 to 1997. Taking fishing mortality into account suggests that natural mortality has been between 0.3 and 0.4 for the same period, i.e., about twice the level of 0.2 traditionally assumed. There has been a pronounced environmentally-driven decline in size-at-age of cod in the late 1980s, early 1990s, indicative of a decline in growth production and hence in surplus production which played a role in the stock collapse. There is some evidence for the loss of substocks in northern Gulf cod indicated by the small area occupied by spawners, although this remains to be investigated in detail.

Linking hypotheses to recruitment for 3Pn4RS cod

In the case of northern Gulf cod, there is evidence for the second depensatory mechanism, poor parental condition resulting in low spawner success (Lambert and Dutil 2000). There is also indirect evidence for mechanism 3, as mentioned above (simplification of population structure), although this has not yet been examined in detail. Recruitment appears to be compensatory in this stock with high recruitment rate at low SSB. The only known compensatory mechanism is the reduced age at maturity in response to the decline in abundance (see Trippel et al. 1997). It is noteworthy that size-at-age has not increased in response to a reduction in abundance, but has actually declined in the late 1980s, early 1990s, due to a decade of colder than normal water temperatures (Dutil et al. 1999) linked to unfavorable conditions of the North Atlantic Oscillation (Drinkwater 1996). Under Ecosystems Mechanisms, evidence points to a detrimental effect of a cold and thick cold intermediate layer on egg development and survival (Ouellet 1997). No relationship could be detected between early (pre-recruit) recruitment rate of 3Pn4RS cod and indices of seal abundance or climatic indices. There is no information on survival during the pre-recruit demersal phase in this stock.

Southern Gulf of St. Lawrence, 4T cod

Current recruitment rate for this stock is average or above average. One reason why the recovery from the previous collapse in the 1970s was so rapid compared to the present situation was that the rate of recruitment during the previous collapse was unusually high (rather than the current rate being unusually low). Two other differences contribute to the present lack of recovery: growth rates or size-at-age are now low and adult natural mortality is high. There is no evidence for loss of substocks in recent times (i.e., since the 1970s), though this has not been investigated in detail. In conclusion, the dilemma of little recovery appears to be due to low growth rates (low weight at age) and a high adult natural mortality rate.

Linking hypotheses to recruitment for 4TVn cod

Recruitment rate appears to be strongly compensatory in this stock, with relatively high R/SSB at low levels of SSB. There are no data available to identify the cause of the decline in R/SSB at high levels of SSB. Recruitment rate of southern Gulf cod appears to be strongly affected by the extent of predation by pelagic fishes, principally herring and mackerel, on cod eggs and larvae. The very high rates of recruitment of southern Gulf cod in the mid to late 1970s coincided with the collapse of herring and mackerel stocks in this area (Swain and Sinclair 2000). These stocks of pelagic fishes are currently at high levels of abundance in the southern Gulf, and their negative effect on recruitment rate may be one reason why the current recovery has been slower than the very rapid recovery of this stock from the previous collapse in the mid 1970s. No relationship could be detected between early (pre-recruit) survival of 4TVn cod and indices of seal abundance. Likewise, no strong relationships were detected between recruitment rate and climatic factors for this stock, though there was a slight but significant tendency for recruitment rate to be higher in years when spring ice break-up occurred at intermediate dates. (The timing of the spring migration of cod into the southern Gulf is related to the timing of the disappearance of ice from the area [Sinclair and Currie 1994]). Although there have been large changes in the age and size composition of spawners and in their growth rate and condition over the past 30 years, no relationships could be detected between these characteristics of the spawning stock and recruitment rate of southern Gulf cod, even after accounting for the effect of pelagic fish biomass on recruitment rate. There is no evidence of depensation over the range of SSB that has been observed for this stock. In summary, recruitment rate of southern Gulf cod appears to be strongly related to cod SSB and pelagic fish biomass, declining with increases in both these factors. No strong relationships of recruitment rate with other factors (climate, spawning stock characteristics, seal abundance) were detected for this stock.

Eastern Scotian Shelf, 4VsW cod

The current recruitment rate for this stock has been below the long-term average. This is in contrast to the high recruitment rate observed during the previous collapse in the 1970s. Also, current size-at-age is very low and natural mortality rates are very high which are contributing to the lack of recovery. The productivity of the stock is very low and there are several factors causing increased mortality overall as well as seal predation on the younger age groups. The spawning stock biomass has not rebuilt since the closure of the fishery.

Linking hypotheses to recruitment for 4VsW cod

Recruitment rate was generally inversely related to SSB suggesting increased survival at low SSB (i.e. compensation). Recruitment rate was extremely high during the 1970s and relatively low during the 1980s. During the 1990s, recruitment rate has generally been well below the long-term average. Adult size at age peaked in the late 1970s and has declined steadily to present small sizes. Condition peaked in the mid-1970s and steadily declined to an historic low level in 1994; recent increases in condition have occurred. Recruitment rates and adult condition were correlated suggesting a maternal effect on offspring survival. Overall, small adult body size and low adult condition were associated with weak year-classes and poor survival.

Surveys indicate that since the mid-1980s, there has been an increase in the mortality of cod, other than that attributable to fishing, and which has persisted even after the closure of the fishery. The instantaneous rate of total mortality averaged 0.75 prior to 1986, rapidly increased during the late 1980s as the fishery intensified, and currently has remained high. The current high rate of natural mortality of cod may be due to several factors, including direct and indirect effects of harsh environmental conditions and predation by seals but these possibilities were not examined at the Workshop.

It is also noteworthy that during the mid-1980s the spring-spawning component of this stock, that was distributed on Western/Sable Island/Middle Banks area, apparently disappeared. This hypothesis was supported by both biological and fishery data (see Frank et al. 1994. ICES mar. Sci. Symp. 198: 110-120) and would be an important factor associated with reduced productivity of the stock if the situation has not changed.

Western Scotian Shelf, 4X/5Y Cod

The 4X/5Y cod stock did not collapse and has never been closed to fishing on a year round basis, so “recovery” per se is not an issue. However, this stock does provide an interesting contrast to the collapsed stocks. It is notable that seal predation is not considered an important component of natural mortality in this stock and environmental conditions have been relatively stable during the past decade. Trends in size at age and condition have not been evident. A spawning area closure on Browns Bank (intended primarily for haddock) has also been in existence and this may have had some benefit to cod.

Workshop Conclusions

Conclusions represent the consensus view from Workshop participants on factors affecting recovery of cod stocks:

- Rapid recovery from previous levels of low abundance of cod stocks in the mid 1970s appears to have been anomalously fast. This may have contributed to create too high expectations for the current recovery.
- There appears to be considerable variation among stocks in the factors affecting recovery of cod stocks to historical levels of abundance, but clearly recovery is more than just a recruitment rate issue.
- Recruitment rate does appear to be lower than normal for some stocks (3NO, 3Ps, 4VsW, and 4X). However, for the three other stocks (2J3KL, 3Pn4RS, and 4T), recruitment rate is not low; hence, the slow recovery (or the lack thereof) cannot be accounted for by this parameter.
- For some stocks, loss of spawning components and/or reduced area occupied by spawners may be preventing recovery (2J3KL, 3NO, 3Pn4RS, and 4VsW).
- A decrease in growth rate (size-at-age) has resulted in a decline of growth production of stocks, which has impeded recovery for some stocks in the first half of the 1990s (2J3KL, 3Pn4RS) and which is still impeding recovery in some cases (3NO, 4T, and 4VsW).
- A high natural mortality of adult cod has also slowed down recovery for some stocks (3Pn4RS, 4T, and 4VsW).
- For all the stocks, changes in structure of the spawning stock (low weighted mean age of spawners, low age diversity, small size) due to intensive fishing in the late 1980s and early 1990s contribute to the problem. To quote Dr. Mike Fogarty, “iteroparity

(i.e., the fact that fish will spawn over many years) is nature's insurance policy and we disrupt it at our peril."

- Given the collapsed age structure and spawning stock biomass of these stocks and the restricted, or collapsed spawning areas, we now are in a unique phase of the history of these stocks.
- Hence, past stock re-building will not be good at predicting future trajectories.
- For many stocks, and in particular 2J3KL and 4VsW, intensive fishing eliminated spawning components and most of the spawning biomass. Scientists do not know if and when the abundance levels of the past will come back but it is clear that until spawning components and spatial structure of spawning are re-established, recruitment comparable to historical levels is not likely to occur.
- Any fishing that crops the little surplus production that the stocks are now yielding may well prevent any future rebuilding.

Recommendations

- After a few years of complete moratorium, fishing mortality has climbed rapidly in some stocks in the past 2-3 years. Although precautionary reference points have not been agreed to for these stocks, their biomasses generally remain far below those associated with even average productivity. Given their current rates of recruitment, growth and natural mortality, further rebuilding of these stocks will be slow, and may not occur at the fishing mortalities achieved in the most recent years. Every effort should be made to facilitate rebuilding to larger spawning biomasses, consistent with the principles of precautionary management of productive resources. This would argue that fishing mortality should be kept to the lowest possible level, and that high priority should be given to establishing appropriate objectives, reference points, and risk tolerances for these stocks.
- The issue of substock structure should be examined in detail for all stocks to determine how modern spatial configurations of spawning differ from historical ones and to assess how such differences impact on recruitment at the stock level.
- More attention should be devoted to monitoring spawning potential of each stock (condition, maturity, fecundity) to provide a broader range of biological information than is currently available for addressing recruitment variability.
- For northern cod, the co-occurrence of both adults and juveniles within the inshore area all year raises concerns regarding cannibalism. Cannibalism should be quantified and its impact on stock recovery assessed.

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Table 1. Factors affecting recovery of cod stocks, obtained from a consensus-derived discussion on last day of Workshop.

Factors affecting recovery	**2J3KL (offshore)**	**3NO**	**3Ps**	**3Pn4RS**	**4T**	**4VsW**	**4X**
Loss of substocks (or reduction of spawning area)	Evidence	Spawning area reduced	No evidence	Evidence	No evidence	Evidence	No evidence
Recruitment rate	Rose to average	Low	Low	High	Average or above	Low	Low
Adult mortality rates	Average	Average	Average	High	High	High	No change
Size-at-age	Rose to above average	Below average	Rose to above average	Rose to above average	Low	Low	Average

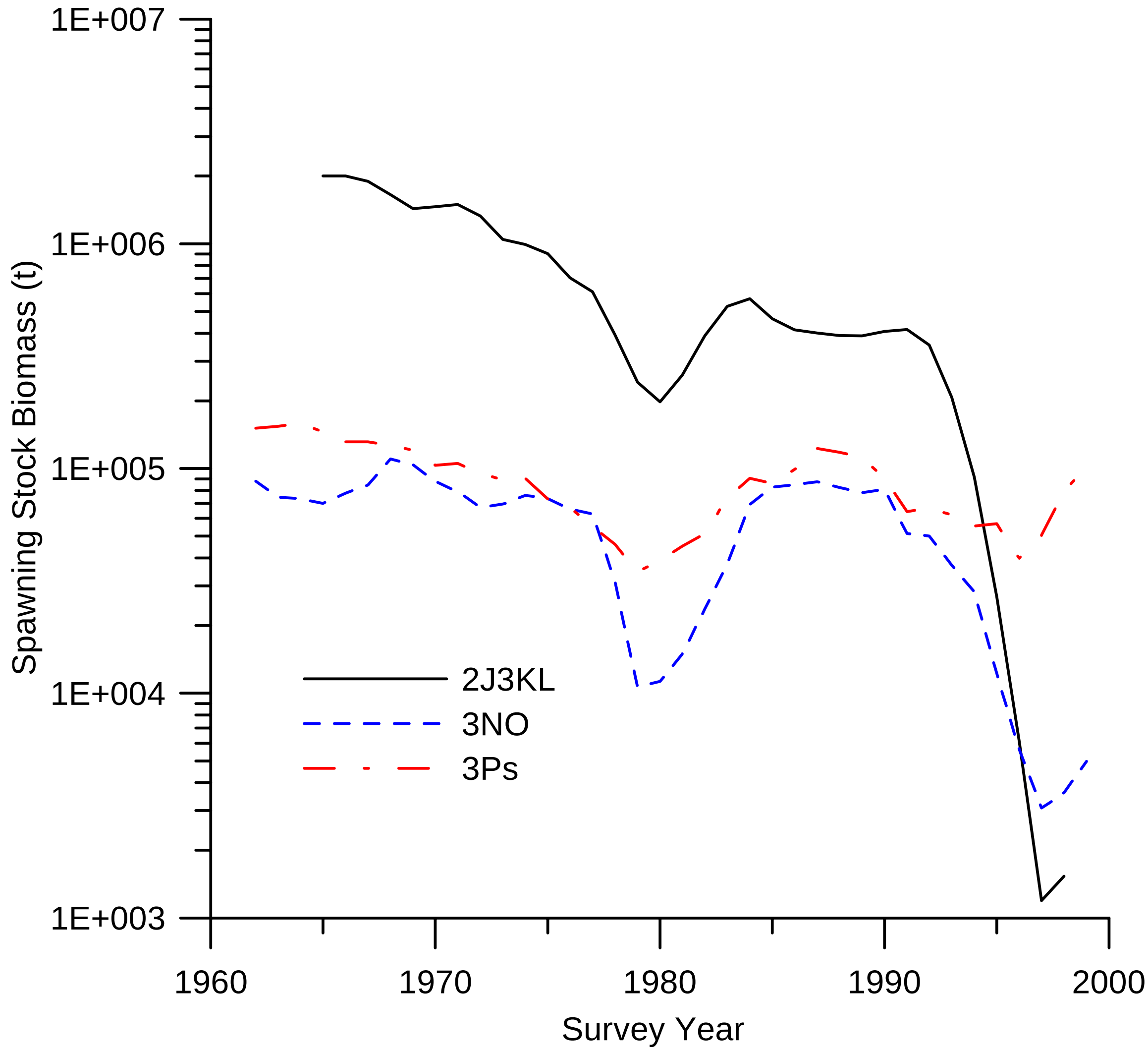

Figure 1. Spawning stock biomass (t) for northern cod (2J3KL), Grand Bank cod (3NO) and St. Pierre Bank cod (3Ps), as estimated from the most recent Sequential Population Analyses.

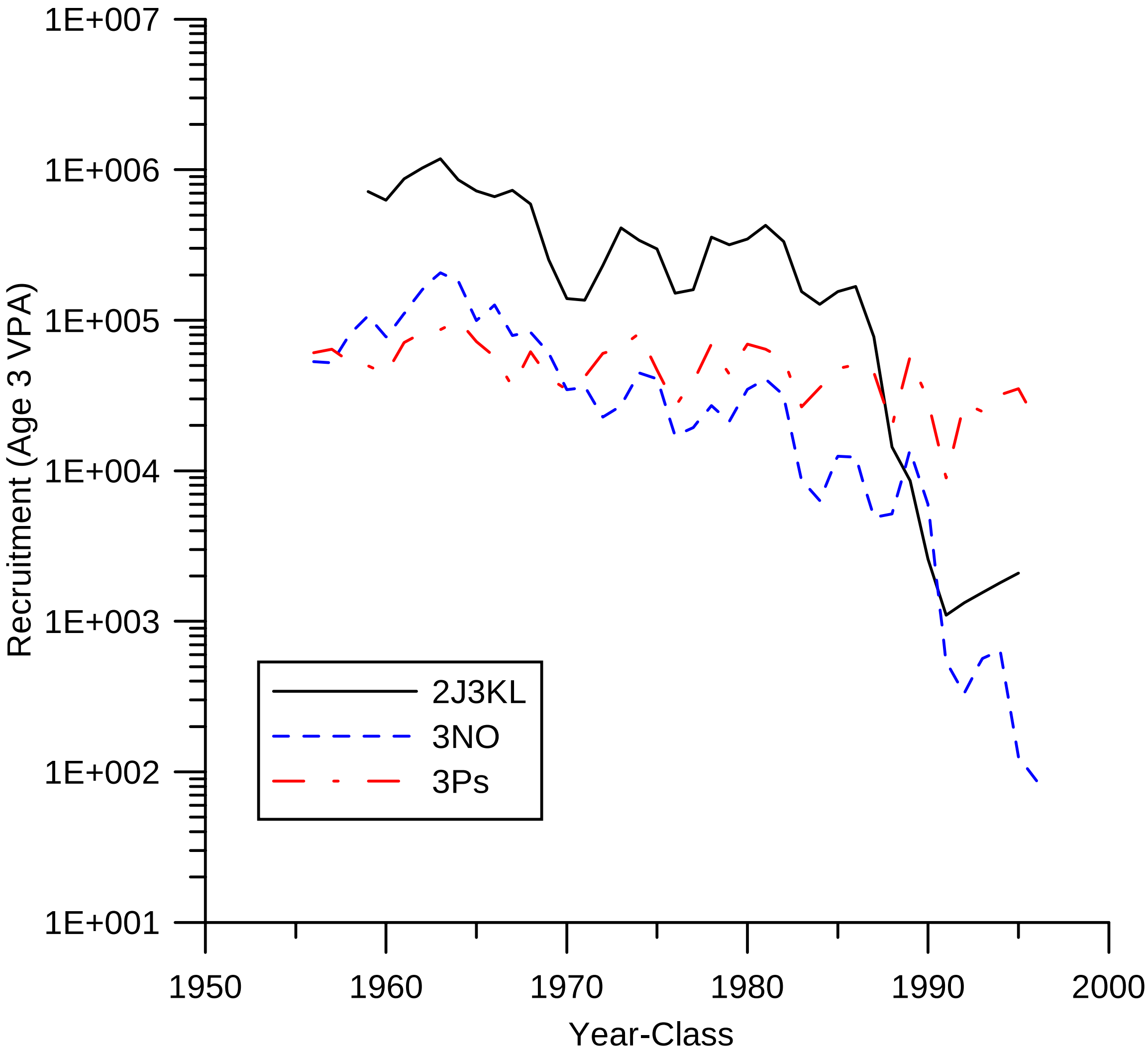

Figure 2. Recruitment in the northern cod (2J3KL), Grand Bank cod (3NO) and St. Pierre Bank cod (3Ps), as abundance estimated at age 3 by Sequential Population Analyses.

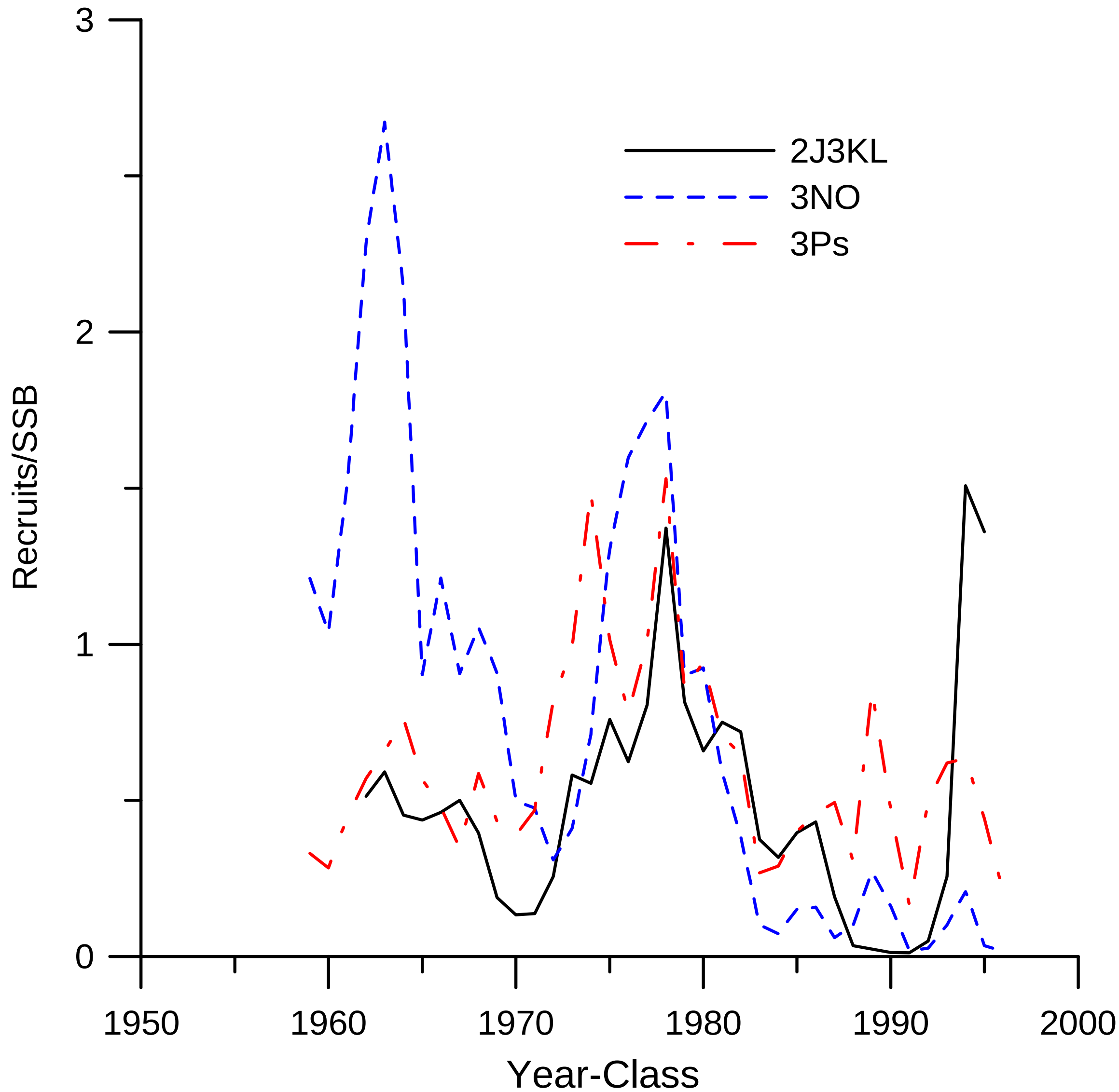

Figure 3. Recruitment rates, estimated as the number of age 3 cod in SPA divided by the spawning stock biomass (SSB) for northern cod (2J3KL), Grand Bank cod (3NO) and St. Pierre Bank cod (3Ps).

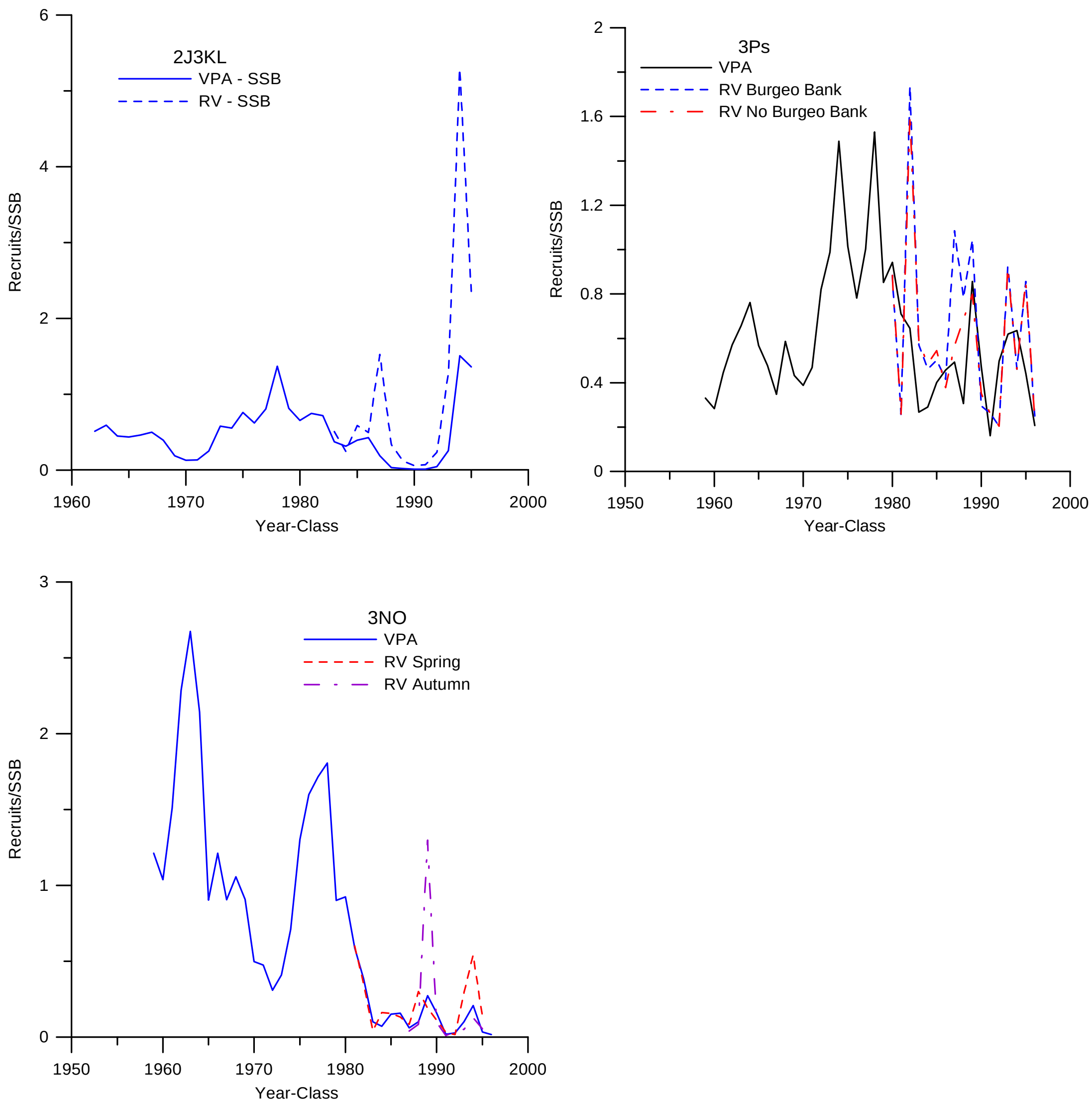

Figure 4. Comparison of recruitment rates, estimated as the number of age three year old cod divided by the spawning stock biomass (SSB) from Sequential Population Analyses (VPA) and as the mean number per tow of age three cod divided by SSB estimated from bottom trawl surveys (RV). For northern cod (2J3KL) surveys were available for autumn. For Grand Bank cod (3NO) spring and fall surveys are available for some years. For St. Pierre Bank cod (3Ps) estimates are presented for different spring survey areas that include and exclude Burgeo Bank from the estimates.

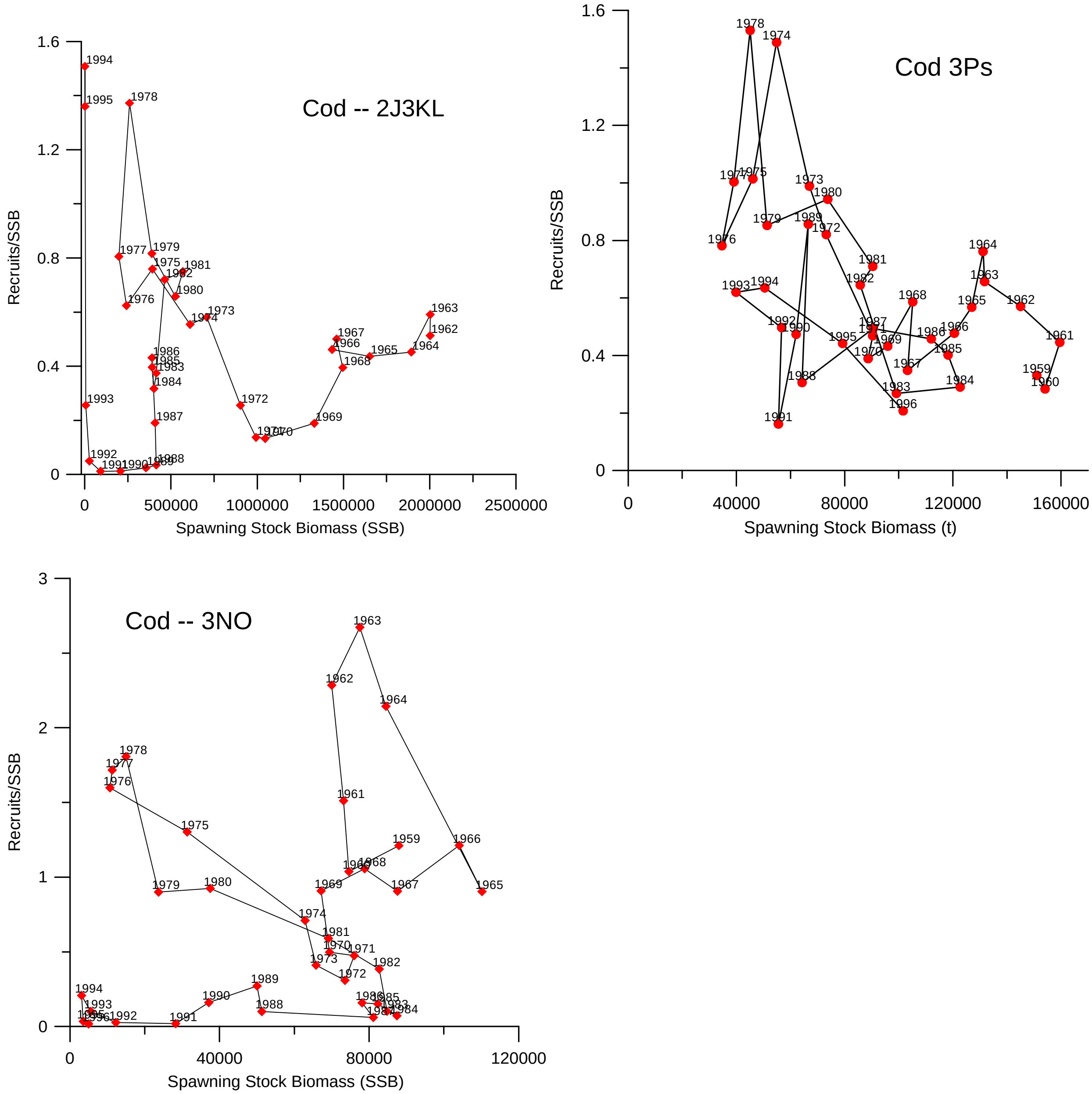

Figure 5. Recruitment rates, estimated as the abundance of three year old cod divided by the spawning stock biomass (SSB), compared to SSB for northern cod (2J3KL), Grand Bank cod (3NO) and St. Pierre Bank cod (3Ps).

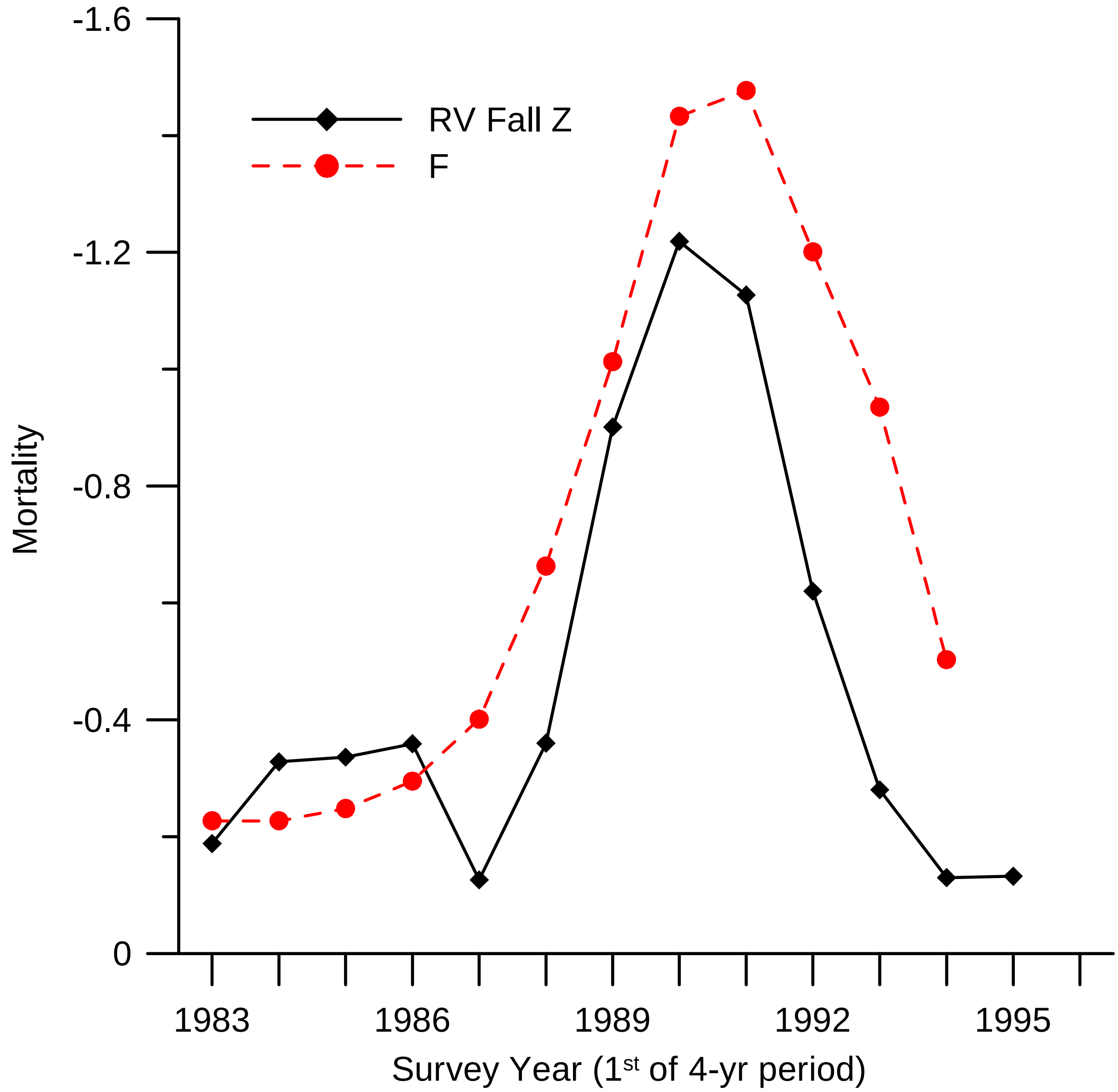

Figure 6. Instantaneous mortality estimated from research vessel surveys for the northern cod stock (2J3KL) for ages 3-7 years for four year time periods, beginning with the 1983-1986 period.

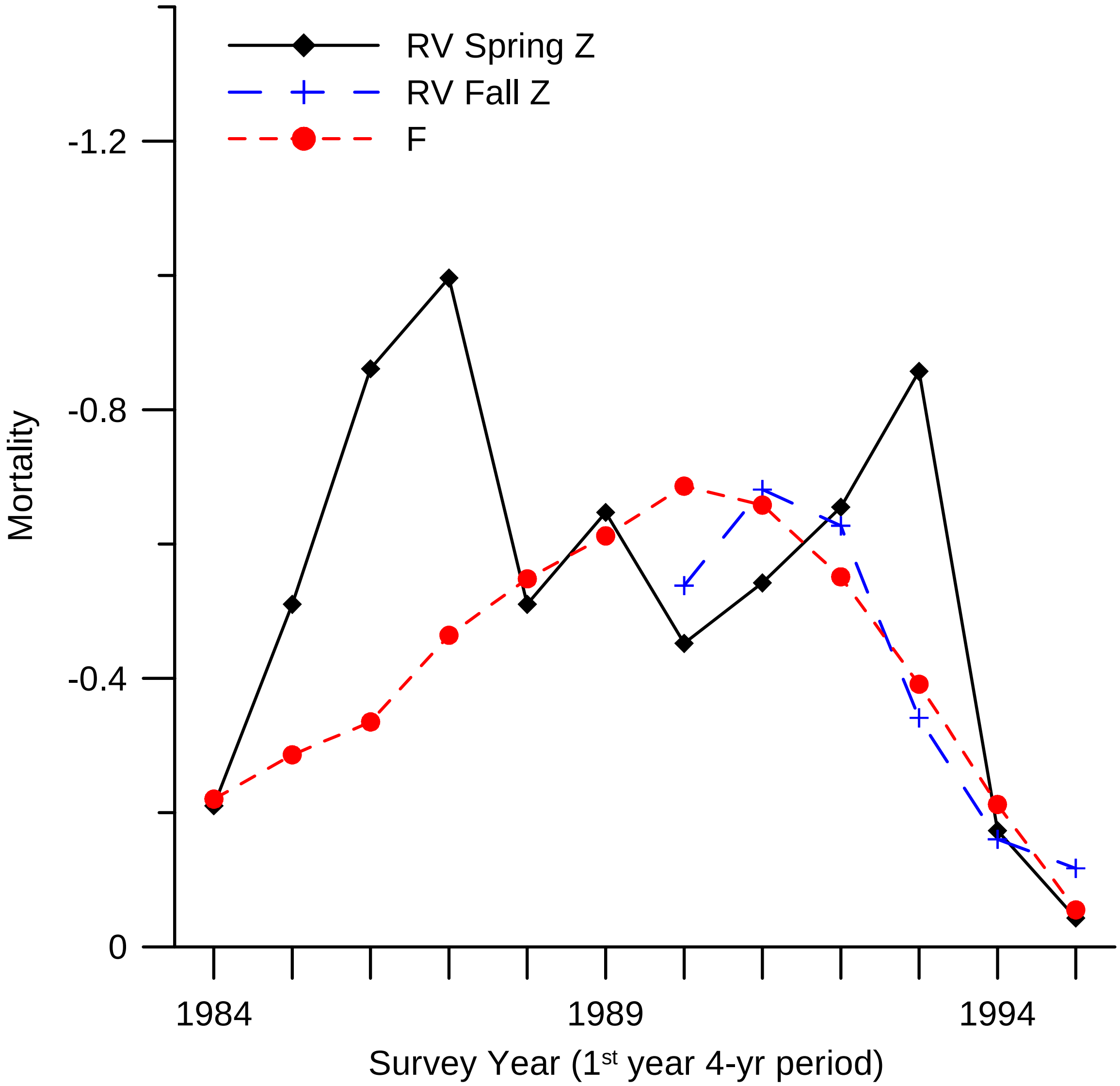

Figure 7. Instantaneous mortality estimated from research vessel surveys for the Grand Bank cod stock (3NO) for ages 3-7 years for four year time periods, beginning with the 1984-1987 period.

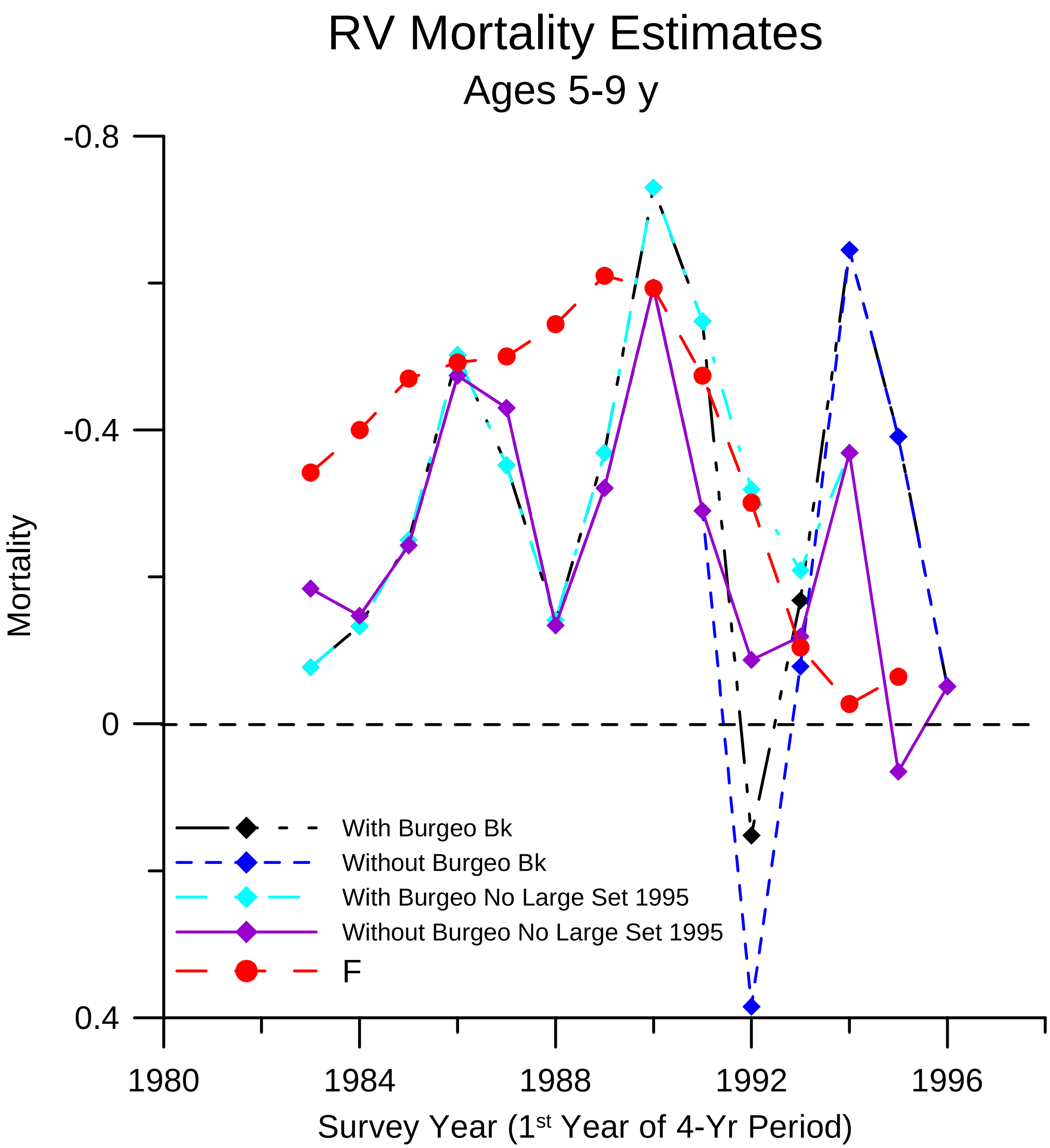

Figure 8. Instantaneous mortality estimated from research vessel surveys for the St. Pierre Bank cod stock (3Ps) for ages 5-9 years for four year time periods, beginning with the 1983-1986 period.

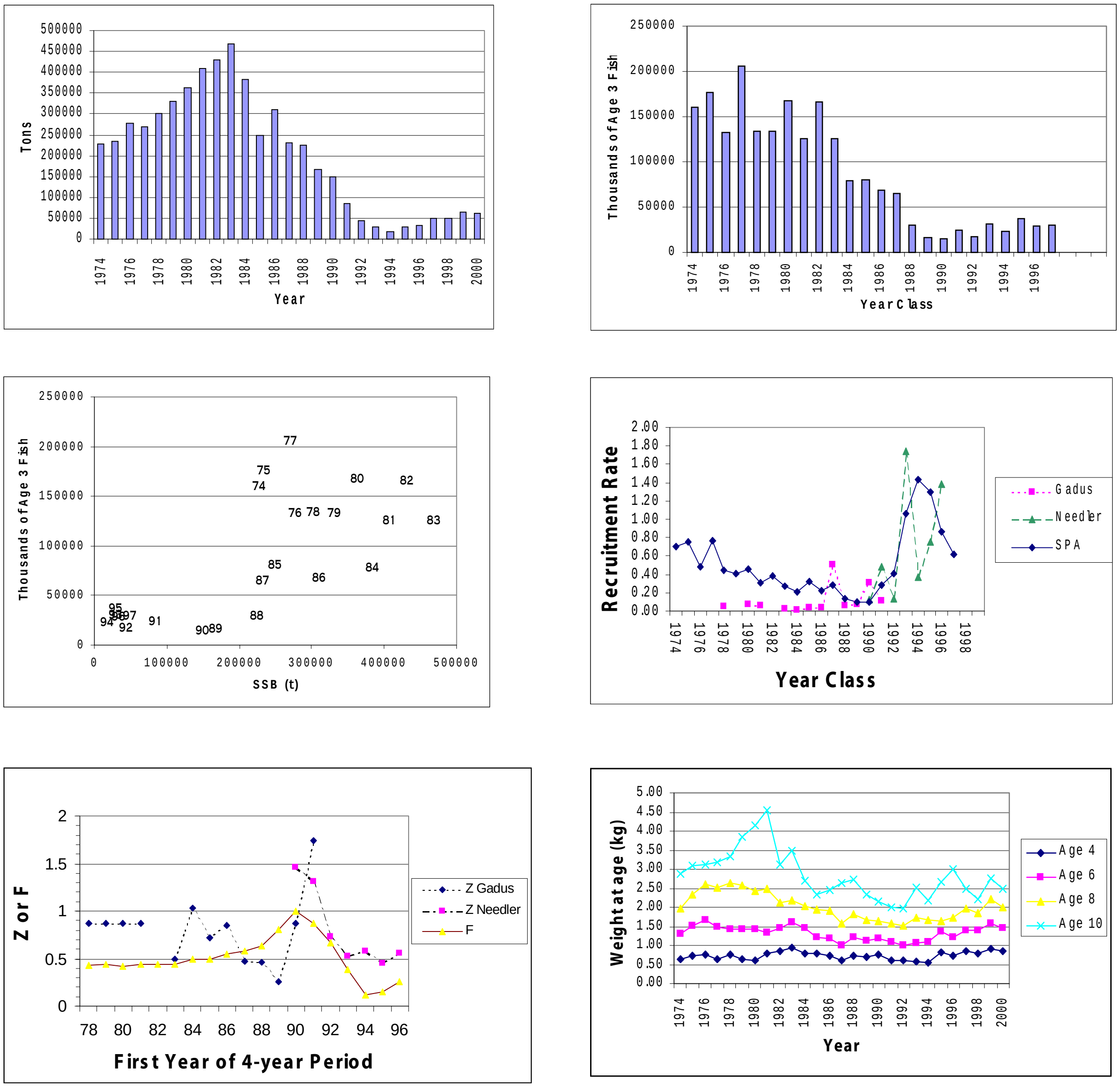

Figure 9. Northern Gulf of St. Lawrence (A) SSB, (B) recruitment (number of age 3 fish estimated from SPA), (C) Stock/recruitment relationship with year-class as labels, (D) recruitment rates estimated from SPA, and the Needler, and Gadus research surveys, (E) Instantaneous rate of total mortality of adults estimated from the Needler (ages 5-10) and the Gadus (ages 6-11) research surveys, and fishing mortality. Data are expressed as 4-year moving averages. (F) Weights-at-age from the commercial fishery for ages 4 to 10.

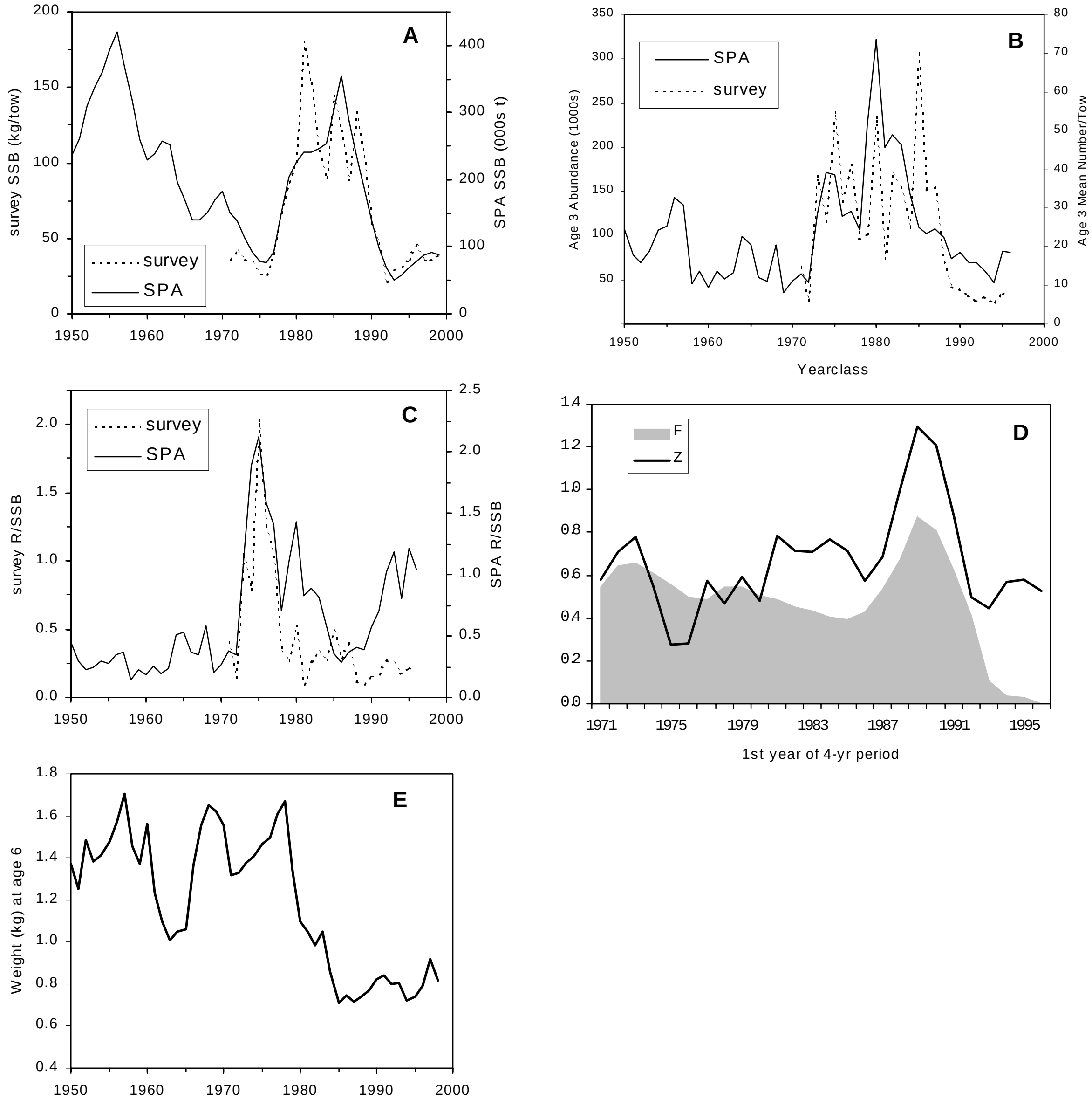

Figure 10. Southern Gulf of St. Lawrence cod: (A) Spawning stock biomass (*SSB*); (B) Recruitment (*R*, age 3 abundance or catch rate); (C) Recruitment rate (*R/SSB*); (D) Instantaneous rate of total mortality of adults (*Z*, estimated from survey catch rates, ages 7-11) and fishing mortality (*F*); expressed as 4-year moving averages; (E) Weights-at-age 6 in the September survey (after 1960) or the commercial fishery (before 1960). Both SPA and survey estimates are shown in panels A-C.

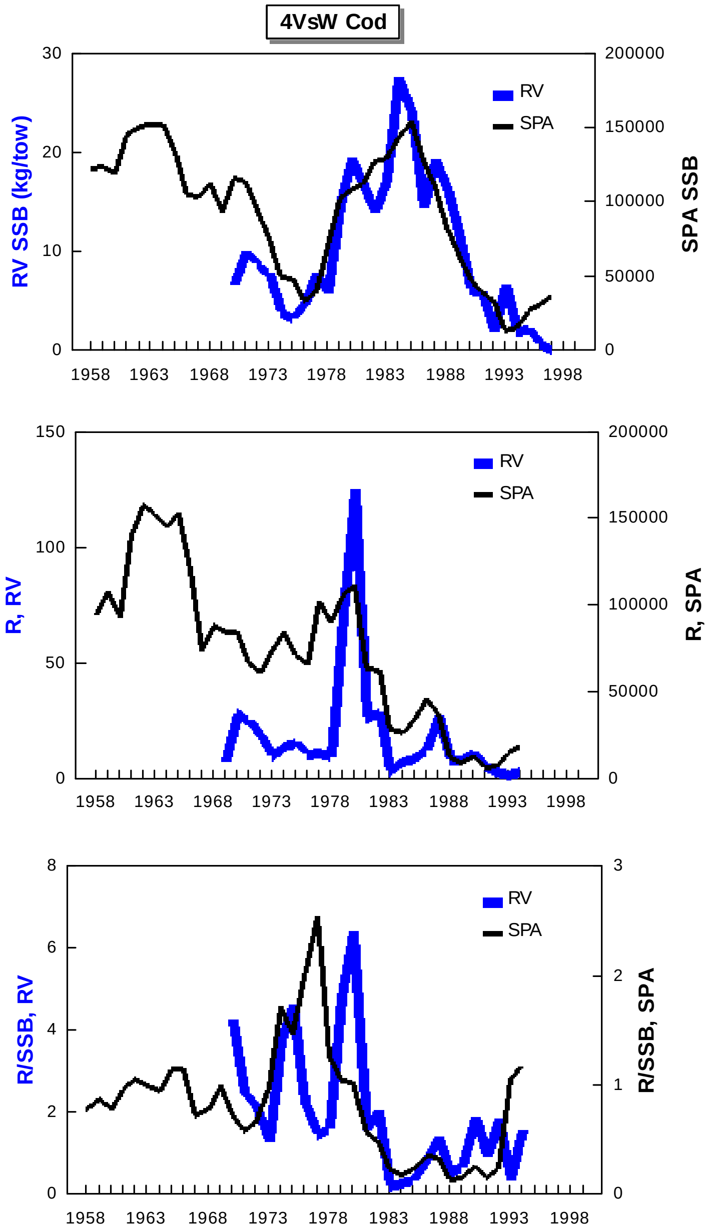

Figure 11. Trends in Spawning Stock Biomass (SSB), Recruitment (R), and Recruitment Rates (R/SSB) for NAFO Div. 4VsW cod based on July research vessel survey (RV) data and a Sequential Population Analysis (SPA).

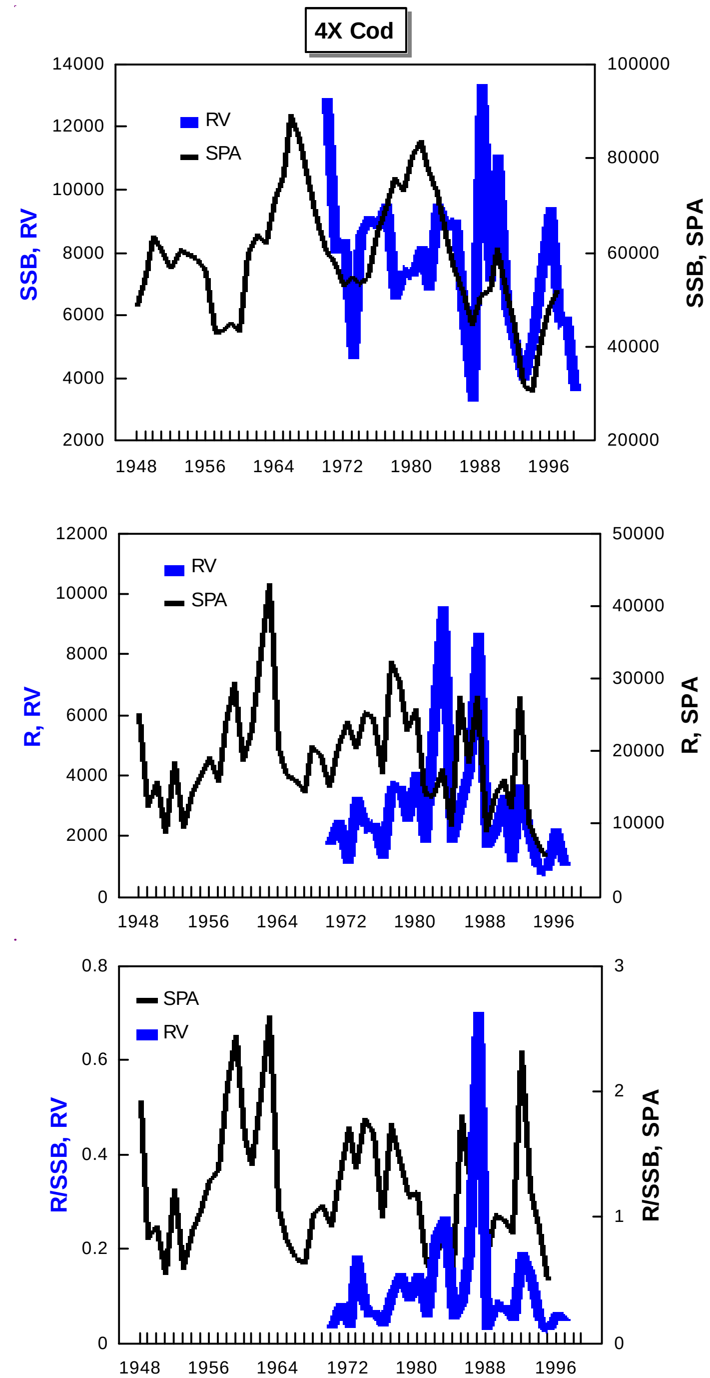

Figure 12. Trends in Spawning Stock Biomass (SSB), Recruitment (R), and Recruitment Rates (R/SSB) for NAFO Div. 4X cod based on July research vessel survey (RV) data and a Sequential Population Analysis (SPA).

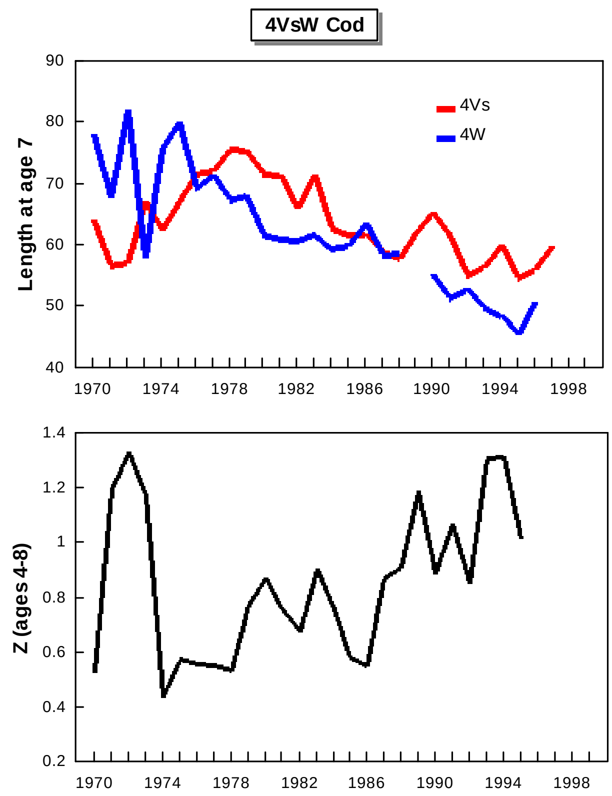

Figure 13. Trends in size at age for 4VsW cod by sub-area and total mortality (Z) estimates for ages 4-8 from the July research vessel survey data.

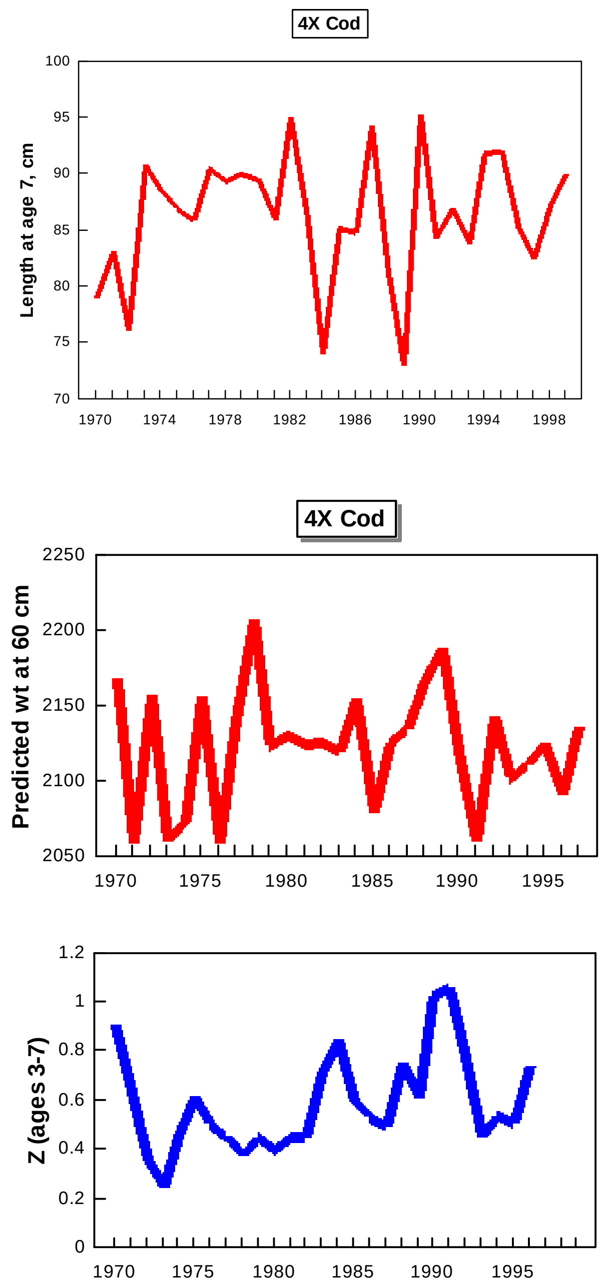

Figure 14. Trends in length-at-age 7, in condition for 4X cod, and total mortality (Z) estimates for ages 3-7 from the July research vessel survey data.

6. Climate Change Initiatives

Savi Narayanan provided a summary of the November 1999 workshop on ‘An Ocean Climaet Strategy for Canada’. It has long been recognized that the Climate Science is important for Canada and for DFO since: a) Canada has a large stake in understanding and predicting climate change and its impacts, because Canada is a Maritime nation, b) the oceans store and move enormous amounts of heat, freshwater & CO_2, and c) marine ecosystems are vulnerable to climate change. Information on climate change will be required by a number of clients, marine and atmospheric scientists, service community, resource sectors, the climate impacts and adaptation communities, policy makers at international, national, provincial and community levels, tourist industry, etc. Recognizing this an inter-departmental, inter-institutional workshop was organized to develop priorities for DFO Climate Science. This WS defined the main Vision of the program as:

- Contribute to an integrated Canadian program on Climate Change;
- Maintain core scientific expertise in the Department to enable the implementation of a relevant Climate Program through productive collaboration with the international climate community and taking advantage of global effort;
- Long-term commitment of resources for sustained observations, infrastructure, and projects leading to predictions of climate change and variability and the impacts on marine resources, transportation, and coastal and offshore developments.
- Maintain an active and integrated climate modelling program from predictions to impacts.

The WS also discussed and recommended the objectives of the Canadian Climate Program as:

- Monitor and provide timely information on ocean climate variability and change in areas of interest to Canada.
- Undertake research on ocean climate processes needed to improve understanding of the climate system, provide convincing predictions of future climates so that socio-economic decisions on mitigation or adaptation can be made, and ensure that climate “surprises” are factored into improved models of the ocean/ice cover/ atmosphere climate system.
- Assess the impacts of climate change on marine ecosystem.
- Provide information and advice on climate related matters to the policy makers and the Canadian public.
- Contribute in a meaningful way to the global climate program.
- Preserve and safe guard scientific data and information for future usage.

The priorities for each ocean related to climate detection, and prediction, for the Canadian greenhouse gas research, and for impacts and adaptation program relevant to oceans were recommended. Crosscutting issues such as partnerships, products and services, modelling, etc were also discussed.

At the end of the overview of the WS, the FOC was informed of the upcoming WS on climate related issues, such as the LMR-GOOS WS in March, Climate Impacts and Adaptation in April and Ocean modelling. It was noted that Ken Frank was involved in the preparations for the

Impacts and Adaptation workshop. He indicated that he was planning to consult widely in his preparations for the workshop, and would keep the FOC posted on developments.

Savi suggested that there was a role for the FOC in planning the department's climate change research and setting priorities, and that these programs were a good opportunity for funding the type fo research that was of interest to the FOC. There was an impression that only climate monitoring and oceanographic monitoring and modelling research would be successful in receiving funding. Savi indicated that this was not the case, and that there was a real interest in funding research on the impacts of climate change on fisheries resources.

7. General Business

7.1 Stock Status Reports

Draft Stock Status Reports (SSRs) for physical oceanographic conditions in the Newfoundland region and on the Scotian Shelf and Bay of Fundy were reviewed and editorial changes suggested. The physical environmental SSR for the Gulf and the biological SSRs were not yet completed. It was decided that they would be forwarded to Swain within 2 weeks for distribution and review, either by email or teleconference.

The name 'Stock' Status Report was considered odd for environmental overviews. Jake Rice indicated that a new name for the series was being considered, and suggested sticking with the old name in the meantime.

7.2 FOC Working Groups

7.2.1 Cod Growth Working Group

Most of the work of this group had been completed and presented at the last two FOC meetings. A few analyses remained to be completed and these would be reported on at the upcoming ICES/GLOBEC workshop on the Dynamics of Cod Growth. Preparations for this workshop have been the main focus of the working group's activities in 1999/2000. The group has also been interested in promoting laboratory ('common-garden') experiments comparing growth of cod from different populations in the same environment. These would indicate whether there are genetic differences among populations in growth rate. A European study is being planned with EU funding. There is interest in including a NW Atlantic stock in this experiment, either a Newfoundland stock or the southern Gulf stock. However, there appear to be problems getting this project under way and nothing has been heard from the organizers in some time. There is also a plan to submit a proposal for a Canadian study to NSERC for funding. Jeff Hutchings is leading this proposal, with help from Joe Brown and Doug Swain. It was agreed that after the workshop this spring, the WG will have met all its goals and will disband.

7.2.2 Environmental Trends Working Group

This group has completed its tasks and will publish its work as a technical report. With the publication of this report, it will have met its goals and will disband. Parallel work on biological indices will be undertaken by the Data Analysis group of the AZMP.

7.2.3 Cod Distribution Working Group

This group has had no opportunity to proceed beyond what was accomplished at its meeting in Moncton in December 1998. It hopes to proceed with a primary publication comparing habitat associations among cod populations in 2000/2001.

7.2.4 Working Group on Incorporating Environmental Information into Stock Assessments

A new working group on incorporating environmental information into stock assessments was formed. Ken Drinkwater will the chair the group. Its general aim will be to assemble environmental indices for factors with a demonstrated or believed link to the production of fisheries resources. This work will aid in the development of programs on climate impacts and provide direction for further work on climate change research. The group will have at least one representative from each region. Jake Rice and Patrick Ouellet were nominated to the group, and accepted. Ken will recruit additional members and develop terms of reference in the near future.

7.3 Other Business

Jake Rice brought up the issue of species at risk (SAR) and their recovery plans. He indicated that there will be an urgent need to define critical habitat for SAR in order to develop and implement recovery plans. He wondered whether the FOC would be interested in undertaking this responsibility. After some discussion, it was concluded that this went beyond both the mandate and the resources of the FOC.

The issue of the roles of the AZMP and the FOC was discussed. Who had the responsibility to review the annual environmental overviews? Should these be reviewed in detail within the AZMP, with only brief summaries presented to the FOC? It was agreed that this should not be the case – that it was the role of the FOC to review the annual environmental overviews.

7.4 2001 Meeting

7.4.1 Theme Session

D. Swain indicated that a suggestion for a theme session or workshop on recruitment of commercially important invertebrate species was made at the last annual meeting of the CSAS office and the RAP co-ordinators. These resources have become increasingly important since the decline of the groundfish resources. Many populations of commercially important invertebrates have recently been at high levels. It is important to understand the basis for these high levels of abundance, and in particular their relation to environmental conditions and species interactions. It was agreed that the theme session for the 2001 meeting would be on invertebrate recruitment (i.e., environmental effects on productivity, predation effects, etc.). Patrick Ouellet agreed to take the lead on preparations for the theme session. It was suggested that an organizing committee with a member from each region should be formed to ensure support for and participation in the session.

7.4.2 Date and Location

The 2001 meeting will be held at the Gulf Fisheries Centre in Moncton.

There was further discussion on the date. A later date had been suggested to allow more time for the preparation of the biological overviews. However, a March date was not good for other groups, in particular it would likely conflict with the cod RAP meeting in Newfoundland Region. It was decided that the meeting would be held the last week in February.

Postscript: During planning of the theme session following the 2000 meeting, it became evident that participation by researchers in the Invertebrates groups would be very limited if the meeting was held in February, as this conflicted with their assessment meetings. A later date, the third week in March, has now been proposed.

Appendix 1: Agenda

Annual Meeting, February 22-25, 2000
E.B. Dunne Boardroom
Northwest Atlantic Fisheries Center, St. John's, NF

Tuesday, Feb. 22

8:30 Introduction and administrative details
- Chairman

1. Review of 1999 environmental conditions in the Northwest Atlantic.

Physical Environment

8:45 Meteorological and Sea Ice Conditions off Eastern Canada in 1999. ***WP1***
- Ken Drinkwater, Roger Pettipas and Liam Petrie

9:15 Oceanographic conditions in NAFO Divisions 2j3klmno during 1999 with comparisons to the long-term (1961-1990) average. ***WP2***
- Eugene Colbourne

Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1999 with comparisons to the long-term (1961-1990) average. ***WP3***
- Eugene Colbourne

9:45 Oceanographic Conditions in the Gulf of St. Lawrence during 1999. ***WP4***
- J. Plourde, D. Gilbert, K. Drinkwater, L. Petrie, D. Lefaivre, F.Saucier, F. Roy and J.-C. Therriault.

10:10 Break

10:30 Physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 1999. ***WP5***
- Ken Drinkwater, Roger Pettipas and Liam Petrie

10:55 Overview of temperature and salinity in the summer groundfish surveys conducted on the Scotian Shelf and Bay of Fundy in 1999. ***WP6, WP7***
- Randy Losier et al.

11:20 Physical and biological monitoring at Prince 5 in 1998 and 1999. ***WP8, WP9***
- Fred Page et al.

11:45 Lunch

Biological Environment

12:45 Variations in biological and chemical oceanographic conditions on the Newfoundland Shelf. ***WP10***
- P. Pepin and G. Maillet

13:10 Short term fluctuations in the pelagic ecosystem of the Northwest Atlantic. ***WP11***
- E. L. Dalley, J. T. Anderson, and D. J. Davis

13:35 Oceanographic conditions in the Gulf of St.Lawrence in 1999: Phytoplankton. ***WP12***
- Michel Starr, Liliane St-Amand and Maurice Levasseur

14:00 Oceanographic conditions in the Estuary and the Gulf of St. Lawrence in 1999 : zooplankton. ***WP13***
- Michel Harvey, Jeffrey Runge, Jean-François St.-Pierre, and Pierre Joly

14:25 State of the Phytoplankton, Zooplankton and Krill on the Scotian Shelf in 1998***. WP14***
- D. Sameoto and G. Harrison

14:50 Break

15:10 The Atlantic Zonal Monitoring Program: Biological/chemical conditions on the Scotian Shelf and Southern Gulf of St. Lawrence during 1998 and 1999. ***WP15***
- G. Harrison et al.

15:35 The Atlantic Zonal Monitoring Program: Biological conditions in the Northwest Atlantic based on SeaWiFS ocean colour data, September 1997-October 1999. ***WP16***
- G. Harrison and T. Platt

16:00 Decadal Changes in Plankton on the CPR E and Z lines. ***WP17***
- D. Sameoto

16:25 Discussion of overviews of 1999 environmental conditions
- Discussion of results; environmental scorecard
- Discussion of the expanded biological monitoring; Are consistent patterns evident across regions? Is methodology comparable among regions? Can a zonal SSR be prepared?

Wednesday, 23 February

2. General Environmental Session

8:30 Interannual variability in chlorophyll fields of the Atlantic Zone. ***WP18***
- T. Platt and Fuentes-Yaco.

8:55 Where did the euphausiids go from 1990 to 1995? Atlantic cod stomachs as a sampling tool for the southern Gulf of St. Lawrence food web. ***WP19***
- Mark Hanson (presented by D. Swain)

9:15 Composite egg and larval distributions of cod and haddock from Cape Hatteras to the Laurentian Channel. ***WP20***
- Fred Page et al.

9:35-10:00
Break

3. Workshop on the Cod Recruitment Dilemma

Session 1: Is there a Dilemma?
Chair: Martin Castonguay
Rapporteur: Michael Fogarty

10:00-10:10
Introductory comments

10:10-10:30
Pre-recruit survival (recruits/SSB) and time series of total mortality Z for cod in 2J3KL, 3LNO, and 3Ps: Past and Present. ***WP21***
- John Anderson

10:30-10:40
Pre-recruit survival (recruits/SSB) and time series of total mortality Z for cod in 3Pn4RS: Past and Present. ***WP22***
- Martin Castonguay

10:40-10:50
Pre-recruit survival (recruits/SSB) and time series of total mortality Z for cod in 4T: Past and Present. ***WP23***
- Doug Swain

10:50-11:20
Pre-recruit survival (recruits/SSB) and time series of total mortality Z for cod in 4VsW, 4X, and 5Z: Past and Present. ***WP24***

- Ken Frank

11:20-11:40
The Cod Natural Mortality Project: conclusions and unanswered questions. ***WP25***
- Denis D'Amours

11:40-12:00
-Northern cod recruitment before, during and after collapse. ***WP26***
- Peter Shelton

12:00-12:20
Factors Affecting the Recovery of Depleted Populations. ***WP27***
- Michael Fogarty

12:20-13:10
Lunch

13:10-14:10
Discussion on Session 1

Session 2: Ecosystem Effects on Recruitment
Chair: Ken Drinkwater
Rapporteur: Mike Heath

14:10-14:30
ICES working group on recruitment processes. ***WP28***
- Pierre Pepin

14:30-14:50
Spawning and year-class abundance in northern cod, 1994-1996. ***WP29***
- John Anderson and George Rose

14:50-15:10
Year-class abundance of pelagic juvenile Atlantic cod in 2J3KLNO, 1994-1999. ***WP30***
- John Anderson and Edgar Dalley

15:10-15:30 Coffee Break

15:30-15:50
Modelling the spatial and temporal structure of recruitment processes in North Sea haddock ***WP 48***
- Mike Heath

15:50-16:10
Ecosystem effects on pre-recruit survival of 3Pn4RS cod in the northern Gulf of St. Lawrence. ***WP32***

- Patrick Ouellet and Denis Gilbert

16:10-16:30

Ecosystem effects on pre-recruit survival of cod in the southern Gulf of St. Lawrence. ***WP33***

- Doug Swain, Alan Sinclair, Ken Drinkwater, and Ghislain Chouinard

16:30-16:50

Do capelin influence cod distribution and recruitment? ***WP34***

- Richard O'Driscoll, John Anderson and George Rose

16:50-17:10

Distribution and abundance of demersal juvenile cod (Gadus morhua) on the Northeast Newfoundland Shelf and the Grand Banks: implications for stock identity and monitoring. ***WP35***

- George Lilly, Eugene Murphy and Mark Simpson

17:10-17:30

Modelling the Retention and Survival of Browns Bank Haddock Larvae using an Early Life Stage Model. ***WP36***

- Dave Brickman

Thursday, 24 February

08:30-08:50

Regional differences in mortality rates of a larval fish: estimating the relative role of dispersion and predation. ***WP37***

- Pierre Pepin and J. Dower

08:50-09:10

Ecosystem effects on recruitment, growth and pre-recruit survival of cod and haddock on the Scotian Shelf. ***WP31***

- Ken Drinkwater and Ken Frank

09:10-09:50

Discussion on Session 2

Session 3: Population Effects on Recruitment

Chair: John Anderson

Rapporteur: Tara Marshall

-

09:50-10:10

Quantifying the reproductive potential of the Northeast Arctic cod stock: works in progress. ***WP39***

- Tara Marshall

10:10-10:30

Variations in the reproductive potential of cod in the northern Gulf of St. Lawrence. ***WP40***

- Yvan Lambert

10:30-10:50

Coffee Break

10:50-11:10

Success and failure of Atlantic cod, a case study from coastal Newfoundland. ***WP41***

- I. Bradbury, G. Lawson, D. Robichaud, G. Rose, and P. Snelgrove

11:10-11:30

Estimation of stock reproductive potential. ***WP42***

- Ed Trippel (presented by Joanne Morgan)

11:30-11:50

An examination of the possible effect of spawning stock characteristics on recruitment in 4 Newfoundland groundfish stocks. ***WP43***

- Joan Morgan, Peter Shelton, Dan Stansbury, and John Brattey

11:50-12:10

Spawning stock characteristics and cod recruitment success in the southern Gulf of St. Lawrence. ***WP44***

- Doug Swain and Ghislain Chouinard

12:10-13:10

Lunch

13:10-13:30

Observations on mass atresia and skipped spawning in northern Atlantic cod, *Gadus morhua*, from Smith Sound, Newfoundland. ***WP45***

- R.M. Rideout, M.P.M. Burton, and G.A. Rose

13:30-13:50

Multiple recruitment pulses of 0-group and relative year-class strength of Atlantic cod in Newman Sound, Bonavista Bay in the late 1990's. ***WP46***

- R.S. Gregory, D.C. Schneider, and J.A. Brown.

13:50-14:50

Discussion on Session 3

14:50-15:10

Coffee Break

15:10-17:00

Discussion on Session 3 (Cont.)

Friday, 25 February

09:00-12:00

Rapporteurs' presentations and general discussion
Presentation and discussion of stock by stock factors affecting recovery of cod stocks
General discussion

13:00-16:00
FOC Business Meeting

1. Stock Status Reports
   - -Discussion and Approval of Environmental Overview SSRs
2. FOC Working Groups
   - -Cod Growth Working Group
   - -Environmental Indices Working Group
   - -Working Group on the relative role of temperature and abundance on the distribution of cod in the norhtwest Atlantic
   - -Other possible working groups? e.g., working group on the precautionary approach.
3. Next year's Meeting
   - -Theme Session
   - -Date and Location
4. Climate Change
5. Other business.

Appendix 2: Working papers and presentations

WP 01: *Overview of meteorological and sea ice conditions off eastern Canada during 1999.*
– K. F. Drinkwater, R. G. Pettipas and W. M. Petrie

WP 02: *Oceanographic conditions in NAFO Divisions 2J 3KLMNO during 1999 with comparisons to the long-term (1961-1990) average*
– E. Colbourne

WP 03: *Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1999 with comparisons to the long-term (1961-1990) average*
– E. Colbourne

WP 04: *Oceanographic conditions in the Gulf of St. Lawrence in 1999.* (Abstract & overheads)
– J. Plourde, D. Gilbert, K. Drinkwater, L. Petrie, D. Lefaivre, F.Saucier, F. Roy and J.-C. Therriault

WP 05: *Physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 1999.*
– K. Drinkwater, B. Petrie, R. Petitpas, L. Petrie, and V. Soukhovtsev

WP 06: *Overview of 1999 hydrographic sampling effort and near-bottom water temperature and salinity conditions during the Canadian research vessel groundfish summer surveys conducted on the Scotian Shelf and in the Bay of Fundy (4VWX)*
– R. Losier, F. Page and J. McRuer

WP 07: *Overview of 1999 near-surface water temperature and salinity conditions during the Canadian research vessel groundfish summer surveys conducted on the Scotian Shelf and in the Bay of Fundy (4VWX)*
– R. Losier, F. Page, P. McCurdy, M. Ringuette and J. McRuer

WP 08: *Overview of 1999 near-50 meter water temperature and salinity conditions during the Canadian research vessel groundfish summer surveys conducted on the Scotian Shelf and in the Bay of Fundy (4VWX)*
– R. Losier, F. Page, P. McCurdy, and J. McRuer

WP 09: *Physical and biological monitoring at Prince 5 during 1998.*
– F. H. Page, M. Ringuette, and A. Hanke

WP 10: *Biological and chemical oceanographic conditions on the Newfoundland Shelf during 1998 and 1999 with comparisons to the 1993-97 observations*
– P. Pepin and G. L. Maillet

WP 11: *Short term fluctuations in the pelagic ecosystem of the Northwest Atlantic*
– E. L. Dalley, J. T. Anderson, D. J. Davis

Oceanographic conditions in the Gulf of St. Lawrence in 1999: Phytoplankton (no WP – presentation only)
- M. Starr, L. St-Amand, and M. Levasseur

WP 13: *Oceanographic conditions in the Estuary and the Gulf of St. Lawrence in 1999: zooplankton*
- M. Harvey, J. A. Runge, J. F. St-Pierre and P. Joly

WP 14: *State of the phytoplankton, zooplankton and krill on the Scotian Shelf in 1998* (SSR)
- D. Sameoto and G. Harrison

WP 15: *Biological/chemical conditions on the Scotian Shelf and southern Gulf of St. Lawrence during 1998 and 1999*
- G. Harrison

WP 16: *Biological conditions in the Northwest Atlantic based on SeaWiFS ocean colour data, September 1997-October 1999*
- G. Harrison and T. Platt

WP 17: *A comparison of decadal plankton changes on the CPR eastern E and western Z lines*
- D. Sameoto

Interannual variability in chlorophyll fields of the Atlantic Zone (no WP – presentation only)
- T. Platt

WP 19: *Where did the euphausiids go from 1990 to 1995? Atlantic cod stomachs as a sampling tool for the southern Gulf of St. Lawrence food web*
- J. M. Hanson (presented by D. Swain)

WP 20: *Composite egg and larval distributions of cod and haddock from Cape Hatteras to the Laurentian Channel*
- F. Page

WP 21: *Recruitment, survival and mortality in Newfoundland cod stocks: Northern (2J3KL), Grand Bank (3NO) and St. Pierre Bank (3Ps)*
- J. T. Anderson

WP 22: *The northern Gulf of St. Lawrence – background information on recruitment*
- M. Castonguay

WP 23: *The southern Gulf of St. Lawrence cod stock – background information*
- D. P. Swain

WP 24: *Trends in SSB, recruitment, survival rates, total mortality growth and condition for cod and haddock in Div. 4VWX*
– K. T. Frank

The Cod Mortality Project – a summary of conclusions (no WP – presentation only)
– D. D'Amours

WP 26: *Northern cod recruitment before, during and after collapse*
– P. A. Shelton and D. E. Stansbury

Factors affecting the recovery of depleted populations (no WP – presentation only)
– M. Fogarty

Overview of the ICES working groups on recruitment processes (no WP)
– P. Pepin

WP 29: *Offshore spawning and year-class strength of Northern cod (2J3KL) during the fishing moratorium, 1994-1996*
– J. T. Anderson and G. A. Rose

WP 30: *Update on year-class strength of Northern cod (2J3KL) and southern Grand Banks cod (3NO) estimated from the pelagic juvenile fish surveys 1994-1999*
– J. T. Anderson and E. L. Dalley

Ecosystem effects on recruitment, growth and pre-recruit survival of cod and haddock on the Scotian Shelf (no WP)
– K. Drinkwater and K. Frank

WP 32: *Ecosystem effects on pre-recruit survival of 3Pn4RS cod in the northern Gulf of St. Lawrence*
– P. Ouellet and D. Gilbert

WP 33: *Ecosystem effects on pre-recruit survival of cod in the southern Gulf of St. Lawrence.*
– D. Swain, A. Sinclair, K. Drinkwater, and G. Chouinard

WP 34: *Do capelin influence cod distribution and recruitment?*
– R. L. O'Driscoll, G. A. Rose, and J. T. Anderson

WP 35: *Distribution and abundance of demersal juvenile cod (Gadus morhua) on the Northeast Newfoundland Shelf and the Grand Banks: implications for stock identity and monitoring*
– G. Lilly, E. Murphy, and M. Simpson

Modelling the Retention and Survival of Browns Bank Haddock Larvae using an Early Life Stage Model (no WP)
– D. Brickman

Regional differences in mortality rates of a larval fish: estimating the relative role of dispersion and predation (no WP)
– P. Pepin and J. Dower

Quantifying the reproductive potential of the Northeast Arctic cod stock: works in progress (no WP)
– T. Marshall

Variations in the reproductive potential of cod in the northern Gulf of St. Lawrence (no WP)
– Y. Lambert

Success and failure of Atlantic cod, a case study from coastal Newfoundland. (no WP)
– Bradbury, G. Lawson, D. Robichaud, G. Rose, and P. Snelgrove

An examination of the possible effect of spawning stock characteristics on recruitment in 4 Newfoundland groundfish stocks (no WP)
– J. Morgan, P. Shelton, D. Stansbury, and J. Brattey

WP 44: *Spawning stock characteristics and cod recruitment success in the southern Gulf of St. Lawrence*.
– D. Swain and G. Chouinard

WP 45: *Observations on mass atresia and skipped spawning in northern Atlantic cod, Gadus morhua, from Smith Sound, Newfoundland*.
– R.M. Rideout, M.P.M. Burton, and G.A. Rose

Multiple recruitment pulses of 0-group and relative year-class strength of Atlantic cod in Newman Sound, Bonavista Bay in the late 1990's. (no WP)
– R.S. Gregory, D.C. Schneider, and J.A. Brown.

WP 47: *Distribution and biomass of capelin, Arctic cod and sand lance on the Northeast Newfoundland Shelf and Grand Bank as deduced from bottom-trawl surveys*
– G. Lilly and M. Simpson

WP 48: *Satellite measurements of sea surface temperature: an application to regional ocean climate*
– B. Petrie and C. S. Mason

Appendix 3: Meeting Participants

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* FOC Core-member

Appendix 4: Abstracts of Working Papers of the Cod Recruitment Workshop

Recruitment, Pre-Recruit Survival and Mortality in Three Newfoundland Cod Stocks: Northern (2J3KL), Grand Bank (3NO) and St. Pierre Bank (3Ps) WP21

John T. Anderson
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Recruitment was estimated as the abundance of three year old cod and population size was estimated as the spawning stock biomass (SSB) based on Sequential Population Analyses (SPA) and research vessel (RV) indices from the most recent assessment documents. Pre-recruit survival was estimated as the abundance of three year old cod divided by the SSB that produced each year-class. Mortality was modelled using four year time periods of RV data for the five youngest ages fully recruited to the research trawls. For Northern cod and Grand Bank cod these ages were 3-7 years, whereas for St. Pierre Bank cod these ages were 5-9 years.

In recent years, SSB and recruitment have been low compared to historical values in both the Northern and Grand Bank cod stocks. In contrast, SSB and recruitment in the St. Pierre Bank cod stock have been relatively high. There was a notable degree of coherence in pre-recruit survival among the three cod stocks. Survival was high in the 1960's, particularly for Grand Bank cod, declined to low values in the early 1970's before increasing to historically high values in Northern and St. Pierre Bank cod in the late 1970's and to the second highest values for Grand Bank cod. Since the mid-1980's survival has been relatively low in all three cod stocks. Recent estimates for the Northern cod stock (i.e. since the 1993 year-class) are not considered to be reliable based on the SPA. However, survival based on the RV index also increased in the mid-1990's indicating relatively high survival in recent years. However, these survival estimates are based on very low SSB's. The low levels of survival observed at extremely low SSB's for the Northern and Grand Bank cod stocks is consistent with depensation. St. Pierre Bank cod had low survival at low SSB's in the 1990's, compared to high survival experienced at similarly low SSB's in the 1970's. Collectively, these data indicate that pre-recruit survival has been low in all three cod stocks during the 1990's.

Estimates of instantaneous mortality modelled over four year periods is considered to be primarily due to natural causes since the introduction of fishing moratoria in the Northern cod stock in July 1992 and the Grand Bank stock in February 1994. For these stocks, mortality rates declined from peak values of –1.2 and –0.86 y-1 in the early 1990's to values less than –0.2 y-1 in recent years. There was a notable lag in the decline in mortality rates following the implementation of the fishing moratoria. As these mortality estimates were modelled for up to five ages for different cohorts over four year periods, the values represent trends in natural mortality for each stock. It was not possible to obtain meaningful estimates of mortality for the St. Pierre Bank stock due to the highly variable RV data that tended to produce positive values. In addition, a fishing moratorium was only implemented for the period 1994-1996 meaning that the mortality estimates combine natural and fishing effects since then.

The northern Gulf of St. Lawrence cod stock –
background information on recruitment. ***WP22***

Martin Castonguay
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The FOC reviewed recent trends in recruitment for all Canadian cod stocks to determine if poor recruitment could account for the slow recovery of stocks. Spawning stock biomass of northern Gulf of St. Lawrence cod (3Pn4RS) gradually declined to a minimum in 1994 and has slowly recovered since. Recruitment has been weak through the 1990s. There appears to be a fairly good stock/recruitment relationship in this stock. Recruitment rate calculated from SPA and the research vessel survey data (Needler) (i.e., recruitment given the observed level of spawning stock biomass) has risen in the 1990s, which may indicate a compensatory response of the stock to low abundance levels. Hence the slow recovery of the stock cannot be accounted for by low recruitment given the observed level of spawning stock biomass. Total mortality of adult cod calculated from survey data has been around 0.5 from 1994 to 1997. Taking fishing mortality into account suggests that natural mortality has been between 0.3 and 0.4, which supports the current natural mortality value of 0.4 assumed for the stock in sequential population analysis. There has been a pronounced decline in size-at-age of cod in the late 1980s, early 1990s, indicative of a decline in surplus production.

The main point of the paper in relation to this workshop is that recruitment rates do not appear to have been unusually low during the 1990s, and were in fact high. Hence the slow recovery of the stock cannot be accounted for by recruitment, given the current SSB. The main factors affecting recovery of this stock are (1) the depleted SSB due to intensive fishing of the late 1980s and early 1990s, (2) a high natural mortality of adults, (3) a slow growth rate of adults in the late 1980s and early 1990s, (4) changes in structure of the spawning stock due to fishing (low mean age of spawners, low age diversity, small size), (6) and possibly the loss of substocks (although this was not properly reviewed at the Workshop).

The southern Gulf of St. Lawrence cod stock- background information. *WP23*

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Spawning stock biomass (SSB) of southern Gulf cod declined to a low level in the mid 1970s, but recovered very rapidly from this stock collapse despite continued fishing. SSB again declined rapidly in the late 1980s and early 1990s to a low level similar to that reached in the previous collapse in the mid 1970s. However, in contrast to the rapid recovery in the 1970s, there has been little recovery from the current stock collapse, despite a moratorium on directed fishing from September 1993 to the summer of 1999.

Changes in SSB depend on rates of recruitment, adult growth and adult mortality. These rates were examined to explain the difference in recovery rates between the 1970s and 1990s. Recruitment rate, R/SSB (where R is the abundance of age 3 cod), rose to unprecedented levels in the mid 1970s, according to both SPA and survey data, and then declined to more typical levels by the mid 1980s. Estimates of recruitment rates in the 1990s depend on whether the survey catch rates or SPA results are used in the calculations. Survey catch rates indicate that the rate of recruitment is currently at a typical level, comparable to that seen throughout the 1980s and in the early 1970s. SPA results depend on the calibration method. SPA calibrated with only the research survey catch rates indicates that current recruitment rates are within the range seen throughout the 1950s, 1960s, and early 1970s, though at the high end of this range. SPA calibrated with both research and sentinel survey catch rates indicates that current rates are high, though still below the peak recruitment rates of the mid 1970s. Stock recruitment plots indicate a strongly compensatory relationship, with relatively high recruitment rates at low SSB. In summary, both SPA-based and survey-based analyses indicate that the rate of recruitment has not been unusually low during the recent period of slow recovery but instead was unusually high during the earlier period of rapid recovery.

Total mortality rate *Z* was estimated for moving 4-yr blocks from the survey data. *Z* increased rapidly in the late 1980s as the fishery intensified, and then declined sharply when the fishery was closed. However, even though fishing mortality has been reduced to levels near zero, *Z* has remained unexpectedly high in recent years. This suggests that natural mortality of adult cod is currently at a high level, about double the level usually assumed for cod in the Northwest Atlantic.

Growth rate has varied widely in this stock. Weight at age was high from the late 1960s to the late 1970s, but then declined steeply to record low levels by the mid 1980s. It has remained near this record low level since then.

In conclusion, the rate of recruitment of southern Gulf cod has not been unusually low in recent years. Instead, it was remarkably high during the previous stock collapse in the mid 1970s. However, adult growth rates are currently unusually low and adult natural mortality appears to be unusually high. Recovery from the recent stock collapse has been slow because adult growth rates have been unusually low and adult natural mortality rates unusually high.

Trends in SSB, recruitment, total mortality, growth and condition for cod in Div. 4VWX. *WP24.*

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The 4VsW cod stock was the largest in the Scotia-Fundy region with annual catches ranging from 10,000 to 80,000 t during 1952 to 1992 (average = 49,600 t). The cod resource was composed of a complex of spawning components, both inshore and offshore, that have been eroded through time. SSB dropped to very low levels in the early 1990s with little recovery evident, despite the closure of the directed fishery in September 1993. This is in contrast to the situation in the mid-1970s when very low SSB was followed by rapid recovery. Recruitment was high during the late 1970s/early 80s; R was below average since 1983 with the exception of 1987 year-class. R has been very low since late 1980s. Pre-recruit survival (R/SSB) was extremely high during the 1970s and relatively low during the 1980s. During the 1990s, R/SSB has generally been well below the long-term average. The instantaneous rate of total mortality averaged 0.75 prior to 1986, rapidly increased during the late 1980s as the fishery intensified, and has remained high despite the closure of the fishery. The current rate of natural mortality of adult cod is very high and there appears to be several factors causing increased mortality overall, in addition to seal predation on the younger age groups. In general, low R is associated with low SSB and vice versa. R/SSB was generally inversely related to SSB suggesting increased survival at low SSB. Adult size at age peaked in the late 1970s and has declined steadily to present small sizes. Condition peaked in the mid-1970s and steadily declined to an historic low level in 1994; recent increases in condition have occurred. Overall, small adult body size and low adult condition were associated with weak year-classes and poor survival.

The 4Vn region (Sydney Bight) is known to represent a mixing ground between the resident stock and the larger neighboring stocks in the southern Gulf of St. Lawrence (4T) and the eastern Scotian Shelf (4VsW). This confounds the assessment of the stock. Annual landings since 1970 have generally been less than 10,000 t. Since September 1993 the directed fishery has been closed. SSB declined rapidly during the late 1980s and early 1990s reaching a minimum in 1996. Recruitment was relatively high during the early 1980s and in 1987. R (based on RV data) has been below average since 1987 while the size of some recent year-classes (1993 and 1994) estimated by SPA are slightly above average. RV and SPA estimates of juvenile survival were not correlated -- great discrepancy seen during the 1990s where SPA estimates are very optimistic and RV estimates are low and variable. Fishing mortality increased during the 1980s and peaked in the early 1990s; closure of the fishery was associated with a significant decrease in F. Total mortality (Z) estimated from the RV has remained high after closure of the fishery in 1993, varying between 0.5 and 1.0. In general, juvenile survival rates were high at low SSB and progressively lower at high SSB. Size at age steadily declined to a minimum in 1992 and since then has been increasing.

Historical landings of 4X/5Y cod (Western Scotian Shelf/Bay of Fundy) have varied between about 15,000 and 36,000 t. Since 1994 landings have been less than 15,000 t. A seasonal spawning area closure of Browns Bank has existed since 1970 and the bank is now closed from 1 February to 15 June each year. Unlike most other cod stocks in the 1990s, this one has remained open. Bottom waters are generally warmer in this stock area than those to the east promoting faster growth rates and early maturity. A cascading decline in SSB has been evident since the early 1980s with current levels near the historical low. Current SSB is considered to be at a stable low level (no collapse) and the temporal dynamics of this stock appears to be different from those cod stocks to the east. High inter-annual variability in R was evident with low recruitment since 1992 (based on RV data) while SPA estimates of R have been below average since 1988 with exception of the 1992 year-class. The highest survival rates (based on SPA) were associated with the production of the largest year-classes; survival rates (based on RV) have been below average since 1987 with the exception of the 1992 and 1993 year-classes. Z exceeded 1.0 during the early 1990s and recently has fallen to near the long-term average (0.6). No clear relationship exists between survival rates and SSB. The low survival rates observed at low SSB for the 1993 and 1994 year-classes are unexpected and if continue could suggest depensation. No trends in condition or size at age were evident in the time series.

Accounting For Mortality of Cod in the Canadian Atlantic *WP25*

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Cod stocks in the Canadian Atlantic zone declined sharply in the late 1980s and early 1990s, and many reached historical low abundances (see review by Murawski et al. 1997). The identity and the relative magnitude of the factors contributing to this decline have been debated throughout the previous decade: some have claimed that "…the collapse of northern cod can be attributed solely to overexploitation" (Hutchings and Myers 1994), when others had claimed that "…a devastating decline in the stock of northern cod…[was]…due primarily to ecological factors…" (DFO 1992).

Such controversy regarding Canadian Atlantic cod stocks is not new. Since the extension of jurisdiction in 1977, explanations as to why the expectations from the cod fishery rebuilding targets often went unfulfilled were equally diverse and polarized. The Resource Prospects for Canada's *Atlantic Fisheries 1980-1985 - DFO Science Branch* (DFO 1980) forecasted achievement of ambitious rebuilding targets for the stocks by the end of the 1980s. However it stressed "<u>These projections, which are given in the form of a projected Total Allowable Catch (TAC) for each stock, should be viewed as only a general guide to likely events. ... projections of stock status in latter years are to a considerable extent best guesses, based on inadequate knowledge</u>." DFO (1980; underlining in original). Even in 1980, rebuilding from the initial depletion by foreign fleets was reported to be underway strongly for cod stocks in 2J3KL, 3M, 3Pn4RS, 4TVn, 4VsW, and 5Z (Fig 1 – map of NAFO areas). Weaker recovery or greater uncertainty about the stock status was reported for cod in 3NO, 3Ps, 4Vn (summer), and 4X. The Economic Council of Canada used these forecasts to build great optimism about the prospects for recovery of cod fisheries as well, based on the premises that "it was not possible for the inshore sector to reduce biomass below the MSY level", and "the resource should be fully utilized" (Monroe and McCorquedale 1981). Beliefs about the capacity and performance of the inshore sector continued to color discussion of Canadian Atlantic cod stocks until the present, although there were few data about the actual evolving properties of that sector.

By the mid 1980s a second *Resource Prospects 1985-1990 - DFO* (DFO 1985) document noted that the 1980 rebuilding targets had not been met. Catches had reached only 1/2 of the 1968 peak catches for the northern stocks, and 1/3 of the historic peaks in the southern stocks. However, it did not question the attainability of these targets, and noted that if the stocks continued to be managed at $F_{0.1,}$ the targets should be attained by 1990. This optimism was not shared by many participants in the fisheries, prompting four special reports between 1986 and 1987, all focusing on cod in 2J3KL. Lear et al (1986), CAFSAC (1986), and Alverson (1987), called progressively more focused attention to a growing retrospective problem (Mohn 1999) with the analytical assessments. However, all concluded that the stock was continuing to rebuild, if slowly, and anomalous environmental conditions, specifically anomalously cold water, was influencing at least migration patterns and seasonal distribution of cod on the Grand Banks. These changes, in turn, fed back on many of the data and indices used in the assessments, contributing increasing uncertainty to estimates of population parameters. A team of university researchers, contracted by the Newfoundland Inshore Fisheries Association, drew much the same conclusions about the assessments, but placed the blame for disappointment performance of inshore fisheries on actions of the offshore fleet (Keats et al. 1986).

The conclusions in the January 1989 assessment of Northern cod by DFO scientists were dramatically different from previous assessments (CAFSAC 1989). The rebuilding had not reached nearly the level estimated in past assessments, and there had been no growth, and possibly a decline in biomass since 1986. Controversy over the unrealized expectations for rebuilding of cod stocks quickly spread through the Canadian Atlantic. The controversy prompted the appointment of several review groups, which confirmed that stocks had begin to decline again, without ever approaching their rebuilding targets, and had been exposed to much higher fishing mortalities than planned for the rebuilding period. (Harris 1990; Haché 1989). The reports gave some attention to the possible effects of harsh oceanographic conditions on the stock, but highlighted predator - prey interactions and more ecosystem-based assessment and management approaches as crucial factors for stock dynamics and rebuilding possibilities. Additional critiques followed from many fronts, including sociological analysis (Finlayson 1991, 1994), journalism (Moore 1993) and legal advocacy (Martin 1995). Details differ greatly, but in general the critiques share a number of conclusions. Critics argued that fisheries scientists were out of touch with the actual fisheries, discounted traditional knowledge, and were not objective.

In the context of the extreme divergence of views regarding the causes of the collapses, the Canadian Department of Fisheries and Oceans initiated a project entitled “Partitioning the Total Mortality of Atlantic Cod Stocks”. The aim of this project was to identify and weigh the relative contribution of the various components of cod mortality in the years leading to the collapse of the stocks. The articles making up the following special section were supported, in part or in total, by that project.

Contributions from the Project “Partitioning the Total Mortality of Atlantic Cod Stocks”

Lambert and Dutil (2000) studied the effect of low condition (small weight for given length and low energy reserves) on the physiological stamina of cod. They identified the condition level may be lethal to the fish in the laboratory. Cod adults in the wild showed lethal or near-lethal levels of condition. Lambert and Dutil concluded that stock productivity and recovery; population reproductive potential and possibly recruitment of cod might have suffered from poor condition.

Energy reserves of individual cod in the northern Gulf of St. Lawrence were low during the period when this stock collapsed, between 1991 and 1993. Dutil and Lambert (2000) examined the extent of energy depletion in the spring and early summer period (1993-1995) in the northern

Gulf cod to determine whether poor energetic condition caused mortalities in the early 1990's. This was done by comparing several indices of condition in wild fish and in fish that either survived or did not survive to a prolonged period of starvation in laboratory experiments. The study showed that natural mortality from poor condition contributed to lower production in the early 1990s. Declining growth rates and declining conditions may have contributed to making this stock and others more vulnerable to manmade perturbations by decreasing their productivity. The study also showed that natural mortality from poor condition contributed to further decrease the productivity of the northern Gulf cod stock in the late 1980s and early 1990s.

Shelton and Lilly (2000) examine the fit of the model used in the assessment of the northern cod stock to the research vessel bottom trawl survey data under the standard assumptions. They conclude that a major cause of the failure of the model to fit the survey catch data is probably catch misreporting in the early 1990s and that in the absence of accurate commercial removals it will not be possible to quantitatively determine the contribution of the other factors such as change in natural mortality or survey catchability to lack of model fit. Nonetheless, Shelton and Lilly conclude, “events which co-occurred with the collapse contradict a previously drawn conclusion that the collapse of northern cod was solely the result of overexploitation”.

Hutchings and Ferguson (2000) investigated the patterns in harvesting dynamics for two sectors of the fixed-gear fishery for Newfoundland’s northern cod, from 1980 to 1991. The patterns identified are interpreted as indicative of a decline more gradual than abrupt and of increasing rates of catch misreporting contributing to increases in fishing mortality.

Summary

What, then, were the various components of the total mortality of cod leading to the collapse of the stocks? First, it is known that the total mortality was very high: for northern cod stock, the archetype stock, fish were exposed to total mortality rates of 2 to 3 in late 80s early 90s (Lilly et al. 1998). During the same years and for the same stock, estimates of fishing mortality had increased to between 0.7 and 1 (Baird et al. 1992). During those years, the hypothesis of an increase in natural mortality lacked credibility because there was no known mechanisms that could produce such an increase, and natural mortality could not be measured on during closed fishery. Since then, work by Dutil and Lambert (2000) and Lambert and Dutil (2000) have described physiological mechanisms potentially responsible for increased natural mortality in cod. Further, natural mortality has been measured after closure of fishery, and proven to be much higher than the assumed baseline of 0.2 (e.g. Sinclair 1999). Such a higher than expected natural mortality, with minimal values of 0.4 and with evidence of increase in the mid 1980s, has been observed on many Atlantic cod stocks after the moratorium, particularly for the stocks that declined mostly (Lilly et al. 1998; DFO 1999).

In summary, current estimates indicate that fishing mortality, during the years leading to the collapse, was very high, typically as high as 1 in early 90. Also, natural mortality, which had increased in the mid-1980s, was at least twice its assumed value of 0.2. Together, estimates of fishing mortality and natural mortality from available data sources still only account for roughly half of the total mortality, which was typically 2 to 3. Note however that because mortality is an exponent in population dynamics equations, accounting for half of such a high total mortality rate, accounts for 80% of the actual number of fish that disappeared.

Conclusion

Recent findings, such as derived from the project "Partitioning the Total Mortality of Atlantic Cod Stocks", still provide only partial explanations of all the changes in Northwest Atlantic marine ecosystems over the past decades. In the assessments there is still a substantial amount of mortality that is unaccounted for. Outside the constraints of analytical assessment models, as in the past, present narrative explanations can invoke excessive fishing, poor fishing practices, harsh environmental conditions, and perturbations to the predator-prey systems as causes individually or in various combinations. When one attempts to account for *all* the changes in the large marine ecosystems - in abundance of commercial stocks, in abundance of non-targeted stocks in growth and body condition, in recruitment, in geographic distribution, in natural mortality, in failure to recover after fishery closures, and in the latitudinal gradients of many of these factors (Rice, in press) - any one of the three factors can explain *some* patterns very readily and others only with a great deal of effort. Any two of them, however, can account for all the patterns readily.

This multiplicity of explanations, all multi-factor, leaves the door open for many more years of speculation, argument, and finger-pointing about what really did happen and why. A few important messages emerge clearly, however. First, uncertainty is with us to stay, and resource use must be precautionary in light of both an uncertain present and a more uncertain future. Second, monitoring carefully and consistently many aspects of the cod stocks, and many parts of the ecosystem, is vital to understanding (and sometimes reducing) the uncertainty. Third, we need to integrate our information across stocks, geographic areas, and scientific disciplines, and then apply the integrated insights in scientific advice and resource management.

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Northern Cod Recruitment before, during and after Collapse *WP26*

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We show that clear recruitment signals are present in the research vessel and commercial catch at age data for northern cod from extension of jurisdiction to moratorium. There have been three main periods of strong recruitment, preceded and followed by brief periods of much lower recruitment. SPA provides good model fits to the first two pulses but is unable to reconcile survey and catch data with respect to the third pulse, under standard assumptions. In this working paper we use a diagnostic formulation that estimates unaccounted for death in the early 1990s (Shelton and Lilly, submitted to Can. J. Fish. Aquat. Sci.) to evaluate recruitment before and during the collapse. With the change-over from the Engel groundfish trawl to the Campelen shrimp trawl in the fall research vessel surveys from 1995 onwards, and the sparse catch at age data from 1993 onwards, there is little justification for the application of SPA techniques after the moratorium. Thus we reconstruct a relative recruitment strength series for the post-collapse period from a number of indices using an iterative reweighting procedure. Recruitment levels in the 1970s and 1980s (with the exception of 1987) were lower than those estimated in the early to mid 1960s consistent with the much lower spawner biomass as well as the virtual elimination of spawners age 10 and older. Recruitment declined from the 1990 yearclass through to the 1992 yearclass, improved slightly to the 1994 yearclass, declined to the lowest observed level for the 1996 yearclass, and appears to have improved slightly subsequently. The rather promising appearance of the 1999 yearclass (pelagic 0-group data) is associated with considerable uncertainty and will need to be confirmed by Campelen survey data. Overfishing in the late 1980s and early 1990s reduced the spawner biomass to extremely low levels and there has been no subsequent evidence of significant recruitment. The impact of the possibly near-complete recruitment failure in 1996 may be significant under even "index" levels (3,000 t) of fishing given the current compacted age composition and low biomass. Viewing 2J3KL cod as a unit stock, there would appear to be no scientific data to support the recommencement of commercial fishing activity in 1999 (TAC of 9,000 t) – conversely extreme caution should be exercised in retaining the very few spawners in the population in the hope that high recruitment rates might occur from even this low spawner biomass to eventually initiate a recovery.

Factors Affecting the Recovery of Depleted Fish Populations. *WP27*

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The expected rate of recovery of depleted fish populations is strongly dependent on the nature of nonlinear processes governing the dynamics of the population, the intrinsic rate of increase, and the state of the biotic and abiotic environment. Mechanisms with important implications for recovery prospects of depleted species include the possibility of systems with multiple stable states, the potential for depensatory dynamics, the possibility of regime shifts in the physical and biological environment, and habitat loss and alteration.

The response of populations characterized by the possibility of multiple stable states to rehabilitation can be complex. If a stock is driven to a lower production state, reductions in fishing mortality alone may not be sufficient to permit the stock to recover to a higher stable state. In this case, a strong recruitment event driven by stochastic variation, could provide the nucleus for transition to a higher equilibrium level under reductions in fishing pressure. Mechanisms that can result in multiple stable states include well known predator-prey dynamics, (Type III functional feeding response associated with prey switching) and a sequence of nonlinear mechanisms operating at different life history stages (e.g. density-dependent growth and cannibalism by adults)..

Depensatory dynamics can result in the extinction of a stock or substock. Here, a lower unstable equilibrium point can result in local extinction of a stock or substock if a lower threshold population level is crossed. In this case, recovery is wholly dependent on recolonization from an adjacent stock or substock. Mechanisms that can result in a depensatory dynamic include predator-prey interactions with a Type II function feeding response.

Low frequency environmental forcing can result in a shift in production regimes to a lower level that is dependent on the state of the environment. If the intrinsic rate of increase of the population is altered by these changes, the expected time scales of recovery will be directly affected. It is particularly important to note that levels of exploitation that are sustainable under high production regimes may not be maintained under lowered production levels. There is an important potential interaction between fishing mortality and the production levels of the stock that must be considered in developing harvesting strategies.

Changes in available habitat also will affect the recovery process and the prospects for recovery to former levels of abundance. If the carrying capacity of the population is altered by factors exogenous to harvesting (e.g. loss of wetland nursery grounds due to adjacent development), then the population may be held at lower levels until restoration efforts are effected. In cases where harvesting itself results in a reduction in carrying capacity, more complex dynamics are possible, including collapsing stability regions in which the population will decline precipitously under exploitation.

Offshore spawning and year-class strength of northern cod (2J3KL) during the fishing moratorium, 1994-1996. ***WP 29***

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An offshore acoustic survey was conducted during June 1994-1996 in the vicinity of Hawke Channel, traditionally reported as the most important offshore spawning area of northern cod (2J3KL). Estimates of spawner abundance and maturities at age combined with published estimates of fecundity at age were used to calculate the potential number of eggs spawned each year offshore. A pelagic juvenile fish survey was conducted during August-September each year, covering the shelf region offshore from Hamilton Bank to the southern Grand Banks (Divisions 2J3KLNO), including all inshore areas along the northeast coast of Newfoundland. Absolute estimates of abundance for pelagic juvenile cod, typically 60-80 days old, were used to calculate natural mortality between the egg and pelagic juvenile stages. The abundance of cod surveyed offshore in June ranged between 16 – 21 million fish among years. There was a sharp decline in the abundance of spawning cod from 1994 – 1996 contrasted with an increase the abundance of juveniles. Spawning biomass decreased from 17,500 t in 1994 to 8,200 t in 1995 to 5,500 t in 1996. The decline in mature cod resulted from the decline and disappearance of cod from the 1987-89 year-classes. This translated into a decline in the number of eggs spawned from 3.7 x 10^{12} eggs in 1994 to 2.7 x 10^{11} eggs in 1996. These declines were mirrored in the distribution and abundance of pelagic juvenile cod. In 1994, juvenile cod were distributed widely offshore and throughout the inshore area. By 1995, few juveniles were observed offshore but they were distributed abundantly throughout the inshore area. In 1996, no juveniles were sampled offshore and only small numbers of juveniles were encountered inshore. Abundance of pelagic juvenile cod declined from 3.1 x 10^9 fish in 1994, to 1.5 x 10^9 fish in 1995 to 1.8 x 10^8 fish in 1994. Natural mortality was estimated to increase from –0.068 d^{-1} in 1994 to –0.084 d^{-1} in 1995 to –0.112 d^{-1} in 1996 for pelagic cod sampled offshore. The decline in spawning fish offshore occurred two years after the implementation of a fishing moratorium for this stock and, therefore, cannot be linked to fishing. This decline in spawning fish combined with the increased rate of natural mortality between the egg and pelagic juvenile stages among years is consistent with depensation mechanisms for a fish population.

Year-class strength of northern cod (2J3KL) and southern Grand Bank cod (3NO) estimated from the Pelagic Juvenile Fish Survey in 1999. *WP30*

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The pelagic juvenile fish survey was carried out from August 23 to September 19, 1999 from southern Labrador to the southern Grand Bank, including the inshore areas of the northeast coast of Newfoundland (NAFO 2J3KLNO). Abundance of pelagic juvenile Atlantic cod (*Gadus morhua*) was high in 1999, compared to surveys carried out 1994-1998, mostly as a result of high catches inshore. However, similar to 1998, higher abundance in 1999 also resulted from relatively high abundance on the Grand Bank (3LNO). Higher abundance was observed on the Northern Grand Bank in 1999, in contrast to 1998, when higher abundance occurred on the Southern Grand Bank. Abundance on the Northeast Newfoundland Shelf (2J3K) was low offshore while inshore it was the highest of any year. Over the six years of the survey, abundance in 2J3KL declined from 1994 to 1996 and has increased since then. Catch rate inshore in 1999 was over 3x the previous high in 1994.

Highest catch rates occurred in Conception Bay (3L) and Notre Dame Bay (3K) along the northeast coast of Newfoundland. Abundance in Trinity and Bonavista Bays was relatively low and almost no cod were found offshore in 2J3K. On the Grand Banks, juvenile cod were found throughout the surveyed area.

Juvenile cod on the Northern Grand Banks (3L) were not as disparately large than more northern areas (2J3K) as they were in 1998. Cod in 3NO averaged 57.5 mm, while those in 3L (NGB) averaged 53.9 mm in length compared to the north within the inshore bays where cod averaged 38.1—49.5 mm in length.

Condition factor was relatively high (1.73) in 1999, in contrast to 1998 when the lowest mean value (1.34) of any year was recorded. The relative condition factor was lower for 3NO than in 2J3KL.

Preliminary growth rate estimates were higher than those of previous years averaging 0.720 mm/day. Larval hatching dates were earlier and spanned a shorter period of time in 1998, compared to 1994-1998.

To the north, in 2J3KL, the production of young fish has increased in inshore areas and also on the Northern Grand Bank in 1999, but continues to be extremely low with no sign of recovery in the offshore areas. A relatively large year-class was measured on the southern Grand Bank for the second year in succession and appears to be a positive response by Atlantic cod to a warmer environment. There has been a general warming of oceanographic conditions throughout the period of the pelagic 0-group surveys (Colbourne 2000).

Ecosystem Effects on the Recruitment, Growth and Pre-recruit Survival of Cod and Haddock on the Scotian Shelf WP31

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Results from an exploratory correlation analysis of environmental factors with cod and haddock recruitment, survival and growth on the Scotian Shelf are presented. The environmental indices include atmospheric (NAO index, winds), hydrological (river runoff), physical oceanographic (temperatures, stratification, sea level elevations and position of thermal fronts), chemical (nutrients, oxygen) and zooplankton indices. The abundance of cod (4VsW, 1958-94; 4X, 1948-1997) and haddock (4VW, 1948-96; 4X, 1962-97) were obtained from the virtual population analysis estimates. The zooplankton data were collected by the continuous plankton recorder (CPR) towed at approximately 7-m depth from commercial ships at regular monthly intervals along fixed routes. Data were averaged over the northeastern and southwestern portions of the Shelf. The CPR data were collected during 1961-75 and from 1991 to present. The zooplankton indices included the abundance of *Calanus finmarchicus* (averaged over stages 1-4 and over stages 5-6), *Paracalanus* and *Psuedocalanus*. The most significant result was the negative relationship between the early stages (1-4) of *Calanus finmarchicus* and the recruitment and survival of cod and haddock on the northeastern Scotian Shelf. In addition, residuals from a Ricker stock and recruitment relationship were negatively correlated with *Calanus finmarchicus* stages 1-4. The larger *Calanus* (stages 5-6) were only significantly correlated with condition of haddock on the southwestern Scotian Shelf. The mechanism behind the negative correlations between zooplankton and fish is unknown, however, it is not considered to be a direct effect of predation on zooplankton by cod and haddock larvae since the relative abundance of the latter is expected to be small compared to the former. Positive correlations with nitrates suggest that high nutrients promote primary production and eventually more food for larvae. The effects of temperature on recruitment and survival were statistically significant but weak. Warmer waters are thought to promote faster growth, which would lower predation rates through reduced time in the larval stages and faster swimming speeds. Multiple regressions were run with recruitment or survival as the dependent variable but these were found not to increase the amount of variance accounted for over a single variable model. Finally, a temperature-dependent growth model was developed for 4VW haddock that accounted for 67% of the variance of weight at age 7.

Ecosystem effects on pre-recruit survival of 3Pn4RS cod
In the northern Gulf of St. Lawrence. ***WP 32***

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1. According to the SPA data, 3Pn4RS cod pre-recruit survival was declining from the late 1970s to the mid 1980s, when it began to increase between 1985 to 1990. Between 1991 and 1996, a period where SSB was very low, the index shows record high values four times the mean of pre-recruit survival between 1974 and 1990.
2. Between 1974 and 1990, the pre-recruit survival index was positively correlated with sea-ice condition in the northeastern Gulf of St. Lawrence: late sea-ice disappearance and long sea ice season were apparently favorable to cod early survival.
3. The recent important increase in the pre-recruit survival cannot be explained by our physical (e.g. water temperature) or ecological data.
4. The earlier positive correlations between sea-ice condition and pre-recruit survival and the recent important increase in pre-recruit survival are unexplainable from empirical evidence of negative effects of cold water temperature on egg development and survival.
5. The value of the pre-recruit survival index from SPA as indicative of true yearly recruitment fluctuations to the population is questionable.

Ecosystem effects on pre-recruit survival of cod in the southern Gulf of St. Lawrence. *WP33*

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The southern Gulf of St. Lawrence cod stock collapsed to similar low levels of abundance in the mid 1970s and the early 1990s. In contrast to the lack of recovery from the recent collapse, recovery from the collapse in the mid 1970s was very rapid. A remarkably high recruitment rate (R/SSB) contributed to the rapid recovery in the 1970s. We examined potential ecosystem effects on pre-recruit survival of cod in search of an explanation for the unusually high recruitment rates in this stock from the mid 1970s to the early 1980s. Factors examined were the biomass of pelagic fishes (herring and mackerel, potential predators of cod eggs and larvae), seal abundance, and a variety of physical environmental variables: air temperatures at the Magdalen Islands in spring and early summer, discharge from the St. Lawrence River system (RIVSUM) in spring and early summer, average minimum temperature in the cold intermediate layer (CIL), the date of last appearance of ice on the Magdalen Shallows, and the North Atlantic Oscillation (NAO) index.

The stock-recruitment relationship of southern Gulf cod appears to be strongly compensatory, with high recruitment rates at low SSB. Residuals from this stock-recruitment relationship showed a strong negative correlation with pelagic fish biomass but no linear association with any of the other potential explanatory variables. Likewise, no nonlinear relationships with these other variables were evident, except for a tendency for the recruitment rate to be highest at intermediate dates of ice breakup. The strong negative effect of pelagic fish biomass on cod pre-recruit survival (i.e., the recruitment rate) reflected the coincidence between the period of remarkable pre-recruit survival of cod from the mid 1970s to early 1980s and the collapse of herring and mackerel stocks due to overfishing.

Significance of these effects on cod pre-recruit survival was tested by including these factors as covariates in the stock recruitment relationship. A Ricker relationship was fit assuming lognormal error and including a first-order autoregressive term for the error. Except for pelagic fish biomass, all linear covariates were nonsignificant ($P>0.1$). The effect of pelagic fish biomass was highly significant ($P<0.01$) and in the predicted negative direction. Results were the same using estimates of cod stock and recruitment based either directly on research survey catch rates or on SPA estimates of abundance, and were not sensitive to the SPA calibration method (i.e., research survey indices alone or both research and sentinel survey indices). The negative effect of cod SSB on pre-recruit survival was also highly significant in all cases. Thus, the remarkably high pre-recruit survival of cod in the mid to late 1970s can be accounted for by the very low cod SSB and the coincident collapse of the herring and mackerel stocks. The recovery of the pelagic fish stocks to relatively high levels of abundance can explain the lower pre-recruit survival rates during the current period of low SSB.

Implications of these results for the recommendation that seal herds off Atlantic Canada should be culled to promote stock recovery were discussed. These results point to the possibility of a triangular food web involving cod, seals and pelagic fishes. A better understanding of the interactions between cod, seals and pelagic fishes is needed before it will be possible to predict the effect of a seal cull on cod abundance.

Do capelin influence cod distribution and recruitment? *WP34*

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Cod and capelin have exhibited similar changes in spatial distribution and abundance during the 1990s. Between 1989 and 1994 the distribution of capelin in 2J3KL shifted to the south and east. This distribution shift occurred at the same time as changes in cod spatial distribution, and potential for contact between cod and capelin did not decrease. In 1999, high acoustic densities of capelin were observed inshore, particularly in Placentia Bay and Trinity Bay. These bays also had relatively high concentrations of cod. Offshore, acoustic estimates of capelin density and biomass in 1999 were low compared to the 1980s. Potential implications for cod recruitment are discussed. We suggest that adult cod will not re-establish offshore areas in NAFO 2J3KL unless capelin abundance offshore increases. There have been encouraging signs of a return to a more northerly distribution of capelin off southern Labrador in 1998 and 1999, and we are currently monitoring the response of northern cod to this change.

Distribution and abundance of demersal juvenile cod (Gadus morhua) on the Northeast Newfoundland Shelf and the Grand Banks: implications for stock identity and monitoring. *WP 35*.

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The relative abundance and distribution of juvenile cod in Divisions 2J3KLNO in the autumn of 1995-1998 and in Divisions 3LNOP in the spring of 1996-1998 (plus 1999 for 3Ps only) were inferred from catches during resource assessment bottom-trawl surveys. Surveys since autumn 1995 have been conducted with the Campelen 1800 shrimp trawl, which is far more effective at catching small cod than the Engels 145 Hi-rise trawl that it replaced.

In Division 2J3KL, there is evidence that cod in some parts of the inshore are faring better (higher densities; larger, older fish) than cod in the offshore. If this is so, then it is of interest to determine if these areas are experiencing different recruitment patterns. In addition, there has been considerable interest in distinguishing and managing individual components within the 2J+3KL cod stock complex, and indeed a quota was established for inshore waters only in 1999. If a management regime with two or more components or substocks is to be considered, then it will be important to create separate recruitment indices for the various components. Previous work on the distribution of juvenile cod in Divisions 2J3KL has revealed that individuals of ages 0 and 1 were found mainly in shallow waters near the coast off southern Labrador and northeastern Newfoundland and on the northern Grand Bank, that individuals of ages 3 and 4 were mainly in those offshore areas occupied by older cod, and that individuals of age 2 were intermediate in distribution. Catches from autumn surveys in 1995-1998 have revealed a similar pattern, with the notable exception that the 1994 year-class, which has been the strongest year-class appearing in the surveys since at least the early 1990s, was already well onto the shelf by age 1. More recent yearclasses have been extremely weak in Division 2J, but have been found to be somewhat more abundant adjacent to the coast in Divisions 3K and 3L. It will be of considerable importance to determine (1) whether these yearclasses are recruiting to the shelf environment from settlement in the offshore or settlement in the adjacent inshore and subsequent migration to the offshore, (2) whether they are derived from spawning on the shelf or spawning inshore and (3) in the case of inshore spawning, whether the parents belonged to a group that is genetically distinct from groups on the shelf. The ontogenetic shift from a coastal distribution at age 0 to a more shelf-wide distribution by age 2 will make it very difficult to create different indices for inshore spawners vs offshore spawners, or inshore substocks vs shelf substocks.

Plots of distribution at age from the autumn surveys also revealed a concentration of juveniles on the southern Grand Bank (Divisions 3NO). Presumably, these fish belong to the 3NO cod stock. During the surveys of 1995-1998, very few juvenile fish were found on the northern Grand Bank.

Plots of distribution at age from spring surveys in Divisions 3LNOP revealed the presence of age 1 cod mainly on western St. Pierre Bank and the southern Grand Bank. Very few were caught in Division 3L. Age 2 fish were more broadly distributed from 3Pn across 3Ps and onto the southwestern Grand Bank in Division 3O. With increasing age, the cod became more heavily concentrated in northwestern and southeastern Division 3P. Age 2 and older fish were also caught in low numbers on the southernmost end of the Northeast Newfoundland Shelf in northern Division 3L.

The identity of the spawning populations that gave rise to the juveniles caught in the autumn and spring surveys is of considerable interest but difficult to infer from surveys alone because of limited bottom-trawl surveying during spawning periods, the lack of egg surveys and little knowledge of the drift patterns of eggs, larvae and early juveniles. Of special interest is the distribution of the 1989 and 1990 yearclasses, which were not particularly strong at the juvenile stage but were protected during the moratorium years and contributed much of the spawning biomass of 3Ps and 3NO cod in the mid- to late-1990s. These yearclasses were found during spring mainly on the outer slopes of Burgeo Bank and the outer ends of the gullies in southeastern Subdivision 3Ps and southwestern Division 3O. These yearclasses also contributed strongly to the cod caught inshore in Divisions 3KL during the 1990s, but they were caught in very low numbers in the offshore of these Divisions.

Regional differences in mortality rates of a larval fish, the radiated shanny (*Ulvaria subbifurcata*): estimating the relative roles of dispersion and predation. WP37

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We investigate the relative roles of dispersal and predation on estimated mortality rates by conducting a series of short term patch studies in coastal areas of Newfoundland (Bonavista, Trinity and Conception Bays). There was considerable day-to-day variation in the pattern of convergence/divergence at the three sites studied, as the patch of larvae moved across the bays. In two of three instances, dispersion dominated throughout the observation period whereas convergence was observed during the later part of the observation period at the third site. Variations in the overall dispersion resulted in substantially different contributions to the estimated mortality rates, accounting for 7, 35 and 68% of the mortality observed in Bonavista Bay, Trinity Bay and Conception Bay, respectively. The residual mortality (i.e. after accouting for the effects of dispersion) showed and increasing trend with increasing abundance of pelagic fish (estimated from hydroacoustic observations). At very low predator levels, the average "biological" mortality of radiated shanny was approximately 0.01 d^{-1}. The association between mortality rates and the abundance of potential predators suggests that planktivorous fish may play a significant role in the dynamic of pre-recruits.

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Quantifying the reproductive potential of the Northeast Arctic cod stock: works in progress. WP39.

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The Bergen Cod Reproduction Laboratory has several ongoing projects investigating the dynamics of cod reproduction at both the individual and stock level. Thematically, all of the projects investigate one or more of the links between food, growth and reproduction of individuals, total egg production by the stock and recruitment. A laboratory project was initiated this year to model condition effects on maturation and potential and realized fecundity of wild-caught cod. Another ongoing project uses Monte Carlo methods to simulate the relationship between spawner biomass and recruitment. Variation in this relationship is added sequentially from the following sources: condition effects on maturation, weight, fecundity and egg quality, shifts in the size composition (modal length) of spawners, and pre-recruit mortality. Preliminary results suggest that condition introduces greater variation into the relationship between spawner biomass and recruitment than do shifts in the size composition. A collaborative project with scientists at the Polar Research Institute of Marine Fisheries and Oceanography (Murmansk, Russia) has been initiated to create an electronic database for the Russian ichthyoplankton surveys conducted in the Norwegian and Barents Sea from 1959 to 1993. These data will be used to develop abundance indices for early life history stages and to explore spatial dynamics of egg and larval distribution. Another project has reconstructed the stock/recruit relationship for Northeast Arctic cod using a bioenergetic index of reproductive potential (total lipid energy, units of kilojoules). In contrast to the indeterminate relationship between spawner biomass and recruitment, the bioenergetic index shows a significant, positive relationship with recruitment. In future, residual variation in the reconstructed stock/recruit relationship will be compared to a range of environmental and ecological variables representing processes that could affect pre-recruit mortality.

Reproductive potential and rate of population increase of cod in the northern Gulf of St. Lawrence. WP 40.

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Important variations in fecundity are observed between and within populations of the same species. Parental genes, endocrine and nutritional status, and fish size have all been identified as major factors affecting egg production. In the northern Gulf of St. Lawrence, nutritional status and fish size could have significantly affected the reproductive potential of cod. A significant decline in condition factor was observed in the early 1990's indicating a decrease in the energy reserves of the fish. During that period, cod condition during spawning declined to levels close to the range where energy reserves are completely exhausted. Fecundity was significantly lower in poor condition females, particularly those of smaller size. Despite lower fecundity, estimated loss in somatic energy during reproduction was proportionally greater for cod with poorer levels of condition. Lower total egg production per unit of spawning stock biomass was observed in the early 90's. Total egg production of the population was severely reduced during the period between 1992 and 1994. The relationship between size of the spawning stock and recruitment to the fishery may thus vary considerably with the nutritional condition of the spawners. The measure of the reproductive potential used in conjunction with life history models provide a mean of examining how reproductive potential, and possibly recruitment may have suffered from the situation observed in recent years and could have contributed to the failure of that stock to recover despite the moratorium on commercial fishing.

Success and Failure of Atlantic cod, *Gadus morhua* : a case study from coastal Newfoundland. WP 41

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Despite a century of study, ecologists still struggle to understand fluctuations in marine populations, including many commercial species whose fisheries have collapsed despite considerable management effort (Hjort 1914, Sissenwine 1984). We present data on Northwest Atlantic cod that encompasses the adult spawning to juvenile settlement stage and demonstrate that timing of spawning is critical, particularly as it relates to spawning location and coastal circulation in regulating recruitment success. In what is presently the largest commercially-exploited Atlantic cod (*Gadus morhua*) stock remaining in the Northwest Atlantic, we found that spawning occurred at consistent, discrete locations that were generally favorable for propagule retention within the bay. However, when cod spawned relatively early in the year (April - May), colder water led to slower development, and currents swept most eggs offshore before hatch. Spawning later in the year (June-August) resulted in faster hatching, thereby reducing duration of early and vulnerable life stages and the probability of being swept offshore. Elevated densities of pelagic larvae and settled juveniles were associated with late spawning. Successful recruitment to the coastal region therefore requires spawning at sites where propagules are likely to retained, and at times when egg development rates are maximized. This 'right time, right place hypothesis' suggests that in tandem with more traditional variables such as spawner biomass and condition, timing and location of spawning may be important spawning success in marine populations that live in highly seasonal environments.

Stock Reproductive Potential. ***WP42***

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The knowledge and scientific history of maternal and paternal aspects of reproduction dates back several decades, though only recently are fishery scientists and managers giving this subject area greater attention in the provision of management advice. A new term referred to as stock reproductive potential (SRP) has been developed. Compared to spawning stock biomass and population fecundity, SRP more accurately represents the annual variation in a stock's ability to produce viable eggs and larvae. An assembled score-card applied to 45 Canadian Atlantic gadoid stock assessments conducted from 1985 to 1998 portrays the evolution and current degree to which this scientific knowledge has been incorporated into fishery advice in eastern Canada.

The score-card results show that only marginal headway has been made towards incorporating reproductive biology into management advice. A paucity of data exists on the reproductive state of wild northwest Atlantic cod and other groundfish species. Fecundity has been recorded for ~600 individuals over the past century for all northwest Atlantic cod stocks combined. Other than the outdated material for the Gulf of Maine cod (ca. 1880), no published fecundity data exist for the four southern cod stocks spanning from Nova Scotia to Georges Bank. Collection of maturity data recently has been discontinued for several Canadian gadoid stocks.

Future sampling of wild fishes for reproductive data should be strongly encouraged. A science program should be founded that would enable a large-scale initiative to monitor fecundity, egg size and egg viability data among northwest Atlantic groundfish stocks. The cod recruitment dilemma may be better understood if appropriate estimates of stock reproductive potential exist.

The Northwest Atlantic Fisheries Organization, as an outcome of a NAFO Symposium held on this subject in Lisbon 1998, has initiated a Working Group on Reproductive Potential (18 members representing eight countries). The terms of reference of the WG prescribe that it (i) detail the state of knowledge on this subject for a variety of stocks, (ii) provide appropriate methodology required to measure a stock's reproductive potential, and (iii) develop applications for assessment and management. The activity plan for the working group will be finalized at the Scientific Council meeting in June 2000. The output of the WG will be prepared in such a way that countries such as Canada will be able to address their shortcomings in this area through valid, scientifically based collections of tissue samples and conduct of appropriate analyses (ovaries, liver, fecundity estimation). These measures will lead towards improved management and conservation of demersal fishery resources as recommended by the Fisheries Resource Conservation Council of Canada.

An examination of the possible effect of spawning stock characteristics on recruitment in 4 Newfoundland groundfish stocks. *WP43*.

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Trends in recruits, spawning stock biomass and age at 50% maturity were examined for three cod stocks (2J3KL, 3NO, 3Ps) and one flatfish stock (3LNO American plaice). Recruitment was estimated as the abundance of two year old cod (2J3KL), three year old cod (3NO, 3Ps) and five year old American plaice (3LNO) based on SPA models. Spawning stock biomass (SSB) was estimated in the standard manner. Notably for the northern cod stock (2J3KL), a special SPA model was fit that attempts to account for "missing fish". SSB and recruitment data were fit to a Beverton-Holt model for each stock. Residuals from the modelled fits were compared to different characteristics of each spawning stock, including: weighted mean age; proportion of first time spawners; proportion of females. Age of maturity has decreased substantially for all four stocks considered, although the extent of the decline and the time period varied among stocks. For the time periods examined, up to 1993-1995, the recruits per SSB have tended to be low since the mid-1980's, although 3Ps cod has been more variable in recent years. Weighted mean age of the SSB, proportion of first time spawners and proportion of females all showed substantial variation over the time periods examined. Mean age declined substantially in 3LNO American plaice, 2J3KL cod and 3Ps cod as a result of a decrease in the abundance of older age classes and maturity at a younger age. 3NO cod have not shown the same trend. The proportion of first time spawners has increased in recent years and has reached high levels in 2J3KL cod. For all four stocks, the proportion of females is generally greater than 50% and the proportion appeared to vary over time for the different stocks. Comparison of the different stock characteristics with SSB were confounded by covariance among the variables, complicating any exploration of effects or attempts to describe functional relationships.

Spawning stock characteristics and cod recruitment success in the southern Gulf of St. Lawrence. *WP44*.

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Recruitment rate (defined here as R, the abundance of 3 yr old cod, divided by SSB, the biomass of the spawning stock that produced them) has varied widely for cod in the southern Gulf of St. Lawrence. In particular, the rate of recruitment was remarkably high from the mid 1970s to the early 1980s. Variation in the quantity or quality of eggs produced by a unit of SSB will contribute to variation in the recruitment rate when it is estimated by R/SSB. We tested effects of spawning stock characteristics (age and size structure) on the recruitment rate of southern Gulf cod.

Over the 1950-1994 period, there was no tendency for high recruitment rates to be associated with an older or more diverse age structure of the spawning stock, or with a spawning stock composed of larger fish in better condition (as measured by growth rate or weight at age). Mean age of spawners, their age diversity and the proportion of older fish in the spawning stock all declined to their lowest levels in the mid to late 1970s, when recruitment rates were at their highest. Size and growth of spawners were high both during the period of high recruitment rates in the mid to late 1970s and in the 1950s and 1960s when recruitment rates were unremarkable. Effects of indices of spawner age and size composition were not significant when included as covariates in the stock-recruitment relationship, even accounting for the effect of pelagic fish biomass on the recruitment rate. It appears that effects of characteristics of the spawning stock on recruitment success of southern Gulf cod are overshadowed by other sources of variation in recruitment rate, at least in the case of the spawning stock characteristics that we have measured.

Observations on mass atresia and skipped spawning in northern Atlantic cod, *Gadus morhua*, from Smith Sound, Newfoundland. *WP45*.

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A relatively large concentration of over wintering adult cod has been observed in Smith Sound, Trinity Bay in recent years. Visual examination of male and female gonads indicated that some large fish had under developed gonads in January 1999. Histological analysis of ovaries indicated that one third of females were undergoing mass resorption of oocytes (atresia) and would not spawn in 1999. Hepatosomatic indices for fish resorbing oocytes were significantly lower than ripening females, suggesting that the interruption in the maturation cycle was related to insufficient energy reserves. It was hypothesized that cod in Smith Sound may have been recovering from a previous period of low nutritional state. It was possible that these cod might have a lower state of atresia the following year, if nutritional status (protein and lipid) were adequate. Atresia in cod may be another important biological variable contributing to low spawning success and subsequent recruitment in the northern cod.

Multiple recruitment pulses of 0-group and relative year-class strength of Atlantic cod in Newman Sound, Bonavista Bay in the late 1990's. WP46

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We have conducted annual beach seining surveys in the nearshore of Newman Sound, Bonavista Bay, during the July to November period since 1995. Recruitment of age 0 Atlantic cod has improved throughout this period, from its lowest point in the middle of the decade to later in the decade. This trend mirrors the data and predictions of the more spatially extensive Fleming Surveys through to 1997, the last year of that survey. Recruitment of age 0 Atlantic cod has been over an order of magnitude higher at present than at its lowest point in 1996. Analysis of length frequency data collected from July to November in Newman Sound indicated that age 0 Atlantic cod settled in the nearshore in two distinct recruitment pulses in both 1998 and 1999 - the first arriving in early August, the second in late September. In both 1995 and 1996, only the second of these pulses was evident. We show evidence that the recruitment pulse structure demonstrated for age 0 fish is preserved in age 1 fish the next year. The implications of each of these pulses on overall recruitment to subsequent age groups remains to be identified.

Distribution and biomass of capelin, Arctic cod and sand lance on the Northeast Newfoundland Shelf and Grand Bank as deduced from bottom-trawl surveys. ***WP 47***

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Small planktivorous fish might influence recruitment to stocks of Atlantic cod (Gadus morhua) in two major ways. As predators, they may consume the eggs, larvae or very small juveniles of the cod. As prey, they may through changes in their abundance or availability influence the quantity of food consumed by mature cod and thereby influence the quantity or quality of the eggs and sperm produced by the cod populations.

The major small planktivorous fish inhabiting the waters from southern Labrador to the southern Grand Bank are capelin (Mallotus villosus), Arctic cod (Boreogadus saida), herring (Clupea harengus) and sand lance (Ammodytes sp.). Herring occurs almost entirely in coastal waters, whereas the other three species occur both inshore and offshore.

Changes in the trawlable biomass and distribution of capelin, Arctic cod and sand lance are deduced from their by-catch during standard resource assessment bottom-trawl surveys during the autumn in Divisions 2J3KL and during the spring in Divisions 3LNO. Catches of these species have increased dramatically since the autumn of 1995 when the Engels 145 Hi-rise trawl was replaced by the Campelen 1800 shrimp trawl as the standard gear in these surveys. There has been no attempt to conduct comparative fishing experiments for these three species with these two trawls, so the change in gear represents a break in the time series for each species. In general , Arctic cod were found mainly toward the coast in Divisions 2J3K, capelin were found throughout the area and exhibited seasonal changes in distribution, and sand lance were found only on the plateau of Grand Bank. The most notable changes in distribution involved a move toward the southeast in Division 2J3K by both capelin and Arctic cod in the early to mid-1990s. In the past two years both species appear to be returning to distributions seen in the 1980s. Other notable features include an increase in the trawlable biomass of Arctic cod in the early to mid-1990s and a decline in the trawlable biomass of capelin during the same period.

Spatial, temporal and parental patterns in cod and haddock recruitment: A summary of the EU-STEREO project (1998-2001). WP 48

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The specific objective of the STEREO project (Stock Effects on Recruitment Relationships) is to build a modelling system that will predict the probability of contributions by different spatial, temporal and parental components of the spawning stock of a species to the juvenile pre-recruit population some months after spawning. The system is formulated in such a way as to address the following strategic questions for a given stock:

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

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

The system being developed includes a spatially and temporally resolved model of egg production by an age or length structured spawning stock. This is coupled to a particle tracking model which simulates dispersal, growth and survival of eggs and larvae, and competition (density dependence) during the transition from the pelagic to demersal stages. Demonstration results for North Sea haddock indicate intricate spatial and temporal structure to the survival of eggs and larvae.