# Proceedings of a Northern Cod Workshop held in St. John's, Newfoundland, Canada, January 27-29, 1993

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ABSTRACT

The May 1991 assessment of NAFO divisions 2J3KL cod (northern cod) conducted by CAFSAC indicated that the age 3+ biomass had reached 1 million tonnes at the beginning of 1990, and that this would increase to almost 1.1 million tonnes by January 1992 under the existing multi-year management plan. Fishing mortality on ages 7-9 would gradually decline under the plan to be at about $F_{0.1}$ by 1993. Subsequent events did not support this view. The 1991 inshore fishery was a failure in many areas, particularly in Labrador. Catches contained very few large fish. The 1991 fall stratified random bottom trawl survey indicated an approximately 50% biomass decline from that of 1990. The offshore fishery began to have difficulty locating larger fish, and by the winter of 1992, could not find fish of commercially acceptable size north of Div. 3L. Subsequent assessments conducted by both CAFSAC and NAFO in 1992 suggested a more pessimistic outlook, and after review of these reports, the Minister announced, on July 2, 1992 that there would be a moratorium on fishing for 2J3KL cod in Canadian waters for 2 years. The only activities to be continued would be hand-lining of fish for personal consumption, and bycatch of cod in various other fisheries such as the flounder fishery in Div. 3L.

Much formal and informal discussion has occurred on possible causes for the observed decline, with blame variously placed on scientists, offshore fisheries (domestic and foreign), inshore fisheries and the environment. In order to more closely examine these, a workshop was convened in January, 1993 by the A/ADM, Science of the Department of Fisheries and Oceans (DFO) during which the current situation was fully reviewed, possible hypotheses put forward to explain the observed situation, and research recommendations made on how to address the various hypotheses. This report describes the proceedings of this workshop, and includes information on the various hypotheses and research recommendations.

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## RÉSUMÉ

L'évaluation des stocks de morue des divisions 2J3KL de l'OPANO (morue du Nord) réalisée en mai 1991 par le CSCPCA révélait que la biomasse des morues d'âge 3+ se chiffrait à un million de tonnes au début de 1990 et qu'elle atteindrait près de 1,1 million de tonnes d'ici janvier 1992, selon le plan de gestion pluriannuel alors en vigueur. D'après ce plan, la mortalité par pêche dans les âges 7-9 diminuerait progressivement pour se situer aux alentours de $F_{0.1}$ d'ici 1993. Les faits subséquents démentirent ce point de vue. La pêche côtière se solda par un échec en 1991 dans de nombreuses régions, en particulier au Labrador. Les prises ne contenaient que très peu de gros poissons. L'échantillonnage aléatoire stratifié effectué au chalut de fond ou printemps 1991 dénotait une chute de la biomasse d'environ 50% par rapport à 1990. Les participants à la pêche hauturière eurent bientôt de la difficulté à trouver des gros poissons, à tel point qu'à l'arrivée de l'hiver 1992 ils n'arrivaient plus à pêcher de poissons de taille commerciale acceptable au nord de la division 3L. Les évalutations réalisées subséquemment par le CSCPCA et par l'OPANO en 1992 révélèrent une réalité encore plus pessimiste. Après étude des rapports d'évaluation, le Ministre annonça, le 2 juillet 1992, qu'il imposait un moratoire de deux ans sur la pêch de la morue dans les eaux canadiennes de 2J3KL. Seules la pêche à la ligne à main aux fins de consommation personnelle et les prises accidentelles de morue dans d'autres pêches, comme celle de la plie dans la division 3L, demeuraient permises.

Les causes possibles du déclin observé suscitèrent d'abondantes discussions, officielles et officeuses, le blâme étant jeté, selon le cas, sur les scientifiques, sur la pêche hauturière (par les flottilles étrangères et canadiennes), sur la pêche côtière et sur l'environnement. Pour étudier plus attentivement la question, le sous-ministre adjoint par intérim des Pêches et des Océans organisa, en janvier 1992, un atelier au cours duquel on procéda à un examen approfondi de la situation, on formula des hypothèses au sujet de cette dernière et on recommanda des recherches connexes à ces hypothèses. Le présent rapport décrit le déroulement de cet atelier et contient des renseignements sur les hypothèses et recommandations en question.

# EXECUTIVE SUMMARY AND RECOMMENDATIONS

## EXECUTIVE SUMMARY

### Background

Stock Size and Assessment: The May 1991 assessment of NAFO divisions 2J3KL cod (northern cod) conducted by CAFSAC indicated that the age 3+ biomass had reached 1 million tonnes at the beginning of 1990, and that this would increase to almost 1.1 million tonnes by January 1992 under the existing multi-year management plan. Fishing mortality on ages 7-9 would gradually decline under the plan to be at about $F_{0.1}$ by 1993.

Subsequent events did not support this view. The 1991 inshore fishery was a failure in many areas, particularly in Labrador. Catches contained very few large fish. The 1991 fall stratified random bottom trawl survey indicated an approximately 50% biomass decline from that of 1990. The offshore fishery began to have difficulty locating larger fish, and by the winter of 1992, could not find fish of commercially acceptable size north of Div. 3L.

An interim assessment conducted by CAFSAC in late January 1992 suggested a more pessimistic outlook than that from the 1991 assessment. The multi-year plan would not result in a reduction of fishing mortality or increase in biomass during its duration. The estimated January 1992 biomass was only about 776,000 tonnes. CAFSAC advised that catches for the first half of 1992 be kept at only about 50% of those for 1991. As a result of this assessment, the Minister, in late February, closed the offshore fishery for the remainder of the spring.

CAFSAC conducted another assessment of the resource in May. In addition, Canada requested that the status of the resource be reviewed in early June, at a Special Session of the Scientific Council of NAFO. Both bodies came to the same conclusions. The January 1992 age 3+ biomass was projected to be only about 527,000 - 696,000 tonnes, and the age 7+ biomass (an approximation of the spawning stock biomass) was projected to be between 48,000 - 108,000 tonnes, amongst the lowest values ever observed. It was recognised by both bodies that a substantial fishery had taken place outside 200 miles, and Canadian surveillance estimates of foreign catch were incorporated into the assessments. Both CAFSAC and NAFO concluded that an 'abrupt' decline in the resource had occurred. Neither was able to determine the main cause of this decline, although a number of factors including fishing mortality, environment, predator/prey relationships and migration were identified as possible contributors. NAFO concluded that assuming there was an increase in natural mortality, it would not be prudent to conduct quantitative catch projections beyond 1992. Meaningful predictions of stock status were not possible until it was determined if the situation would continue. NAFO went on to recommended that fishing mortality be reduced in 1992 from levels of recent years. CAFSAC recommended that the 1992 catches be kept to the lowest possible.

After review of these reports, the Minister announced, on July 2, that there would be a moratorium on fishing for 2J3KL cod in Canadian waters for 2 years. The only activities to be continued would be hand-lining of fish for personal consumption, and bycatch of cod in various other fisheries such as the flounder fishery in Div. 3L.

For 1992, estimates of the total catch (foreign, plus domestic by-catch and recreational fishery) are only about 30-40,000 tonnes. Nonetheless, results from the fall 1992 survey suggested a further substantial decline in trawlable biomass. The majority of this decline occurred in Div. 2J and 3K.

It was the consideration of the Workshop that while the results from the 1992 survey are alarming, it is premature to consider their meaning at present. The decline observed between the 1990 and 1991 surveys (and the 1991 and 1992 assessments) largely confirmed results of acoustic surveys, scouting trips and the 1991 inshore and offshore fisheries. At this juncture, there are no ancillary data to indicate whether the 1992 results are real or confounded by year effects causing a low estimate. While it is possible that many cod remained inshore and therefore outside the survey area in 1992, limited searching in the inshore bays did not locate any. An acoustic survey of the area is scheduled for February 1993. No further discussion of the 1992 results took place.

Other North Atlantic Cod Stocks: Background information concerning other cod stocks in the North Atlantic was examined. This indicated a number of similarities as well as differences with northern cod. The collapse of the Barents Sea stock has been attributed to an 'ecological crisis.' The prey of cod disappeared, and there was evidence of substantial cannibalism that substantially reduced the size of the 1984 and 1985 year classes. However, there were no indications of increased natural mortality of adult cod. Around Iceland, the stock appears to be fluctuating in response to fishing pressure. Of note, however is that recent years represent the longest consecutive period of low recruitment. It is also the longest period during which there has been low stock increase through immigration from West Greenland.

The cod stock off West Greenland, like that in Div. 2J3KL exists in water temperatures at the low end of the range for cod in the North Atlantic: much colder than the two noted above. The size of this stock has been clearly related to the environment. Before the 1920s, there were very few cod off West Greenland. The stock size (and catches) increased during the 1920s and this period corresponded to one of increased temperatures. High biomass continued until the early 1980s when a dramatic decline took place. This decline corresponded to a period of cooling. With subsequent warming, the strong 1984 year class appeared. It was assumed that it originated from spawning off East Greenland and Iceland. Much hope for the future was placed on this year class, but it subsequently disappeared. Although first thought to have migrated back to Iceland, further analyses have indicated that the losses from West Greenland cannot be fully accounted for by increases in biomass in the Iceland area. Thus, an estimated 200 million fish 'disappeared.' Prior to disappearing, there was a re-distribution of the fish in a southward direction in the West Greenland area. Another interesting aspect of this year class is that for three years before its disappearance, there was no apparent growth of individual fish. This may indicate a stressed population although a growth decline with selective disappearance of larger fish could also account for this observation.

Environment: Like West Greenland cod, the northern cod stock dwells in water temperatures from about -1.5 to 6.0 °C. Being at the low end of the range, these cod are probably more susceptible to environmental influences than those in more temperate waters. There was a gradual cooling of water in the 2J3KL area through the early 1980s, followed by some warming in 1986 and 1987. Since then, temperatures have cooled again, and the extent (volume) of the Cold Intermediate Layer (CIL) has increased. For 1990 and 1991 this was estimated to be about 40% greater than normal. In 1991, ice was present in the inshore areas well into the summer and records were set for the latest presence of ice. Low ocean temperatures persisted through the summer and early autumn with negative anomalies extending from the Labrador Shelf to southern Newfoundland. Bottom temperatures in 1992 were slightly higher than 1991, but still well below normal. Predictions are that the CIL will remain above average in size for 1993.

Workshop Purpose: Information available suggests that the decline has been 'abrupt' as was concluded by both CAFSAC and NAFO in 1992. Based on the assessment results, this was about 500,000 tonnes. The Workshop purpose was to determine, through discussion, possible causes for the decline, then to focus on those considered to be of most significance. After discussion, recommendations of research necessary for evaluation of the different possibilities would be forthcoming. It is also important to realize that the total decline may be the result of more than one factor, and the overall effects may be multiplicative rather than additive.

Discussions

Timing: This deals with the timing of the observed decline, as well as the timing of events leading up to the decline. CAFSAC and NAFO considered the decline to be 'abrupt' and to have occurred during the first half of 1991. Survey data support this. Results from the fall of 1990 indicated that although there was some apparent re-distribution of biomass between divisions, the total was as expected. Results from an offshore acoustic survey in February 1991 were approximately the same as those from 1990. The biomass estimate from the spring survey in Div. 3L was the lowest in the time series, and only one third as high as the 1990 estimate. The 1991 June acoustic survey results suggested there had been an approximate 50% decline from 1990. A 50% decline in the bottom trawl survey results from the entire 2J3KL area occurred between the fall of 1990 and 1991. Inshore fishery data also suggest a sudden decline. Overall, catches in 1990 were on par with those of earlier years. In 1991, catches were poorer over a wide geographic area and the fish were smaller than expected. Scouting trips to try to locate concentrations of fish in both the offshore and nearshore in the first half of 1991 were largely unsuccessful. Interpretation of these observations generally indicates that the decline probably occurred between February and May - June 1991.

The offshore fleet did not however, encounter major difficulties in catching their allocations in either Div. 3K or 3L in 1991. Only in January 1992 were problems encountered with no commercial sized fish being located in 3K and smaller than usual fish found in 3L.

The Workshop also considered the hypothesis that the decline was more gradual, happening over a number of years. From survey as well as fishery results, a substantial decline took place in Div. 2J in 1990. Many other demersal species, both commercial and non-commercial exhibited gradual declines throughout the 1980s based on survey data. Further examination of the trawl survey data is necessary to evaluate this. If these analyses support a more gradual decline, then it will be necessary to reconcile the apparent sudden reduction as perceived from the other data sources.

There are indications within the data that the decline began in the north then moved south. It is also possible that events took place in Div. 2GH even earlier. For example, the biomass in Div. 2J showed an increase in 1988. Where did these fish come from, and could it have been 2GH? In 1989, while many fish remained in Div. 2J, the biomass had declined compared to 1988 whereas that in Div. 3K increased. It is possible that some of the 3K fish had come from 2J. There was no winter fishery in Div. 2J in early 1989 because of a strike in the industry. The last good offshore fishery in Div. 2J took place in the fall of 1989. Severe ice conditions in early 1990 prevented the fleets from returning to this area during winter, but officials were not overly concerned because of the good fall fishery in 1989. The trawler captains themselves were not so optimistic however. They felt that the 1989 fall fishery in Div. 2J was abnormal particularly because of the size of fish; they were thought to be larger than normal 2J fish. Their concerns were borne out. During the fall of 1990, catch rates in Div. 2J were lower, and the fish were smaller and not in as good shape. This may have been a first indication of stress as discussed later.

The biomass in Div. 2J declined further in 1990 as did that in Div. 3K. The offshore fleet had a good year in Div. 3K in 1990 although the fish were smaller than previous years. The offshore captains claimed these were 2J fish. At the same time, the biomass estimate for Div. 3L increased to the highest in the time series. Confirmation of increased biomass in Div. 3L comes from the excellent gillnet fishery in Div. 3L around the Virgin Rocks and at the '40 fathom edge' during the same year.

There are other indicators of changes occurring before 1991. Condition factors for northern cod began to decrease in 1990. Capelin biomass increased dramatically in Div. 3L in May of 1990, while the estimate for Div. 2J3K in the fall of the same year declined significantly. At the time, the interpretation placed on these data was that the fish had re-distributed into Div. 3L. Subsequent surveys to Div. 2J3K as well as 3L have indicated substantial decreases in biomass. The inshore fishery data also indicate some decline, but they do not suggest as great a magnitude as do results from the offshore acoustic surveys. Although some questions remain as to the biomass of capelin remaining at present, there is no doubt that they have changed their distribution, and that this was first detected in 1990. It was also in 1990 that the prey of gannets from Funk Island changed as well. The species composition of their stomachs, taken in August, showed a dramatic shift when compared to earlier years. This change of diet remained in effect through 1992, and was interpreted as indicating a drastic change in the pelagic environment. Sea mortality of salmon has increased from about 1987, again suggesting an environmental change occurring before 1991.

An examination of trends in biomass of other demersal species caught during the annual fall groundfish cruises also suggests that events may have been happening before 1991, and even as far back as 1981, the earliest time when data from all 3 divisions is available. Diverse species such as American plaice and roughhead grenadiers have shown a gradual decline in biomass through the 1980s, even without substantial fisheries. For American plaice, a natural mortality rate of >60% year after year would have been necessary to account for the declines observed. As with cod, these declines appear to have been most dramatic in Div. 2J. In all 3 divisions, the proportion of cod to other demersal species gradually increased. Also similar to cod, it appears that abundance of larger American plaice declined at a faster rate than that of the smaller ones.

Limited information on invertebrates such as shrimp and crab does not suggest similar trends. Instead, these resources appeared to increase somewhat during the 1980s and early 1990s.

Thus, it appears that although the rapid decline may have occurred in the first half of 1991, climatic events and distribution and biomass changes may have been beginning to happen, particularly in the north, even earlier; at least as early as 1990 and possibly back through the 1980s. Major changes took place in capelin distribution and gannet feeding in 1990, and liver weights for cod began decreasing at the same time, presumably in response to some other factor. Biomass of other demersal fish species declined through the 1980s even without fisheries. Observations of inshore fishers also suggest changes occurring since about 1983.

Causes: The foreign fishery for cod outside 200 miles on the nose increased substantially in 1991 and surveillance estimates of catch were approximately double what was reported. This information was taken into account during the 1992 assessments so could not account for the decline observed. A careful examination of the fishery statistics led to the conclusion that although it is possible that both foreign and domestic catches may have been underestimated over time, the amounts would be insufficient to account for a decline in the resource of the magnitude observed, or even a significant portion of it. If the decline has not been as 'abrupt' as presumed, then a continuous under-estimation, accumulated over time, may account for the loss. This would imply a systematic over-estimation of the resource through time, and would bring into question the correctness of the index (bottom trawl surveys) used in calibration of VPA. For the present, this is unlikely, and therefore any examination of this possibility will await results from other studies into the timing of the event.

A possible explanation for the observed decline is migration - movement out of the area, perhaps due to temperature changes or other factors. If fish were moving from north to south, perhaps they didn't stop in Div. 3L but continued on further. This was ruled out as a plausible explanation however, because the declining and low state of the cod stocks further south, both individually and collectively, is such that this could not significantly account for the declines observed in the 2J3KL stock. It is also possible that the fish moved offshore into deeper water not normally surveyed (>1000 m). This may have happened either outside 200 miles in 3L (the nose), or inside 200 miles further north. Neither of these were considered reasonable. If they moved outside 200 miles, it was assumed that they would have been caught in the foreign fishery, yet surveillance estimates do not show this. Neither is there any anecdotal information from European scientists suggesting that their fleets encountered concentrations of cod of sufficient magnitude to account for a significant portion of the observed decline. Also, in September 1991, Canada conducted a deepwater trawling survey for Greenland halibut in depths of 750 - 1500 m from Flemish Cap to Cape Chidley. No cod were encountered during this survey.

Predation by seals is also a possible explanation of the decline. The seal population has increased in recent years, although there has not been an 'explosion' as is often reported. The current population is estimated to be 2.7 - 3.5 million animals. Data from stomach samples collected over many years suggests that cod comprise only a small fraction of seal diet (<4%) but these data are from inshore areas only, and in winter seals inshore do not overlap to any large extent with cod distribution. The percentage of cod found in the relatively few offshore stomach samples from 1991 and 1992 is much higher, in the range of 50%, although these samples were collected during the offshore trawl fishery directing for cod and may be biased because of this. Some samples obtained from the area of the Virgin Rocks contained primarily capelin and sand launce. The sampled group from the offshore (age 7+ males) represents only a small portion of the population. It is unknown if this sample is representative of the body of seals offshore or if behavioural differences between age groups and sexes accounted for disproportionate sampling.

Given the available information, the Workshop concluded that predation on cod by seals probably increased during the early 1990s. The extent of this increase could not be determined. Important data are lacking from the offshore, and increased sampling of seals in the offshore areas is necessary to address this shortfall.

Even if the seals did not actually prey upon the cod, it is possible that they caused mortality through some other means. For example, if the fish were in a weakened condition for some reason, then perhaps being chased generated enough stress or depleted reserves such as to cause higher than normal mortality. This type of consideration leads into another completely different, and little explored field; that of cod physiology and stress.

There were a number of plausible hypotheses put forward as to the possible effects of stress on cod. Stress related death is a possible explanation for the observed decline, but it is not believed that this was necessarily caused as a direct and immediate result of starvation. Based on research on cod in the southern Gulf of St. Lawrence, it is possible, however, to create an energy deficit in cod that could accumulate over one or more years and eventually cause higher than normal mortalities. The volume of the cold intermediate layer (CIL) was about 40% higher than normal not only in 1991, but in 1990 as well, and if this caused a deficit through unavailability of prey, then higher than normal mortality might occur after spawning in the subsequent year. This would result in a disproportionate decline in larger fish in 1991, consistent with what actually happened.

The above type of event would indicate a cumulative rather than immediate effect. Some type of accumulation of effects probably occurred. The extra-ordinary events of 1990 and 1991 were perhaps the 'straw that broke the camel's back.' It is also possible that the stress built up over a longer period. Indications are that many organisms can tolerate stress for long periods before finally succumbing to it. In this situation, the final cause of death may be only a small further change in a critical factor such as environment, and therefore difficult to detect.

## Recommendations

The following specific recommendations, arising from the Workshop, identify areas of research that, for the most part, rely on existing data sets. From these analyses should follow recommendations for further research. It is important that these activities take place in a co-ordinated fashion and that progress be monitored closely. Results of these studies must be examined in total before drawing any conclusions or inferences from them, or recommending further research activities. Because of this, priority must be assigned to the work activities, and consideration should be given to holding a follow-up meeting within a suitable period to collate results.

### Timing:

1. Because of the uncertainties whether the declines in biomass were abrupt or more gradual, it is ***recommended*** that a modelling exercise be carried out using the trawl survey data to test the rate of decline. Depending on the results of this work, further recommendations may follow pertaining to evaluations of the commercial fishery data.

2. Related to the above, and because there was an apparent shift to deeper water in recent years, it is ***recommended*** to analyze the SCANMAR data collected over the past number of years to determine if it is possible that trawl catchability is different in deeper water. It is also ***recommended*** that otter trawl catchabilities in each of the divisions be examined using commercial trawl data to determine if there are any differences between divisions.

3. As another approach to determining the timing and rate of decline, it is ***recommended*** that any catch/effort data from the Virgin Rocks gillnet

fishery in Div. 3L be examined, as well as length frequency data. Examination of length frequency data from the offshore fishery in Div. 2J, 3K and 3L should also be examined as an aid to pinpointing the time of decline of larger fish. It is ***recommended*** that length frequencies from the Div. 3L fisheries and research vessel surveys in 1990 should also be examined to ensure that the increased survey estimates for that year were not partially due to fish moving north from Div. 3NO.

4. Information on the sizes of fish captured in different areas is also available from production records of the offshore companies (FPI and National Sea) as well as the Canadian Saltfish Corporation. It is ***recommended*** that these records be examined in as much detail as possible to obtain information on the sizes and possibly condition of the fish caught in different areas over time.

5. During the assessment process, data from the inshore areas are usually grouped by gear and NAFO Division. This makes it difficult to determine if there have been systematic changes in the inshore fishery over time. To address the issue of timing and rate of decline as well as the matter of a north - south progression, it is ***recommended*** that spatial analysis of the inshore fishery data be examined. This should not only include evaluation of catches in the different areas, but also an examination of length frequencies from these areas if available. It would also be useful to examine length frequency data from the Div. 3L gillnet fishery as well as length frequency data from 2J and 3K to see if movements between divisions can be detected.

6. Declines in the biomass of other species have also been noted. For cod, it appears that the larger animals are disappearing at a faster rate. It is ***recommended*** that information for other species be examined to determine whether their declines are age specific or not.

<u>Causes</u>:

1. There is a recognised gap in seal feeding data from the offshore. It is ***recommended*** that every effort be made to collect increased numbers of samples from all parts of the offshore areas where seals are found during winter months. Some information suggests that seals are being found in poor condition as well. To confirm this, it is ***recommended*** that analyses of blubber condition be carried out, and that this be related, if possible to stomach content data.

2. It was well recognised during the Workshop that knowledge of the physiology of cod is lacking. There is work underway in the Gulf Region

and at MLI, and through OPEN so more information should be available in the literature over the next few years. There is also work going on in Europe, and some information is available in existing literature. It is ***recommended*** that a Workshop on Cod Physiology be held as soon as possible to identify ongoing research as well as areas where there are knowledge gaps, and to recommend areas of research necessary to address these gaps. Issues which should be addressed include the physiological response of cod to $O_2$ levels, cold, starvation and spawning both in the short and longer term, as well as ways these may be measured.

3. One of the possible factors contributing to stress and/or mortality is the $O_2$ content of the water. A long time series of $O_2$ data is not available, but there are indications that it correlates with $\sigma t$ (sigma-tee) 27 (a density gradient). It is ***recommended*** that this possible correlation be investigated to determine if $\sigma t$ 27 could serve as representative of $O_2$ thus enabling an examination of $O_2$ for a longer period.

4. It is ***recommended*** that comprehensive mapping of such things as the shape/volume and intensity of the CIL, as well as examination of $O_2$, and oceanic currents be carried out in order to obtain clear indications of the extent of changes over time as well as the timing of their occurrence. It is also important to determine exactly what factors may have the greatest importance. For example, some of the acoustic work studying cod migration has indicated that temperature gradients are important.

5. Work on cod anti-freeze can yield information on whether the fish are in cold water, and if so, for how long. Sampling associated with this work is currently taking place but on a large geographic scale. It is ***recommended*** that this work be expanded to allow for analyses of smaller geographic units within Div. 2J3KL to help determine how cod are relating to the cold water, and assist in determining if cold water stress may be a factor contributing to mortality.

6. Parasite loads may serve as indicators of stress. It is ***recommended*** that the substantial database of *Lernaeocera branchialis* infestation of cod in the 2J3KL area be analyzed to determine if any shifts have occurred which may indicate a change. Information on other types of parasites might be useful if this is available.

Other:

1. It was quite clear from discussion during the Workshop that a closer link between the biologists and oceanographers is necessary. Steps in the right direction have occurred with the formation of CAFSAC's Fisheries

Oceanography Subcommittee in late 1991. These initiatives must continue and be strengthened. Close collaboration between the two groups is essential to understanding the ecosystem and solving many of the problems facing us. It is ***recommended*** that every effort be made to enhance the communication and collaboration between fisheries scientists and oceanographers.

2. Considerable discussion took place of the role of plankton and benthos both as indicators of environmental change, and as possible causes of change through the food web. Clearly our knowledge of this part of the marine biota is lacking but should be increased. It is ***recommended*** that mechanisms be put in place to facilitate the initiation of plankton and benthos research to address this gap in our knowledge base.

# INTRODUCTION

Historically, the northern cod stock (NAFO Divisions 2J, 3K and 3L - Figure 1) is the largest in the Northwest Atlantic, contributing about one half of the Canadian cod catches and about one quarter of total groundfish landings. A dramatic decline in this stock was indicated from assessments carried out in 1992 which suggested a decrease of about 500,000 tonnes compared to the 1991 assessment results. Both the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) (Anon. 1992a) and the Northwest Atlantic Fisheries Organization (NAFO) (Anon. 1992b) in 1992 concluded that this decline had been 'abrupt.' Fisheries scientists are faced with the task of determining the cause of this decline. To address these concerns, the Newfoundland Region of the Department of Fisheries and Oceans (DFO) held a multi-disciplinary workshop on the northern cod stock (2J3KL cod) chaired by Dr. William G. Doubleday, A/Assistant Deputy Minister, Science, Department of Fisheries and Oceans, Canada.

A Workshop, held to establish possible hypotheses for the decline, focus on those considered to be of greatest significance and then make recommendations of research necessary for testing the hypotheses was held January 27-29, 1993 in St. John's, Newfoundland. The agenda of the workshop is presented in Annex I.

The recommendations of the workshop wêre formulated to assist research managers and scientists in planning their respective activities over the next few years.

Attending the workshop were scientists and managers from Newfoundland, Scotia-Fundy, Gulf, Quebec, Ottawa and Pacific Regions of DFO. DFO participants represented Science Branch and Fisheries and Habitat Management Branch. Other invited Canadian participants included representatives from the Fisheries Resource Conservation Council, Department of Fisheries (Newfoundland), Atmospheric Environment Service, and Memorial University of Newfoundland. As well, researchers from Norway, Iceland, Denmark and the United States accepted invitations to attend. A list of participants is provided in Annex II.

A Steering Committee condensed each day's discussions and summaries were presented at the start of the following day's sessions. The workshop itself was conducted as a continuous plenary session. In addition to the formal discussions, a series of posters were available for review.

# BACKGROUND

The series of initial presentations made during the first two days of the workshop provided background information which formed the basis for subsequent discussion and facilitated the development of hypotheses. The biomass trends of northern cod and other species in the Northwest Atlantic were outlined, followed by a synopsis of the physical environment of the area. Enforcement and surveillance procedures utilised by Canada were described to provide background for discussions of catches and fishing effort, particularly that outside the 200 mile limit. Experiences with the Northeast Atlantic cod (Barents Sea, Iceland) and West Greenland cod as well as some Alaska fisheries and oceanography were reported in order to provide comparative background information.

## BIOMASS TRENDS

### Northern Cod and other Groundfish; (J. Baird)

Catches of northern cod began to increase in the mid 1950's with expansion of the foreign trawler fishery offshore. They peaked at about 800,000 tonnes in 1968 but subsequently declined steadily to 1978 (Figure 2).

Total allowable catches (TACs) were first introduced as a management tool in 1973. After 1978 catches again gradually increased, and from 1982 to 1988 averaged 260-270,000 tonnes. In 1988 the sustainability of the northern cod stock at these catch levels was reviewed and estimates of the size of stock revised downward. In late 1990, a three year management plan was implemented with TACs of 190,000 tonnes for 1991, 185,000 tonnes for 1992 and 180,000 tonnes for 1993. In 1991, CAFSAC concluded (Anon. 1991) that the age 3+ biomass had reached 1,000,000 tonnes at the beginning of 1990, and that this would increase to almost 1,100,000 tonnes by January 1992 under the three year management plan. Fishing mortality on ages 7-9 would gradually decline under the plan to be at about $F_{0.1}$ by 1993.

Subsequent events did not support this view. Canadian landings in 1991 were among the lowest since 1977 when jurisdiction was extended to 200 nautical miles offshore (Figure 2). The inshore fishery was a failure in many areas, particularly in Labrador. Inshore gear of all types experienced the biggest single year decline in the past 16-17 years having taken total catches of about one half that for 1990. The inshore gillnet fishery (normally based on fish 6-10 years old) suffered the largest decline. This reflected expected weak year classes from 1983-84, but the magnitude of decline was unexpected. Overall, catches contained very few large fish. In fact, catches and survey estimates had been very low in northern areas since 1990. The entire stock appeared to have shifted to the south and into deeper water.

In 1991, the Canadian offshore fleet also had difficulty locating larger fish and poor catches in Division 2J and northern Division 3K led to a reduction in expended effort. The total catch for Divisions 2J3KL in 1991 was only 170,000 tonnes, (of which 120,000 tonnes was Canadian), a shortfall of 70,000 tonnes with respect to the Canadian TAC of 190,000 tonnes. However, foreign catches (outside 200 mile limit) were among the highest since 1977 indicating increased availability of the stock in this relatively small area (Figure 1).

The 1991 fall stratified random bottom trawl survey indicated an approximately 50% biomass decline from that of 1990 (Figure 3). By the winter of 1992, the offshore fleet could not find fish of commercially acceptable size north of Division 3L. An interim assessment conducted by CAFSAC in late January 1992 suggested a more pessimistic outlook than that from the 1991 assessment. It was concluded that the three year plan would not result in a reduction of fishing mortality nor an increase in biomass during its duration. The revised estimate of the January 1992 age 3+ biomass was only about 776,000 tonnes, more than 300,000 tonnes less than estimated in the 1991 assessment. CAFSAC advised that catches for the first half of 1992 be kept at only about 50% of those for 1991. As a result of this assessment and recommendation, the Minister of the Department of Fisheries and Oceans, in late February, closed the Canadian offshore fishery for the remainder of the spring.

CAFSAC conducted another assessment of the resource in May of 1992. In addition, Canada requested that the status of the resource be reviewed in early June, at a Special Session of the Scientific Council of NAFO (Baird *et al.* 1992). Both bodies came to the same conclusions (Anon. 1992a, b). The January 1992 age 3+ biomass was projected to be only about 527,000-696,000 tonnes (another decline of 100,000-250,000 tonnes), and the age 7+ biomass (an approximation of the spawning stock biomass) was projected to be between 48,000-108,000 tonnes, the lowest values ever observed. It was recognised by both bodies that a substantial foreign fishery had taken place outside 200 miles in 1991 with actual catches being greater than those reported. Canadian surveillance estimates of foreign catch were therefore incorporated into the assessments. Both CAFSAC and NAFO concluded that an 'abrupt' decline in the resource had occurred. Neither was able to determine the main cause of this decline, although a number of factors including fishing mortality, environment, predator/prey relationships and migration were identified as possible contributors. CAFSAC recommended that the 1992 catches be kept to the lowest possible. NAFO concluded that assuming there was an increase in natural mortality, it would not be prudent to conduct quantitative catch projections beyond 1992. Meaningful predictions of stock status would not be possible until it could be determined if the situation would continue. NAFO went on to recommend that fishing mortality be reduced in 1992 from levels of recent years.

After review of these reports, the Minister of the Department of Fisheries and Oceans announced, on July 2, 1992, that there would be a moratorium on fishing for northern cod in Canadian waters for two years. The only activities to be continued would be hand-lining of fish for personal consumption, and by-catch of cod in various other fisheries such as the flounder fishery in Division 3L.

For 1992, the preliminary estimate of the total catch (foreign, plus domestic by-catch and recreational fishery) is only about 30-40,000 tonnes, a significant reduction from 1991. Canadian catches were estimated to be about 18,000 tonnes (including 5,000 tonnes estimated for recreational catches, although recreational catches may have been as much as 15,000 tonnes). Foreign catches of 12,000 tonnes were estimated to have been taken outside of the 200 mile limit (EEC reported catches of only 10,000 tonnes). Nonetheless, results from the fall 1992 survey suggested a further substantial decline in trawlable biomass (Figure 3). The majority of this decline occurred in Divisions 2J and 3K.

Annual fall research vessel survey results indicated high variability in biomass estimates between Divisions 2J3KL since 1987-1988. This may be related to a gradual south and eastward (offshore) displacement, although the range of estimates has been less variable in the more southern Division 3L. Highly variable individual research vessel catches indicated increased aggregation of the fish in recent years. In 1991 observed catch per tow fell short of predicted for every age class (ages 3-4 dropped 20-30%; ages 5-7 dropped 50-60%; and ages 8-10 dropped 70-90%). The numbers of age 6+ fish per tow in 1991-92 were the lowest in 17 years. Virtually no mature fish were taken in Divisions 2J3K in 1992. Only a few were taken in Division 3L. The observed decline of 6+ fish in 1991 appeared to extend to lower ages in 1992. Younger fish (age 1-5) were strongly represented in 1991 but were present in comparatively low numbers in 1992. The strong year classes of 1986-87 were much reduced based on the 1992 results. The 1981-91 autumn surveys for Divisions 2J3KL indicated that even with the decline in cod, its proportion relative to other groundfish species increased during the 1980's.

Research vessel surveys using acoustics found a shift of pre-spawning concentrations of northern cod during February to deeper waters along the shelf edge (300-400 m in early 1980's compared to about 800 m in 1990-91).

Trends observed during the surveys are not reflected in the Sequential Population Analysis (SPA) results because the models commonly used tend to smooth trends over time because of the built in assumptions. For example, natural mortality (M) is assumed to be constant at 0.2. The model will therefore attribute sudden changes in the size of a stock to changes in fishing mortality (F).

Capelin, Shrimp, and Crab; (J. Carscadden)

Capelin are managed as two stocks, one in Divisions 2J3K and the other in Division 3L (Figure 1). Offshore acoustic surveys are conducted in the spring (Division 3L) and fall (Divisions 2J3K) annually to measure recruitment and project the following year's stock size. The major capelin fishery targets inshore spawning females in late June and July. TACs have been set at or below 10% of projected spawning biomass. In Division 3L the catches generally reflect the TAC.

A composite of available data indicates high capelin abundance in the 1970's, low abundance in the early 1980's and high abundance in the late 1980's (Figure 5). The 1990 offshore acoustic surveys indicated high abundance in Division 3L but not in Divisions 2J3K where capelin were only found concentrated in the southern part of the area. The 1991-92 offshore acoustic surveys estimated dramatically lower abundance. The offshore distribution of young capelin in Division 3L had shifted to the south and mature fish were not located during the surveys.

The inshore abundance indicators have been somewhat contradictory to the low biomass estimates recorded offshore during the 1990s. Trap catches in Division 3L correlated well with offshore abundance estimates before 1991. In 1991 capelin arrived late inshore, but the catch rates were good while the offshore estimate was low. Mature fish were smaller in 1991 and still smaller in 1992, and in both years spawning was delayed. However, egg and larvae surveys on beaches did not indicate reproductive failure in either 1991 or 1992. The timing of spawning has been linked to temperature, and cold waters in 1991-92 might have caused the delay. There was little fishing for capelin in 1992 because of small (unmarketable) fish sizes.

The northern shrimp fishery occurs throughout the area extending from Division 0A in the north to 3K in the south (Figure 6). Recently, the fishery increased substantially in Divisions 2J and 3K, but stocks in Division 3L and on Flemish Cap have not yet been exploited. Previous low landings from Divisions 2J3K were due to a lack of knowledge on distribution and seasonality of shrimp concentrations in these areas. Catches rose in the late 1980's and have remained fairly stable into the 1990's. Commercial catch rates for shrimp in these areas do not relate to trawl survey biomass estimates as illustrated by data from the Hopedale Channel (Figure 7). Generally, the stocks of shrimp appear healthy and have displayed no negative effects due to fishing.

Snow crab landings around Newfoundland declined in the early 1980s then levelled off before increasing dramatically in many areas recently. Increases in catch rates over the last 4-5 years are attributed partially to earlier reductions in TACs leading to stock recovery, but more importantly to exploitation in new areas. Surveys of these areas in the early 1980's detected few crabs. More recent sampling indicates recent colonisation rather than immigration of adults to these new areas.

<u>Atlantic Salmon</u>; (D. Reddin)

Salmon abundance is often measured by egg deposition in natal rivers with each river's population being considered a discrete stock. Total catches of Atlantic salmon, for the world and for Canada have declined in recent years with the lowest level occurring in 1991. Part of the decline in catches is due to recent management measures that have reduced fishing effort, however the decline also coincides with cold water temperature years. In some years on the east coast of Newfoundland, salmon have been delayed in arriving, catches have been reduced, and abundance appears to be reduced.

Counting fence data from the Gander River support the apparent recent decline in 1991, and also in 1992 if adjustment is made for the moratorium on the commercial salmon fishery (Figure 8). Sea survival has been calculated from counting fence data from Conne River (on the South Coast) (Figure 9). A steady decline was observed from 1987 to 1991 (based on returns from 1988-1992) in spite of the commercial salmon moratorium. Similar results have been reported from other rivers. In the late 1960's and early 1970's multi sea-winter salmon from the Miramichi River displayed better survival than one sea-winter fish; in the past couple of colder years, the opposite has been indicated.

On the east coast of Newfoundland, commercial salmon catches decline when there is an increase in area (volume) of the Cold Intermediate Layer (CIL) (Figure 10). Salmon arrival time at the Terra Nova River is later when sea surface temperature is colder (based on number of days $T<4^{\circ}C$). There seem to be strong effects on salmon when the CIL is large but no correlation when it is smaller.

Commercial salmon catches on the north-east coast declined in years of extensive ice cover, but concurrently increased on the ice-free south-east coast. Tag returns confirmed an apparent change in migration routes (*i.e.* of New Brunswick bound salmon) due to cold water.

Smolt have difficulty osmoregulating in cold water. Below 6°C, mortality increases as temperature decreases. Mortality in salmon, like other fish, can occur if they contact ice while super cooled.

<u>Plankton</u>;(A. Longhurst)

Plankton data as they relate to the ecological systems under consideration are available from: i) the International Continuous Plankton Recorder (CPR) program which utilises continuous recorders towed behind ships of opportunity; ii) scientific grid surveys; and iii) satellite oceanography. The relevant data, have not been analyzed adequately to satisfy the information requirements of the workshop.

<u>Marine Mammals</u>; (G. Stenson)

Six species of seals and approximately 25 species of cetaceans are found in Divisions 2J3K but the harp seals are the most numerous and controversial. They migrate in early fall from the Canadian Arctic and West Greenland down the Labrador coast (Figure 11). They arrive in the Strait of Belle Isle by

November-December (in 1992 they were there by October); the Front group moves off the north-east coast and the Gulf group move into the Gulf of St. Lawrence. The populations whelp from late February through early May. Feeding is suspended for about a month during whelping, after which they disburse, feed, and then form into moulting concentrations from mid-April to early March. Following moult, when feeding is also reduced, the seals disperse, feed and begin their northward migration to the Arctic summering range (May-July). These movements are not well defined and the timing is variable (possibly depending on water temperatures, ice cover, water currents and available prey).

Most data on harp seals feeding in Newfoundland waters are based on near-shore observations. Population estimates over the past 40 years are based on pup production as assessed by; age composition, mark-recapture, and visual or photographic survey techniques. A model incorporating pup production using assessed or age specific pregnancy rates and catches is used to estimate the total population. The most recent survey, in 1990, resulted in an estimated pup production of 578,000 and a total population of 3.1 million. The 1990 estimate represents a likely increase in the population but the rate of increase cannot be estimated. Based primarily on age structure analyses, the Royal Commission on Seals and Sealing (1985) estimated that the population was 1.5-1.75 million in 1978. The 1990 estimate represents an increase of 7% per year. However, if the results of mark-recapture experiments conducted between 1978 and 1983 are considered, the rate of increase would be less.

The Royal Commission on Seals and Sealing estimated that harp seals obtained approximately 30% of their annual food requirements in Divisions 2J3KL. However, this is considered a rough approximation and may need to be increased due to changes in the length of residency in southern areas which may have occurred in recent years. Traditionally diets have been expressed as the percentage of stomachs examined which contained specific prey organisms. However, reconstructing the wet weights of the stomach contents are felt to provide a better indication of the contribution of different prey to the diet. Reconstruction of stomachs collected in 1991 indicate that Arctic cod (>50% wet weight) were the most important prey among seals in nearshore areas. Capelin accounted for less than 8% of the diet and Atlantic cod less than 4%. This general pattern for capelin and Atlantic cod held for different ages of seals. Young seals tend to eat more squid and less Arctic cod. Historically, Arctic cod has been the most commonly occurring prey (based on relative frequency of occurrence). The proportion of stomachs containing Atlantic cod has remained relatively constant while the proportion containing capelin varied in a manner that does not appear to be related to offshore capelin abundance estimated acoustically.

Traditionally, sampling of harp seals has taken place in winter in inshore areas where cod are not common when seals are present. Two sources of samples from offshore areas have been analyzed. The first consisted of seals taken in trawls that were fishing for cod. These samples were predominantly adult males of ages 7+, and they had cod in their stomachs. The cod were smaller in size than those being harvested in the trawls but larger than seen in nearshore areas. A second sample, obtained from harp seals of a range of ages and both sexes, caught in gillnets fishing flatfish near the Virgin Rocks, contained capelin and sand lance predominantly. None of the sampled stomachs contained Atlantic cod.

PHYSICAL ENVIRONMENT; (G. Mertz)

The shelf water mass in Divisions 2J3KL, including the Labrador Current has displayed a cooling trend from 1983 onward. Oceanographic data from Station 27 (south-east of St. John's) (Figure 1) have been shown to be typical of shelf water south of Hamilton Bank. These waters undergo great cooling from December through March, achieving minimal heat content in March. As spring and summer heating occurs, August surface temperatures reach 12°C and greater while waters deeper than 50 m remain below 0°C (the Cold Intermediate Layer [CIL]). The magnitude of the cooling correlates with a general North Atlantic weather circulation. A stronger north-westerly circulation produces colder winters and a larger CIL. At the same time, warmer winters are experienced on the east side of the North Atlantic and this relationship flip-flops episodically (hence the term North Atlantic Oscillation to describe this). The shelf bottom temperatures declined strongly in 1972-73, again in 1983-85, and for a third time in 1989-91. All of these declines corresponded to a high North Atlantic Oscillation index. Temperature registered in the CIL did not fully return to normal during the intervening periods resulting in a long term cooling trend.

In 1991 the anomalies were well below the long term mean (1910-89). The surface 2°C contour for June 1991 was pushed south by 800 km. The CIL (at 100 m depth) was about 0.5°C cooler in 1991 and had a large tongue of -1°C that would not normally be present in the area. By November 1991 the surface anomalies were not evident, but at 100 m depth the CIL had not diminished significantly from the June pattern. The pattern in 1992, based on the cross-sectional area of the CIL for the Cape Bonavista transect (Figure 1) indicated a partial return towards average values but still with colder than normal temperatures.

The global surface air temperature warmed from 1900 to the 1940's, followed by cooling to about 1970, with rapid warming since then. The sea-surface temperatures for the North Atlantic reached a peak in the 1930's. Changes in the biota in the North Atlantic have been documented for this period. Recent cooling, since 1970, in mean water temperature of the North Atlantic is anti-phasic in relation to atmospheric warming.

Consideration of the physical environment was given based on the predictability of physical conditions, particularly in the light of any decadal periodicity. Modelling of parameters in the North Atlantic has been done statically but not dynamically. Components have been atmospheric, ocean currents, the CIL, and ice. Incorporation of freshwater data from the north still needs to be considered. The only forecasting available now is based on an evaluation of cold air temperatures and strong north-west winds that combine to increase the CIL. These effects take a year or two to decay. The predictability for deep water (150 m) is about six months and this declines with decrease in depth because atmospheric effects are more closely coupled to events in shallower layers. The winter mixing over the shelf is usually to the bottom and that limits effects on the deep water to less than a year. The prediction for 1993 is for a cold year and larger than average CIL.

Whereas regional scale events provide some predictive capability, *e.g.* the ensuing inshore fishery, there is, at present, little predictive capability on the scale of the North Atlantic. Until oceanic modelling is improved, predictive capabilities are very limited.

An index of the cross-sectional areas of the combined four standard hydrographic transects from Divisions 2J3KL shows an increase in CIL area from 40% below average starting in the late 1970's to above average by about 30% for 1983-85, slightly below average for 1986-87, and again slightly above for 1988-89 (Figure 12). An abrupt increase to 45% above average area occurred in 1990, the largest single year change in the series. The index remained about 30% above average in 1991. The prognosis is that if there is a lot of inshore ice, this index will remain high in 1993.

This index correlates to recruitment somewhat in that years with below average CIL area correspond to those with good year classes and *vice-versa*. This relationship does not hold for the data prior to 1978.

The above provides a six-year predictive capability of year class strength of northern cod that may be useful. Recognising that there will not be good recruitment in a cold year, the impact on the fishery would be felt approximately six years later. The 1986-87 year classes were predicted to be strong and this was confirmed from trawl survey data. Their numbers declined significantly in 1992.

There are also indications of significant relationships between salinity and year-class strength.

ENFORCEMENT AND SURVEILLANCE; (L. Strowbridge)

There are four components to the surveillance program: i) aerial surveillance over a large geographic area to identify and track fishing activity; ii) patrol vessels to board and inspect fishing boats; iii) observer program to monitor compliance and catch rates; and iv) dockside monitoring to verify Canadian fish landings. There is 100% coverage of foreign vessels fishing within Canada's 200 mile limit. Although there is not 100% coverage of the Canadian fleet, it is felt that coverage is sufficient so that significant violations or changes in patterns will be detected. There are 30,000 $km^2$ of Continental Shelf (nose and tail of the Banks and the Flemish Cap) that are outside the 200 mile limit but within the NAFO Regulatory Area. This area is annually subjected to an estimated 20-25,000 fishing vessel-days of effort by non-Canadian fleets. Catches in this area are calculated from an average of 250-275 vessels per year and logbook information totalling about 8000 fishing days and 20,000 entries per year (grouped by nation, vessel type, species and catch rates). These calculations are used to extrapolate, via aerial sightings, the catch and effort of all vessels in the entire area. In the years that coverage is considered adequate and misreporting is not extensive, the modelled estimates are considered to be reasonably accurate ($\pm$20%).

Summarizing,

- Aerial surveillance utilises radar coverage of 200 nautical mile radius that can detect all activity within that range.
- Surveys are flown every day and each identified vessel is located every 4-5 days throughout the season.
- Illicit foreign fishing in Divisions 2J3K would be negligible due to the distance of incursion inside 200 miles that would be required to get to the fishing grounds. Problems would more likely occur at the nose and tail of the Grand Banks (Figure 1).
- EU catches, as estimated by Canadian surveillance, coincide quite well with unofficial estimates provided by EU scientists.
- Non-contracting (NAFO) party vessels are inspected at a level of about 10% and estimates are otherwise based on similar vessel types from contracting parties.
- The number of non-contracting party vessels has remained the same but the proportion of their catch is increasing coincidental with a reduction in catches by NAFO vessels.
- Undersized meshes are assumed more prevalent than observed but it is difficult to catch violators or estimate the overall degree of use.
- The total foreign catch of 2J3KL cod was estimated at 50,000 tonnes in 1991 and 12,000 tonnes in 1992 and underestimates of foreign catches would account for only 5-10,000 tonnes in 1992.
- The drop in foreign catches in 1992 is mainly due to suspension of fishing effort by the EU, although some vessels had already left because they could not find fish. There has been a steady decline in catch rates since 1991.
- Since 1986 there has been 100% coverage of domestic trawlers >100' in directed 2J3KL cod offshore fishery.

- Domestic catches of record for 1980-85 are probably underestimates due to unreported discards in the offshore fishery.
- Inshore discards were not reported, although they are assumed to be low.
- Recreational catches would have been about 5,000-10,000 tonnes in 1992.
- Misreporting in logbooks can take the form of misrepresenting quantity, species or area. Hold inspections can validate quantity, surveillance will verify area, but species cannot be confirmed for processed fish.
- Misreporting usually occurs when there is an incentive - *i.e.* when quotas are low and fish apparently plentiful, as happened in 1988-89.
- The observers have submitted no anecdotal observations of emaciated fish, dead fish or other biological oddities, except for increased observations of seals.
- Deep water trawls (> 1,200 m depth) for halibut have produced no significant cod by-catches.
- In 1991, EU fishing reported the best catch rates in Division 3L at 800-1200 m.

NON-CANADIAN STOCKS

Norway (Arctic-Norwegian cod); (K. Sunnana and S. Sundby)

The yield of Arctic-Norwegian (Barents Sea) cod declined steadily from the mid 1970's but the fishing mortality increased from about F = 0.8 to F = 1.0 in 1987. This high point was concurrent with an increase in yield of smaller fish as a single strong year class entered the fishery. In 1989, fishing mortality was reduced sharply to about 0.3 and it fell to 0.2 by 1991. The assessments during this period indicated that when F is high it tended to increase even when the quota was reduced and, when management reduced F, it declined to a lower than planned value.

Spawning stock biomass (SSB) and recruitment (R) have fluctuated slightly out of phase over time. Levels of both were generally higher during the 1960s than during the 1980s. The steady decline of Norwegian cod stocks since World War II, presumably due to fishing pressure, displays some exaggerated amplitudes that are attributable to environmental factors. Recruitment of 0-group and the SPA age 3 in recent years have been compared, and the correlation is good except for the crisis in 1986-88 when low plankton production decreased the capelin stock and ensuing cannibalism by cod depressed a couple of year classes. Strong potential year classes originating in 1984-85 were subject to cannibalism by the 1983 year class and suffered dramatically. This occurred during a warm period. It was warm again in 1990-92 and 0-group surveys showed the 1992 year-class to be the highest ever estimate. The 1982-84 year classes produced these due to repeat (second time) spawning which produces more numerous and more robust eggs.

Numerous surveys have monitored Arctic Norwegian cod over time. When the data for all of these surveys are transformed to a common index and superimposed, similar patterns over the years show a dramatic peak in 1989 followed by an equally dramatic decline in 1990 (for age 6 fish). Individual surveys show large fluctuations which may not always reflect the situation of the stock. The most recent surveys indicate different trends which may be either one of these fluctuations or a real trend that will be verified by future data. This type of observation may indicate potential problems when evaluating the status of northern cod since there is only one annual index available for calibration of SPA.

Multi-species considerations have shown interrelated patterns. The herring fishery produced a consistent catch from 1952-1966 whereupon the stock, which had been in decline since 1956, collapsed. The stock has very slowly recovered and is only now approaching a level that will sustain a limited fishery. With the collapse of the herring fishery, effort switched to capelin and during 1965-1977 increasingly greater catches were taken. After 1981, the stock declined due to continuing high catches coupled with poor recruitment. Recovery of the stock was indicated following 1990 and reasonable catches were taken in 1991-92. The cumulative herring and capelin declines mirror a similar pattern of decline in cod. An interrelationship on the basis of available prey biomass is probably a factor. The decline in the Barents Sea cod in 1986-88 can be linked to low capelin abundance caused by low plankton abundance. During this "crisis" there were no cod in one area and weak year classes in another; some fish lost up to 40% their average weight over the three years.

Different cod stocks live in different temperature ranges, northern and Greenland cod from -1 to 3°C, Barents Sea cod from 1-7°C, Iceland cod from 4-9°C and North Sea cod from 6-13°C (Figure 13). For Barents Sea and Greenland cod, there is a link between temperature and recruitment at the extremes of the stocks' temperature range. Good recruitment does not occur during cold years whereas good or poor recruitment can occur during warm years. The effect(s) may be direct or indirect, acting on a prey species (e.g. *Calanus finmarchicus*) and/or other influence(s).

An examination of length at age and temperature for age 6 fish showed an inverse relationship prior to 1976 and a direct relationship after that time. The difference in the two time periods may be due to stock density. If density is high, the stock increases with temperature and the length at age (individual growth rate) declines.

In summary, during the crisis, the Norwegian experience was that there was a decrease in weight at age, an increase in cannibalism on the young year classes. Unlike the apparent situation with northern cod, there was no indication of increased natural mortality in adult cod.

Iceland;(S. Schopka)

Cod spawn in March-April along the south coast of Iceland. The larvae drift clockwise about the island and end up off the north-east coast. In some years the drift extends to West Greenland and there is some movement of adults between Iceland and West Greenland, enough to affect the perceived year class strength. There is no compelling evidence of migrations involving northern cod or Barents Sea cod, nor is there evidence to support the local belief that in resent years Icelandic cod have migrated out of traditional areas.

Post-war catches peaked at 500,000 tonnes in 1954 and then declined gradually to the present level of under 300,000 tonnes. Over the past 60 years the stock has declined from 3,000,000 tonnes down to 600,000 tonnes in 1992. Fishing mortality rose in the post-war era, dropped after the 200 mile limit was declared in 1975, but has risen again with expansion of the domestic fleet. Fishing mortality peaked in 1988 and in 1992 at about 0.8.

There is no clear relationship between temperature and recruitment or between spawning biomass and recruitment based on Icelandic data.

In recent years the year classes have been consecutively weak, recruitment is declining and the spawning stock has declined. Weight at age has fluctuated but there has been no consistent decline. In 1982-83 a crash of the capelin stock had a transient effect on the cod. No environmental causes for recent declines have been identified so it is assumed that they are related to fishing pressure which should be reduced.

While there has been no increase in seals in Iceland in recent years, there has been an increase in whales.

The Iceland experience seems to be a decrease in cod resulting from increased fishing. There are no indications of distinct environmental effects. The West Greenland influence (migration) has decreased in recent years.

West Greenland; (H. Hovgaard)

In some years there is a drift of '0' group cod from Iceland to West Greenland. In addition, spawning areas are located on the east and west of Greenland, and there are some inshore stocks off West Greenland. Tagging experiments with adults have indicated that fish in the north (Division 1D) (Figure 1) remain in West Greenland waters while half of those in Division 1E to the south migrate to Iceland.

Historically there was little cod found in West Greenland before 1920. With a general warming trend beginning around 1920, catches increased from almost nil to 100,000 tonnes prior to World War II, and to 500,000 tonnes around 1960. Following a crash in the resource, the fishery for the past 20 years has fluctuated between no fish and 100,000 tonnes. In 1992, no fish were taken offshore and only 6,000 tonnes were caught inshore. SPA results show good recruitment on average from 1945-1965 but since then, good year classes occurred only in 1973 and 1984, both of Icelandic origin. Much hope for the future was placed on this 1984 year class, but it subsequently disappeared. Although first thought to have migrated back to Iceland, further analyses have indicated that the losses from West Greenland cannot be fully accounted for by increases in biomass in the Iceland area. Thus, an estimated 200 million fish have 'disappeared.' Prior to disappearing, there was a re-distribution of the fish in a southward direction in the West Greenland area. It appears that strong eastward migrations started in 1989 and continued in 1990-91 with the net result of very few cod remaining in West Greenland. Temperature may have triggered this movement directly or otherwise. SPA modelling is now being undertaken on the combined Iceland/West Greenland stocks in an effort to eliminate this problem of migration.

Growth rates of the cod seemed to have declined in this same time period. This could be due to actual declines in growth or it could be that larger fish were migrating out of the area first.

There is a correlation between cod catches (and recruitment) and temperature and a decrease in temperature might have affected the cod in the 1960's and 1980's. Higher recruitment always correlated to higher temperatures.

There may be an increase in seals in West Greenland in recent years but assessments have only recently started.

Environmental factors are indicated to influence the West Greenland fishery. Reduction of growth and mass migration have occurred but their contribution to the overall stock decline is not known. This is similar to the northern cod situation, particularly with regard to the effects of temperature.

Similar to in Divisions 2J3KL, there has been a decline in other groundfish species in recent years off West Greenland.

<u>Alaska</u>;(T. Royer)

Off Alaska, there has been a steady warming trend from a cold decade to a warm decade over the past 20 years. The trend then reverted to cooling around 1990. This pattern, for the short period of record, correlates to the Sitka air temperature which gives a proxy record of sea temperature of over 160 years. Fluctuations during this long period, roughly correspond to the 18.6 year tidal signal. Fluctuations in the tidal signal are more dramatic as you move north of 35° N latitude. The question as to whether fish stocks can be shown to be influenced by this global cycle has been raised.

A smoothed average biomass of Pacific halibut shows a regular fluctuation of which 60% of the variation can be explained by an 18.6 year sinusoid. A similar pattern can be demonstrated for pollock but the correlation is not particularly good possibly because the pollock are in the middle of their temperature range and thus subject to minimal temperature effects.

This tidal cycle is about 7.75 years out of phase between the North Pacific and the North Atlantic, and the temperature cycles would be phased accordingly. In 1965 Russian researchers displayed a correlation between surface temperature (Greenland/Iceland) and the 18.6 year cycle. They further related this to herring distributions. Another study showed that 27% of the variance in Norwegian cod and 54% of the variance in American mackerel can be explained by the 18.6 year cycle.

The tidal effect will be out of phase between the eastern and western North Atlantic. At any one time, the magnitude of this tidal effect is too small to measure but given the prolonged period of influence, the cumulative effect may be considered significant; certainly of the same order of the much shorter well known 4 and 15 day circulation anomalies. Being related to lunar declination, a shift at higher latitudes may occur between diurnal and semi-diurnal tidal components. This could have ramifications on such things as fish nursery areas.

The effect in the entire North Atlantic would produce no net change in heat input but rather to shift the circulation on one side up slightly while the other side goes down correspondingly. A calculation of this effect, based on data from West Greenland shows the maximum cold effect, amounting to an anomaly of -0.2 °C, occurred in 1992 and the trend reversed in 1993. The range of amplitude would be 0.4°C compared to the range of record for Station 27 of 0.6°C.

# DEVELOPMENT OF HYPOTHESES

## TIMING AND EXTENT OF THE DECLINE

Two possible interpretations of the data emerged concerning the timing of the decline. The first, based on various surveys, is that a sudden and catastrophic decline occurred. It involves the loss of about 50% of the biomass between 1990 and 1991, with a less pronounced decline between 1991 and 1992. These declines may have been the result of two separate events. Ancillary data validated the decline indicated by the 1991 survey data but it is too early to be able to validate the further decline observed in 1992.

The second interpretation is that a smaller, more gradual decline occurred. Short-term population peaks from surveys in 1986 followed by sequential peaks in Division 2J, Division 3K and Division 3L would have to be regarded as annual anomalies.

It was considered important that the actual magnitude and timing of the decline in stock status be determined, as this will have a fundamental effect on the merits of the various hypotheses dealing with causes.

### Hypothesis: The Decline was sudden in 1990-91, 1991-1992

*A sudden and catastrophic decline (involving approximately 50% of the stock) has occurred between the fall seasons of 1990 and 1991, possibly in the first half of 1991. A further, and less pronounced decline occurred between fall 1991 and fall 1992, possibly during the second half of 1992.*

An abrupt decline in stock is indicated by results of stratified random bottom trawl surveys, hydroacoustic surveys, additional unsuccessful searches during other research vessel surveys in 1991 and abrupt changes in the inshore and offshore fisheries between 1990-92.

In May 1990, the stock size estimate from the trawl survey in Division 3L was the largest in recent years. Hydroacoustic survey results from Divisions 3KL in the following month also indicated substantial stock size. The summer fixed gear catch in Division 2J was low but as expected in Divisions 3KL, and although the autumn trawl survey in 1990 resulted in a low biomass estimate for Division 2J, high estimates were obtained for Divisions 3KL resulting in an overall estimate similar to that from 1989. The subsequent winter fishery (1991) also yielded low catches in Division 2J, but catch rates remained high in the more southern areas. The same season saw the foreign fleet take very good catches on the nose area of Division 3L outside 200 miles.

The February, 1991 hydroacoustic survey results were as expected, being high for Divisions 3KL and low for Division 2J. Subsequent surveys conducted in 1991, however produced estimates that indicated drastic declines. Results of the May trawl survey in Division 3L were one third of the previous year's. The hydroacoustic survey in June and trawl survey in autumn indicated stock size one half that of the previous year in Divisions 3KL and even lower in Division 2J. The summer fixed gear fishery in 1991 continued to be poor in Division 2J, and landings were only about 50% of those expected further south.

Based on an examination of 8 year old fish from the 1987-92 fall surveys, the decline began in Division 2J in 1989; Division 3K in 1990; and major changes in combined areas in 1991 between February and May.

All of these results combined would suggest that a major decline occurred during the first half of 1991.

In February 1992, a hydroacoustic survey resulted in a continuing low biomass estimate for Division 2J and declines in Divisions 3KL compared to the 1991 results supportive of results obtained after February of 1991. The winter offshore fishery, both domestic and foreign, was poor. The Canadian fleet could only find commercially acceptable sizes in Division 3L.

Results of the June, 1992 acoustic survey were not very different from the 1991 results, but the biomass estimate from the fall, 1992 bottom trawl survey indicated another significant decline in biomass. Thus it appears that a further decline took place in the second half of 1992, between June and November.

The difference in biomass estimates between 1990 and 1991, and 1991 and 1992 are greater than can reasonably be attributed to catch in that period or to inherent errors in the SPA modelling.

Hypothesis: The Decline was not sudden and abrupt but started during the 1980's

*A population decline began in the 1980's and was accelerated by environmental conditions. The apparent sudden decline in 1991 is not due to an increase in natural mortality but rather an overestimate of the 1990 stock size that lead to over harvesting (increased fishing mortality) in 1990-91.*

The survey variance from research vessel surveys was noted to match closely the positive or negative residuals from the sequential population analysis. High variances in 1989-90 might mean that the stock size was overestimated in those years. The overestimate in 1990 has exacerbated the perceived decline in 1991-92.

A review of numbers caught at age show fairly constant numbers over the last 15 years with a shift to more smaller fish. The numbers of three and five year olds are some of the highest in recent years. An overestimate of stock size in 1990 by a factor of two would lead to increased fishing mortality that would account for the apparent decline.

As the population of many species declines, the range and distribution declines and the between-year variability in survey results will increase. This has probably happened with the northern cod. One year's survey could find a concentration and produce a high mean value and high variability. A subsequent survey could miss a concentration, thus producing a low mean with low variability.

Cod were aggregated more during the past few surveys but with the fishing coverage of 400 - 500 sets and the acoustic equipment surveying continuously, it is unlikely that the research vessel surveys are missing fish to the extent of single year decline from 400,000 tonnes to 200,000 tonnes (1990 -1991) and 200,000 tonnes to 60,000 tonnes (1991-1992).

Biomass estimates from the fall surveys from mid-1980's and onward show generally steady declines in Division 2J and in Division 3K and Division 3L, except for a few (possibly anomalous) years. However, during the 1980's the surveys estimated total biomasses between 400-500,000 tonnes; suddenly in 1991 the figure was 200,000 tonnes and in 1992 it was down to 60,000 tonnes. Large scale underestimates in 1991 are unlikely, as survey coverage was so extensive. SPA overestimation in 1990 of 100,000 tonnes or even as much as 250,000 tonnes is possible, but an error of 500,000 tonnes (approximately 50%) seems unlikely.

There may be evidence of a decline that began around 1981 possibly due to population stress rather than individual stress. Strong decline has been indicated in Division 2J since 1985 with no particular emphasis in 1991. The stock may have been stressed for 30 years and is now at its lowest spawning biomass ever. With the exception of one or two year classes, a decline has occurred since 1981, and even the strong year classes have not bolstered the stocks as anticipated. The older fish have been depleted over this time. On average the fishing pressure has been excessive. A critical minimum sustaining biomass has been violated and the stock cannot recover.

The Barents Sea cod had experienced progressively increased fishing mortality until certain age classes disappeared. There are similarities with the current northern cod situation.

Hypothesis: Fishing Mortality has been Underestimated

*Current modelling techniques are not accurately portraying natural and fishing mortalities in the cod stock.*

The ADAPT and Laurec-Shepherd modelling are not capable of distinguishing between fishing mortality (F) and natural mortality (M). Only total mortality (Z) can be estimated.

Concurrent declines in other species, some not subjected to fishing pressure, would suggest that fishing mortality may not be the major cause of the cod decline. This was also found in the West Greenland groundfish situation.

An analysis of Division 2J Greenland halibut and American plaice gives confusing results. With no fishing mortality the survey results indicate that older fish are disappearing, presumably not due to fishing or emigration. By-catch in the cod fishery might have taken low numbers of these fish but there is an apparent and unexplained natural mortality of about M = 0.6 for American plaice.

Hypothesis: The Decline Occurred Sequentially Through Divisions 2J3KL

*The decline began in Division 2J and proceeded through Division 3K and 3L.*

Results from the annual fall bottom trawl surveys suggest that the decline may have begun in the north (Division 2J), then proceeded sequentially through Divisions 3KL. The biomass began declining in Division 2J in 1989 but simultaneously increased in Division 3K that year (Figure 3). In 1990, the biomass continued to decline in Division 2J and also declined in Division 3K but increased in Division 3L. These changes took place without any significant changes in the overall estimated biomass perhaps suggesting a gradual shift southward. The significant drop in overall biomass occurred between 1990 and 1991.

Data exists on fishing time, location, catches and yields from the big companies such as FPI and National Sea Products. Stocks were large enough until 1989 to enable the trawlers to follow migrations from one location to another. A labour dispute precluded fishing in the winter of 1989. Good inshore fisheries took large healthy fish during the summer and the offshore quotas were all taken in the fall of 1989. The anticipation of a good winter fishery in 1990 was not realised partly due to ice. Increased effort in the fall of 1990 failed to fill the quota and, the fishery in Division 2J has been poor since then. Reports that fish were small in the fall of 1990 could be confirmed by reviewing yields. Smaller fish were taken in Division 3K in 1991. In that year the Division 2J quota was reallocated to Division 3K and Division 3L and harvested. A couple of months later, in the winter fishery of 1992, no commercial size fish were found in Division 3K and those taken from Division 3L were small. Production information from 1981 and 1991 indicated a doubling of the count reflecting a shift to catches of much smaller fish.

Two possibilities would result in this pattern of an increasing proportion of smaller fish. One is that one population of smaller fish were in Division 2J, then moved to Division 3K and Division 3L sequentially. The other is that there were three populations which sequentially underwent the loss of larger fish.

Migration from north to south might shift the mean weight-at-age in the area from which the fish is sampled. A movement from Division 2J to Division 3K for example, would result in Division 3K fish appearing to have a smaller mean weight-at-age. This has not been observed. The migration of fish would also result in low estimates for Division 2J but not in Division 3K whereas in fact both might be in decline, with the decline in Division 3K masked. A review of the cohort matrices for the three adjacent areas indicates generally stable proportions of three to five year olds in the three areas, indicating no migration.

Hypothesis: Decline Began 40 Years Ago

*General stock declines and reduction of species distributions have occurred over the past 40 years or longer.*

A review of all survey data, some going back 40 years, indicates larger areas of distribution particularly to the north. Divisions 2GH had substantial cod and American plaice catches in the 1960's and moderate catches in the 1980's but nothing has been found there recently. The Greenland stocks have also declined since the 1960's. It may be that the recent decline is only a continuation of a very long term process and has been accelerated in recent years by high fishing mortality.

Hypothesis: Change in Catchability

*There has been a change in catchability during surveys due to different gear performance in the deeper water.*

This hypothesis says that the fish are there but traditional sampling methods are underestimating their abundance. When the stocks were found to move to deeper waters, particularly along the shelf break, reduced biomass estimates would be in part due to reduced catchability of the survey gear. A difference in catchability may also exist between divisions and, had the biomass shifted from Division 2J to Division 3K and then Division 3L; this may have affected survey estimates. This might be reflected in the commercial catches.

Opposing this hypothesis is the fact that many different indicators all point to the same decline: research vessel surveys, acoustic surveys, offshore fishery, and inshore fishery. A major shift in horizontal dispersion and vertical distribution might influence the effectiveness of different fishing and sampling methods, including the acoustic surveys. The consistency of survey results over time, coupled with the continued indication of decline would argue against some anomalous behaviour. The small fish were reasonably abundant in the 1992 winter fishery indicating that any shift in distribution on the grounds did not include small fish.

There is an indication that catchability varies with temperature. The commercial catch rate appears to vary inversely in relation to the temperature anomalies in the central Grand Bank and northern shelf areas. At lower temperatures, catchability would increase resulting in overestimates of biomass.

A review of American plaice biomass for Division 2J and Division 3K shows that, in the absence of high fishing pressure, beginning in 1983 there has been a steady decay in biomass that is significantly greater than can be explained by catches. These stocks do not migrate. The pattern in cod might be the same as in American plaice, but it has been masked by catchability. Since 1982, cod biomasses have been in an anomalously low situation and a change in catchability based on fixed timing of sampling may have caused systematic overestimation of stocks that has masked a similar decay as was seen in American plaice. This decay trend would carry through to 1990 but it would not account for the precipitous decline in 1990-91. The American plaice did not show a precipitous decline in 1990-91, neither did the cod in Division 2J.

<u>Hypothesis: Physiological Cycles</u>

*A shift in the annual physiological cycle would lead to the perception of different status when scheduled (fixed time) sampling occurs. This could produce erroneous conclusions regarding the size and condition of the population.*

This hypothesis would have the 1990 and 1991 surveys underestimating the stock by a growing margin. If the fish are not found where they are supposed to be, they are perceived as missing, hence a stock decline. However, the stock may have moved 'out of phase' with the annual cycle, they may have been inshore instead of offshore.

Beginning around 1990, the cod were distributed deeper and further offshore. For there to have been significant numbers inshore, the distribution would have to be discontinuous between 'inshore' and 'offshore' components. While this cannot be ruled out, there is presently no evidence for this.

In the fall of 1991, the inshore fishery off the southern Avalon extended through December indicating that a shift in distribution may have occurred although the magnitude is unknown.

The 1992 research vessel survey completed the coverage of Divisions 2J3K and estimated the biomass at 10,000 tonnes for the combined area. Additional surveys were then conducted inshore off the Northern Peninsula, and along the east coast to Conception Bay. The coverage was quite extensive but the yield of Atlantic cod from 26 fishing sets was 10 fish. Cod were not found inshore in the areas surveyed.

Coverage by the various surveys and fisheries was extensive enough in 1990-91 to verify that the fish were missing and had not simply moved. In 1991-92 the combined coverage was reduced but the data obtained supported the same conclusion.

Hypothesis: 18.6 Year Tidal Cycle

*The status of the North Atlantic fish stocks is partially affected by the 18.6 year tidal cycle.*

If meteorological events, which cannot be forecasted, are driving the currents and the currents are determining sea temperatures, then temperature anomalies cannot be forecasted.

The periodicities in the Northwest Atlantic tend to be 5-8 year cycles but, good and poor cycles for cod production do fit the 18.6 year cycle. Strong cycles have been indicated in cod recruitment and physical parameters in the North Sea also.

This 18.6 year cycle provides an attractive model in that it might provide predictability to some of the variation in temperatures, even if only 30%. The Pacific/Atlantic phasing could be examined to test the hypothesis.

## CAUSES OF THE DECLINE

Many changes seem to have occurred around 1990: the capelin biomass as determined from offshore acoustic surveys appeared to decline in 1990; changes in gannet diet reflect a change in the pelagic zone beginning in 1990; offshore catches reflected strong changes during 1989-90; cod condition factors changed beginning in 1990; sea mortality increased in Atlantic salmon in the late 1980's; and other species declined through the 1980's.

The potential causes for the decline are many, and most are interactive. Generally these can be subdivided into three general categories: fishing and fishing related; physical environment; and biological environment.

Fishing and Fishing Related

Overfishing (including under-reporting) is an obvious candidate to explain for decline in northern cod.

Hypothesis: Under-Reporting of Catches

*Under-reporting of foreign catches accounts for a minimum of 100,000 tonnes of northern cod.*

Surveillance coverage is such that an annual under-reporting of catches to a maximum of only 20,000 tonnes is thought to be possible. The impact of foreign under-reporting would not be a major factor if the stock decline was sudden and recent. However, if the decline was gradual, a cumulative impact (domestic and foreign) might be significant.

Hypothesis: Ghost Nets

*Ghost nets from the gillnet fishery cause non-catch fishing mortality of sufficient magnitude to account for a significant portion of the decline.*

The gillnet fishery on the Virgin Rocks started around 1985. Catches peaked at about 30,000 tonnes in 1988-89 but have declined since then. The size of cod taken by gillnets conforms to the missing fish sizes, i.e. ages 6+. Without a knowledge of the numbers of nets involved, the possible impacts of ghost nets are difficult to assess. It is known that when the gillnet fishery in the area of the Virgin Rocks (Division 3L) expanded greatly, there was a 'cottage' industry producing nets on a continuous basis.

Very high non-catch fishing mortality would have to occur to account for a significant portion of the decline in Division 3L and gillnets would have no effect on the decline in Division 2J except for migrants. The nets in the shallow area would have to survive the hostile sea conditions, whereas nets set in deep water may have more impact. If the major decline was in a very short time period, it appears to have been in the off-season for gillnet fishing.

Hypothesis: Habitat Degradation

*Trawlers have damaged the benthic environment to a degree that has caused decline in all groundfish species.*

The popular claim that trawlers have torn up the bottom might be in part responsible for a general decline of groundfish on all fishing grounds. Cumulative impacts (or stresses) of this, combined with fishing pressure and the sequence of cold years, might have precipitated a new ecological balance as former stability was lost. Current modelling does not seem to address many potential environmental stressors of the fish and thus would be unable to cope with the cumulative effect of multiple stressors.

Changes in natural mortality due to habitat degradation might be responsible for a decline in recruitment in all groundfish in Division 2J, the decline in adults of non-commercial species and part of the decline in the commercial species.

There is evidence of a decline in Greenland halibut biomass even in the absence of fishing and direct habitat destruction. A single strong year class was followed for a period of 6 years and then it disappeared from no apparent cause. Its main food source, capelin, also disappeared that year based on offshore acoustic surveys.

## Physical Environment

### Hypothesis: Environmental Stress

*Changes in the environmental conditions, more than fishing pressure, are responsible for the decline in northern cod.*

This hypothesis is supported by the fact that similar patterns of stock decline have been observed in other species, particularly in their northern ranges. In late 1991 and early 1992, American plaice in Division 3L showed an apparent depletion in stock size, particularly in older fish. This decline was greater than can be explained by the fishery. The sudden apparent recent decline in the offshore capelin stock, coincident with the decline in the cod, would argue that a common environmental pressure has affected both.

The apparent movement of northern cod to deeper water could be in response to physical environmental factors. Cod in the Gulf of St. Lawrence have also been migrating to deeper water in recent years. The shift of northern cod distribution to the shelf edge might be selective or stress induced. Environmental preferences of the fish could be used to determine this. If the cod were pushed to a marginal habitat, then stress is compounded and the cod are compromised. There is the basis for a number of testable hypotheses.

New water masses encountered by cod might have additional hazards associated with them. This could include low temperature, toxic algae, or some chemical component or deficiency. The limited data available for the Grand Banks do not indicate this. Such hostile environment phenomena are usually associated with enclosed water bodies or coastal areas.

Increased environmental stress would lead to increased mortalities due to disease and parasitism. There are cod parasite data (*Lernaeocera branchialis*) that could be reviewed as an indicator of stress.

Hypothesis: Low Temperatures Have Suppressed Recruitment

*Low temperatures have directly or indirectly decreased recruitment.*

The experience in Norway and Iceland indicates that although recruitment is not tied directly to temperature, strong recruitment does not occur during periods of relatively low temperatures.

The decline of Barents Sea cod in 1986-88 did not involve an increase in adult mortality. Adults however, are missing from the northern cod and West Greenland, indicating a higher adult mortality rather than a recruitment failure. Recent poor recruitment, whether linked to low spawning stock biomass and/or cold water will impact on the rate of stock recovery.

Hypothesis: Freezing/Cold Water

*Extreme cold water or supercooling has lead to freezing and direct mortality in cod.*

Winter fish kills of North Sea plaice about 10 years ago were attributable to abnormally cold water. An apparently similar kill on the Grand Banks in 1973-74 likely resulted when super-cooled fish were seeded with ice crystals which precipitated instant freezing of the flesh. This happens in the laboratory and in inshore shallow water situations. In the absence of ice crystals, fish can survive temperatures to -1.7°C.

There is no evidence of inshore cod distributions that would have been trapped in bays and subjected to freezing. The offshore cod near the shelf break could presumably move to deeper water to avoid cold water and freezing. However, in 1965, Templeman reported numbers of cod being killed off Labrador, in the northern Gulf, and in Trinity Bay, presumably as a consequence of being trapped in colder water. The numbers involved were not great in the context of causing a stock decline.

Ice cover has been shown to affect younger fish more so than older ones, and thus reduce recruitment.

Although direct mass mortality from freezing or cold water is normally unlikely, a stressed population (as evidenced by a decline of condition factors), particularly in the northern areas, may respond acutely to cold water effects.

This could result in the perceived sudden decline, whereas a factor such as starvation would be more gradual. Colder (below average) temperatures have been experienced since 1983.

Hypothesis: Oxygen Depletion

*Low oxygen levels associated with the CIL have reached incipient lethal levels.*

Low temperature or low food supply are not lethal in the short term; low oxygen is. Fish avoid such conditions, hence cod distribution might be influenced by the oxygen levels directly or indirectly (e.g. if the capelin are avoiding low oxygen and the cod are following).

The limited available data on oxygen levels suggest a link between low levels and the CIL. Evidence from the Gulf of St. Lawrence indicates that cod survive levels as low as 20% saturation while other data indicate that lethal effects can occur at levels as high as 60%.

Although a long time series of $0_2$ data is not available, oxygen levels in the ocean have been correlated to st (sigma-tee) 27 (a density gradient) and if this is true then Station 27 could be used as a longer term indicator of $0_2$ levels.

Hypothesis: Low Temperature and Redistribution

*Low temperatures have forced major redistribution of cod stocks outside of their normal areas of distribution. The fish have not died, but are 'lost.'*

Cod can survive sub-zero waters but are generally not found in such waters. When the CIL has been its largest in Division 2J, it has extended to the bottom and almost to the shelf break. This could drive the cod from their traditional habitat, either to deeper water along the shelf break or southward to Division 3K.

Investigations are being conducted on cod in cold water using blood anti-freeze proteins as a marker to indicate the duration of exposure to the cold water.

Hypothesis: Low Temperature and Feeding

*Low temperatures have suppressed feeding to a point where starvation has ensued.*

Two series of experiments have been conducted on American plaice. The first was short term acclimation to temperatures followed by rapid change. No effect was evident when American plaice, acclimated to temperatures above 10°C, were exposed to -0.4°C, a larger change than would be experienced under natural conditions. This would imply that a sudden exposure to low temperature would not be directly lethal.

In the long term experiments, American plaice were acclimated and held at low temperatures for prolonged periods. Fish held at -0.4°C for 77 days did not feed (although food was present), they lost weight and were more active. The activity is presumed to be in an attempt to get out of the cold water mass. The implication is that prolonged exposure to low temperatures would stress fish, making them susceptible to other stresses or predation or, if the condition was poor to begin with, actual starvation.

While American plaice did not feed in cold water, cod have been found with full stomachs when trawled from waters at -1°C. In laboratory experiments cod fed readily at 0°C. Therefore, cold temperature alone will not stop cod from feeding. Other investigations found that food consumption by cod decreases with decreasing temperature and, although the stomach may be full, the consumption rate declined due to reduced metabolism. It was noted that water at 5°C, a change of $\pm$0.5°C might not have much effect but at -1°C, changes of $\pm$0.5°C might have marked effects. Normal temperatures encountered by the northern cod would be about 2-3°C and not at the sensitive -1°C. However, if the fish are at 2-3°C and not finding food, their search may be active, their metabolism normal and their reserves might be depleted. The availability of food at lower temperatures, a biological factor, is discussed below.

Biological Environment

Hypothesis: Primary Production

*Environmental conditions have depressed primary production and this is having direct or indirect effects on the northern cod.*

During cold years, when more solar energy is required to melt ice and warm water (as in 1990-91), this energy is lost to primary production. Phytoplankton blooms would be reduced or delayed. This might lead to indirect starvation in the cod stock. An examination of known temperature declines might provide a relationship with year class success in cod.

Temperature may not be the prime determinant for algal productivity, rather, it could be such factors as available nutrients, depth of mixing and the time to achieve stability in the water column. In 1991 the extensive ice probably delayed the phytoplankton bloom. Cold years also have a shallower mixed layer resulting in less nutrients being available and hence a reduced amplitude to the plankton bloom.

Generally northern cod, up to 20 cm length, feed on invertebrates (primary consumers). Piscivory begins at about 20 cm and by 35 cm the cod are taking adult capelin, sand lance and Arctic cod. The diet of 60-80 cm sized cod comprises capelin and Arctic cod in the north, and sand lance, shrimp, euphausiids, amphipods and crabs on the Grand Banks. Larger cod feed on crabs and smaller bottom fish, with reduced consumption of capelin.

Time sequences to any effect would vary, depending on the complexity of the food chain. Reduced plankton productivity could result in direct effects such as mortalities of post larval cod, whereas in older individuals any effects would be indirect and delayed. The lag time might be shortened in certain situations, *e.g.* the energy content of capelin could influence feeding cod within the same season.

The primary production hypothesis does not account for the change in stock size if the decline was abrupt. Fall 1990 survey results suggested a 'normal' stock, but six months later, the summer 1991 inshore fishery indicated a sharp decline. Primary production declines affecting the food chain (capelin to cod) would have had to occur in a time frame of 6-7 months or less.

Hypothesis: Cumulative Energy Depletion

*Adverse environmental conditions occurring in consecutive years would cause a cumulative effect of depleting cod energy reserves.*

Examination of total condition factor (*Kf*: (gutted weight in g) X 100/(length in cm)$^3$) and *Kl* (liver weight/gutted weight) was conducted from samples collected during fall surveys. In Division 2J, *Kf* declined in fish aged 3 to 9 in the past few years and in 1991, had some of the lowest values since 1977. The same pattern, although less pronounced, was found in Division 3K for fish aged 3-11. Decline in condition factor was not evident in the 3L cod. The value for *Kl* in 1991, showed sharp declines in 2J cod of all ages. The decline in liver weight was less pronounced in Division 3K, whereas in Division 3L there was an increase. If the seasonality of building liver reserves had shifted however, the apparent declines may be difficult to interpret. Monthly sampling would be required to address this point.

Attempts to relate variations in condition factors with biomass in capelin (based on offshore acoustic estimates) or water temperature anomalies at Station 27 produced correlations only for cod in Division 2J. A cold anomaly in 1985 coupled with a large CIL was reflected by a decline in condition of 2J cod and 3K cod.

In recent years cod have been shorter (*i.e.* smaller) at age, however this is not necessarily reflective of poor condition. A recent decline in mean weight-at-age is dramatic if referenced to values from the late 1970's and early 1980's. These reference years (when research surveys began) had the highest means over the 32 years of record taken from commercial catches. The severity of apparent declines in the mean weight-at-age will depend on the selection of reference values. Means for the past few years are comparable with those of the late 1970's. Low mean weights occurred in 1973, which was a cold year.

Studies in the Gulf of St. Lawrence analyzed the energy stores of cod and their seasonal cycle. An energy peak is reached in September, when cod have 62% of lipid energy in the liver and 27% in the carcass (muscle and bone). The liver lipids represent 80% of the stored lipids, while muscle represents 87% of the body protein. Cod, unlike mammals which first metabolise lipids, and then proteins, utilize both at the same time.

Cod in Division 4T do not feed during the winter apparently due to the lack of available food. Following spawning (June), both sexes feed very heavily. The spring energy uptake is primarily to rebuild gonads. Feeding again declines to nil by the beginning of December.

In 1991 a 45 cm cod weighed 850 g and fed mostly on invertebrates. With the long winter (two month delay until ice-out), normal spawning did not start until late June. With the corresponding late start in feeding, the muscle reserves were not restored by September (a deficit of 20-30%), however lipid reserves had been restored. During the past three years up to 1992, ice-cover has persisted later in the spring. If the same happens in 1993, it is predicted that a cumulative fish energy depletion may occur and this could result in mass mortality, if such has not already happened. In 1992, fish had 2.5 months to feed instead of the normal 5 months. Fish sampled this winter (1992-93) indicate that the pattern is continuing. The cod that would normally have been 850 gm only weighed 750 gm, indicating that the reserves were not replenished.

The fish affected most by this cold season cycle will be the smaller mature individuals. Larger mature cod, although few in numbers, eat more fish and have replenished reserves to a greater extent. Juveniles are believed to feed during the winter.

An overall deterioration in condition factor would not be a good indicator of a decline in body reserves. A pattern of gradual muscle depletion could be masked by the liver weight when total weight is considered.

The apparent timing of the decline of northern cod (February to June) conforms to what might be expected in a stock which was in a weakened state during spawning, with consequent mortalities as continued or additional stresses are applied. To determine if a cumulative effect of energy depletion resulted in the 1991 cod stock decline, the pattern of energy reserve-depletion prior to 1991 would have to be investigated.

Data from fish samples suggest that during starvation the water content of muscle will at first, remain stable while liver lipid levels will decline as energy is depleted. As the liver becomes depleted the muscle protein starts to diminish and muscle water content increases above the normal 80% level. Distress is experienced as levels exceed 81% and death ensues as levels approach 90%. Older fish are more tolerant of this stress. There is evidence that during winter both liver lipid and muscle protein will be depleted at the same time, as described for the Division 4T (Gulf) cod. The increase in tissue water content will mask a decline in condition when condition factor is based on body weight. Therefore, water content would be a better indicator of this stress.

Data from laboratory fish deprived of food showed an increasing trend in water content (onset of stress) after about 8 weeks. Post mortem pH also increased. The onset of distress will vary with temperature and starting condition ( e.g. if the fish were replenishing their gonads).

The current stock decline disproportionately involves mature fish and that is consistent with additional stress being applied by the diversion of energy to the gonads. Limited research vessel survey samples of northern cod have been analyzed for tissue water content but no increases were evident. However, a small sample (4-5) of fish taken during 1983-84, off Cape Bonavista had elevated water content and also displayed full gonads, although it was late in the spawning season. While they were showing metabolic distress, it was not determined if they were building gonad tissue.

Direct death by starvation is unlikely but weakened fish may succumb to disease or predation. During an ecological crisis in the Barents Sea in 1986-87 prey were not available; starving cod were found to be thin, in poor condition, and short for their age, but were surviving. There were no indication of higher natural mortality on mature fish. Decline of the stock was attributed to other factors such as predation/cannibalism on juveniles. Thus older year classes were maintained at the expense of younger.

An indicator proposed for the detection of starvation was RNA/DNA ratios.

Experiments on cod are underway at St. John's and in New Brunswick to determine the effects of starvation on the ability to produce antifreeze.

Starvation in cod would be indicated by reduced growth rates. This has been documented over the past few years, and 1992 showed some of the lowest rates in 40 years for all regions.

Data on American plaice indicate that older mature fish have a higher proportional gonad production. The jelly condition in American plaice, reflecting high water content, is also more pronounced in older fish. Natural mortality has been found to increase following the onset of maturity and there may be a relationship between reduced condition and increased natural mortality in the older fish along the same pattern suggested for cod.

Northern cod which were found to occur in deeper (800 m) water along the slope may have been in circumstances similar to Gulf cod which migrate to deeper water in the winter. The impetus for the migration might be a search for food. Depth of capture or duration of deep water residency could be investigated. While the fish found at 800 m were in pre-spawning condition and would not have been feeding, an earlier migration to deep water in search of prey may have occurred.

The cod at the edge of the shelf in Division 3L do feed in winter and spring where their distribution overlaps with that of capelin. This overlap occurs to a depth of 300 m; beyond which cod have less food in their stomachs. In February 1991, during tagging experiments, cod were taken concurrently with capelin to a depth of 500 m along the shelf break. Presumably the cod were feeding on capelin. However, in the last couple of years capelin were not present along the edge of the shelf and were not found in cod stomachs from that area.

Hypothesis: Migration Out of the Area - "Lost at Sea"

*The cod stock has undergone some non-traditional migration during 1988-92, and has left the area.*

In 1988, a peak in the survey estimate occurred in Division 2J; in 1989 it occurred in Division 3K; and in 1990 it occurred in Division 3L. In 1991, low estimates were obtained in all 3 Divisions. The foreign catches beyond the 200 mile limit were higher in 1991 which might have resulted from migration to deeper water outside 200 miles in Division 3L. The foreign catch however, would have to be at least double that estimated in order to account for a significant decline in the stock.

The movement of cod from Division 2J to Division 3K and then Division 3L could have been either the same continuous phenomenon, or a sequence of different events. The condition factors of the cod in the three areas reflect a different level of stress, higher in Division 2J than Division 3K and lacking in Division 3L.

The apparent redistribution of northern cod to deeper water might be an artefact of the pattern of fishing activity. The commercial fishery is not a reliable indicator of population distribution as it is not conducted in accordance with systematic sampling.

Fish tagging programs conducted from 1990-92 have had various rates of recovery but the recoveries to date do not indicate any unexpected migrations from traditional grounds. Lack of returns might be evidence of disappearances, but that is speculation. In 1991, tags were applied on a migrating school estimated to be about 50,000 tonnes. The fish appeared to be moving toward the nose of the bank, but as yet, there have been no tag returns. While foreign vessels might be reluctant to report recovered tags, there was little foreign activity at the nose following the period of tagging (June).

That body of fish may have normally moved toward the Virgin Rocks but, 1991 being a cold year, the CIL may have kept the stock further offshore. This would be an example of one component of a stock performing non-traditionally while other components might behave normally. Tag returns could indicate a large non-traditional migration of northern cod south to Divisions 3NO. However, in 1991, a part of the Divisions 3NO fishery was illegal and recovered tags may have been discarded rather than returned. Research vessel surveys in Divisions 3NO and Subdivision 3Ps, found no tags or any evidence of a large shift in distribution. It is unlikely that significant numbers of northern cod have shifted undetected to Divisions 3NO or Division 3M (Flemish Cap). In fact, increases in the Flemish Cap projected in the 1980's did not materialize;

instead the pattern in recent years has been a decline similar to that in Divisions 2J3KL. Declines have also been documented for Divisions 3NO, Division 3P and in Divisions 2GH to the north.

If emigration has occurred it has been beyond the shelf break and the cod became oceanic. There is little evidence to support or refute this idea. Cod are fished in deeper waters (to 800 m) but deep water fisheries (1000 m) for Greenland halibut and witch flounder have not reported by-catches of cod. There is no evidence of deep water benthic distribution. Surveillance of foreign fishing has not provided evidence of cod off the shelf break. Research vessel surveys in 1991, conducted in Divisions 2G to 3M at depths of 750-1500 m produced virtually no cod.

Research survey data as well as information from the commercial offshore fishery indicated that cod are distributed deeper in recent years. Cod may have been driven deeper by predators (seals). Temperature is normally assumed to be constant at these depths. However, there is evidence that the temperature regimes at the shelf break and even on the shelf and banks are quite dynamic. Given the sensitivity displayed by fish, temperature might be a major influence in horizontal and vertical distributions. Cod were found to 800 m depth in 1989-91. Other species have shown a movement to deeper distributions, perhaps responding to temperatures but in some cases moving into non-traditional temperature regimes. Oxygen, salinity or nutrient cues might be involved although temperature is the parameter most often recorded.

The "lost at sea" hypothesis is not currently testable but it was felt that it should be retained as it might hold a truth that can be verified in the future.

<u>Hypothesis: Increase in Predation</u>

*Increased predation by seals, mainly on adult cod, has occurred.*

Increased sightings and by-catch of seals in recent years indicate that their numbers have increased in Divisions 2J3KL in offshore areas. Increased predation on the cod spawning aggregations could have an impact on the stock that is more pronounced than indicated by seal stomach contents.

If the major decline in cod occurred after February 1991, it coincided with a period when seals are not feeding (breeding and moulting season).

Predatory pressure would be expected to selectively apply to smaller prey rather than larger prey. That pattern is inconsistent with the apparent disproportionate decline of larger cod. Even if the pre-spawning aggregations were the target, smaller fish would be more susceptible to capture. Harp seal stomachs, collected in the past few years, never contained the larger cod which represent the missing ages. However, trawls in the same area did not contain those sizes either. It may be difficult to establish that harp seals have taken significant numbers of large cod if there are no large cod left.

The estimated total population of 3,100,000 harp seals, if they were all in the Divisions 2J3KL offshore area, could consume in the order of 50,000 tonnes of northern cod if 5% of their total diet is northern cod. The actual samples of harp seals taken offshore were predominantly adult males which are known to comprise 15% of the harp seal population. Assuming the entire portion is in the offshore area for 3 months of the year, and that 50% of their diet is cod, then they could consume about 30,000 tonnes. The actual number of harp seals spending time offshore in Divisions 2J3KL is not known. Harp seals display distribution differences based on sex and age, and it is not known whether juveniles or females are present in the areas in which the adult males predominated.

The distribution of harp seals in 1991 might have been influenced by extensive ice in that year. However, significant seal by-catch also occurred in 1992. The assumption has been made that if seals were present along with cod, then the seals must have eaten cod. This is supported by evidence from seals taken from otter trawls (directing at cod) which contained significant amounts of cod in their stomachs, but seals from gillnets (Virgin Rocks, May-July) had no cod in their stomachs. Data presented from 1989 indicate that the seal by-catch distribution overlapped the distribution of capelin and Greenland halibut more so than that of the cod. However, by-catch of seals in the cod fishery has increased since 1989, while the offshore capelin have apparently declined based on acoustic survey data. Last winter the fishery in part of Subdivision 3Ps was suspended when the gillnets took more harp seals than cod. The same was found in other fisheries.

An apparent increase in seals concurrent with the decline in cod might result in feeding stress and a loss of condition in the seals. This would be indicated by reduced energy reserves (blubber thickness) in the seals.

Hood seals occur at about 10% the rate of harps. Hood seals eat cod, although stomach content analysis indicates that consumption rates are lower than for the harp seals.

It was suggested that even if seal predation on cod is not heavy, the presence of seals could force the cod to deeper water and less favourable habitat. This has been suggested for grey seals on the Sable Bank and might occur at the shelf break, but similar deeper distributions of cod in the Gulf and St. Pierre Bank have occurred in the absence of seals.

The final consensus was that seals could only play a minor role in a short-term catastrophic decline. A larger cumulative influence could be caused by seals if the decline in cod was gradual over time.

Hypothesis: Changing Ecology

*There has been some fundamental changes in the ecology of the northern cod which is having an, as yet undefined, impact on the population. . .*

As the proportion of cod increases in the total groundfish population, it is natural that predators will take more cod. This does not take into account pelagic prey species such as Arctic cod or capelin. Arctic cod is an undefined resource but assumed not to be declining. In 1992 the capelin had an apparent decline offshore but the fisheries experienced a normal year inshore. The Canadian Wildlife Service has reported that seabird populations which feed heavily on capelin at the surface collapsed in 1991-92, whereas diving birds seemed to fare better. Analysis of gannet stomach contents from Funk Island established a traditional August diet of mackerel, squid and saury. In 1990-92 there were cold surface temperatures, and the diet shifted to capelin, herring, cod and salmon. The pelagic ecosystem had apparently changed following 1989. The seasonality of sampling could mean a profound change, a seasonal shift, or a combination of the two. There is evidence of a profound effect over the entire region, rather than just a seasonal shift.

Other Possible Causes of Decline

Regionally and globally there have been cases documented of stock declines caused by other influences. While there is no existing evidence of these types of events affecting northern cod, they cannot be ruled out at this time.

- In the 1950's a crash in 4T (Gulf of St. Lawrence) herring was attributed to parasitic infestation causing high mortality.
- The South Coast fishery in Newfoundland was once decimated for seven years following a tidal wave.

# DISCUSSION AND CONCLUSIONS

## TIMING

CAFSAC and NAFO considered the decline to be 'abrupt' and to have occurred during the first half of 1991. Survey data support this. Results from the fall of 1990 indicated that although there was some apparent re-distribution of biomass between divisions, the total was as expected. Results from an offshore acoustic survey in February 1991 were approximately the same as those from 1990. The biomass estimate from the spring survey in Division 3L was the lowest in the time series, and only one third as high as the 1990 estimate. The 1991 June acoustic survey results suggested there had been an approximate 50% decline since 1990. A 50% decline in the bottom trawl survey results from the entire 2J3KL area occurred between the fall of 1990 and 1991.

Inshore fishery data also suggest a sudden decline. Overall, catches in 1990 were on par with those of earlier years. In 1991, catches were poorer over a wide geographic area and the fish were smaller than expected. Scouting trips attempting to locate concentrations of fish in both the offshore and nearshore in the first half of 1991 were largely unsuccessful. Interpretation of these observations generally indicates that the decline probably occurred between February and May-June 1991.

The offshore fleet did not however, encounter major difficulties in catching their allocations in either Divisions 3K or 3L in 1991. Only in January 1992 were problems encountered with no commercial sized fish being located in 3K and smaller than usual fish found in 3L.

It is also possible that the decline was more gradual, happening over a number of years. From survey as well as fishery results, a substantial decline first took place in Division 2J in 1990. Further examination of the trawl survey data is necessary to evaluate this. If these analyses support a more gradual decline, then it will be necessary to reconcile the apparent sudden reduction as perceived from the other data sources.

There are indications within the data that the decline began in the north then moved south. It is also possible that events took place in Divisions 2GH even earlier. For example, the biomass in Division 2J showed an increase in 1988. Where did these fish come from, and could it have been 2GH? In 1989, while many fish remained in Division 2J, the biomass had declined compared to 1988 whereas that in Division 3K increased. It is possible that some of the 3K fish had come from 2J. There was no winter fishery in Division 2J in early 1989 because of a strike in the industry. The last good offshore fishery in Division 2J took place in the fall of 1989. Severe ice conditions in early 1990 prevented the fleets from returning to this area during winter, but officials were not overly concerned because of the good fall fishery in 1989. The trawler captains themselves were not so optimistic however. They felt that the 1989 fall fishery in Division 2J was abnormal particularly because of the size of fish; they were thought to be larger than normal 2J fish. Their concerns were borne out. During the fall of 1990, catch rates in Division 2J were lower, and the fish were smaller and not in as good shape. This may have been a first indication of stress as discussed later.

The biomass in Division 2J declined further in 1990 as did that in Division 3K. The offshore fleet had a good year in Division 3K in 1990 although the fish were smaller than previous years. The offshore captains claimed these were 2J fish. At the same time, the biomass estimate for Division 3L increased to the highest in the time series. Confirmation of increased biomass in Division 3L comes from the excellent gillnet fishery in Division 3L around the Virgin Rocks and at the '40 fathom edge' during the same year.

There are other indicators of changes occurring before 1991. Condition factors for northern cod began to decrease in 1990. Acoustic survey estimates of capelin biomass increased dramatically in Division 3L in May of 1990, while the estimate for Divisions 2J3K in the fall of the same year declined significantly. At the time, CAFSAC noted that a shift in distribution of capelin from Divisions 2J3K to Division 3L could be a possible explanation for the unexpected decline in the fall. However, subsequent surveys during 1991 and 1992 in both Division 3L and Divisions 2J3K have resulted in low biomass estimates. Abundance indices for the inshore are somewhat contradictory to the offshore indicators in that they do not indicate a decline in the mature biomass that would have been expected based on the offshore data. Spawning of capelin inshore was delayed in both 1991 and 1992 but the abundance of eggs on the beaches was within the ranges observed previously. Although there are some questions as to the biomass of capelin at present and the reasons for the contradictions in the offshore and inshore indicators of abundance, it is clear that the first low biomass estimate in the current series occurred in the fall of 1990 in the north. It was also in 1990 that the prey of gannets from Funk Island changed. The species composition of their stomachs, taken in August, showed a dramatic shift when compared to earlier years with capelin assuming greater importance. This change of diet remained in effect through 1992 and for 1991 and 1992, the shift in diet to heavier reliance on capelin is consistent with the later inshore migration of capelin. This later inshore migration of capelin would make them more available to gannets. Sea mortality of salmon has increased from about 1987, again suggesting an environmental change occurring before 1991.

An examination of trends in biomass of other demersal species caught during the annual fall groundfish cruises also suggests that events may have been happening before 1991, and even as far back as 1981, the earliest time when data from all 3 divisions are available. Diverse species such as American plaice and roughhead grenadiers have shown a gradual decline in biomass through the 1980's, even without substantial fisheries. For American plaice, a natural mortality rate of >60% year after year would have been necessary to account for the declines observed. As with cod, these declines appear to have been most dramatic in Division 2J. In all 3 divisions, the proportion of cod to other demersal species gradually increased. Also similar to cod, it appears that abundance of larger American plaice declined at a faster rate than that of the smaller ones.

Limited information on invertebrates such as shrimp and crab does not suggest similar trends. Instead, these resources appeared to increase somewhat during the 1980's and early 1990's.

Thus it appears that although the rapid decline may have occurred in the first half of 1991, climatic events and distribution and biomass changes may have been beginning to happen, particularly in the north, even earlier; at least as early as 1990 and possibly back through the 1980's. Offshore biomass estimates of capelin have been low since 1990 in Divisions 2J3K, and in 1991 in Division 3L gannet diet composition has changed since 1990. Capelin spawning was delayed in 1991 and 1992. Liver weights for cod began decreasing at the same time. Biomass of other demersal fish species declined through the 1980's even without fisheries. Observations of inshore fishers also suggest changes occurring since about 1983.

The Workshop concluded that while the results from the 1992 survey were low, it is premature to consider their meaning at present. The decline observed between the 1990 and 1991 surveys (and the 1991 and 1992 assessments) largely confirmed results of acoustic surveys, scouting trips and the 1991 inshore and offshore fisheries. At this juncture, there are no ancillary data to indicate whether the 1992 results are real or confounded by year effects causing a low estimate. While it is possible that many cod remained inshore and therefore outside the survey area in 1992, limited searching in the inshore bays did not locate any. An acoustic survey of the area is scheduled for February 1993. No further discussion of the 1992 results took place, pending results of the acoustic survey.

CAUSES

The foreign fishery for cod outside 200 miles on the nose increased substantially in 1991 and surveillance estimates of catch were approximately double what was reported. This information was taken into account during the 1992 assessments so could not account for the decline observed. A careful examination of the fishery statistics led to the conclusion that although it is possible that both foreign and domestic catches may have been underestimated over time, the amounts would be insufficient to account for a decline in the resource of the magnitude observed, or even a significant portion of it. If the decline has not been as 'abrupt' however, then a continuous under-estimation, accumulated over time, may account for the loss. This would imply a systematic over-estimation of the resource through time, and would bring into question the correctness of the index (bottom trawl surveys) used in calibration of VPA. For the present, this is unlikely, and therefore any examination of this possibility will await results from other studies into the timing of the event.

A possible explanation for the observed decline is migration/movement out of the area, perhaps due to temperature changes or other factors. If fish were moving from north to south, perhaps they did not stop in Division 3L but continued on further south. This was ruled out as a plausible explanation however, because of the declining and low state of the cod stocks further south, both individually and collectively. No increases which could account for the declines observed in the 2J3KL stock have been observed. It is also possible that the fish moved offshore into deeper water not normally surveyed (>1000 m). This may have happened either outside 200 miles in 3L (the nose), or inside 200 miles further north. Neither of these were considered reasonable. If they moved outside 200 miles, it was assumed that they would have been caught in the foreign fishery, yet surveillance estimates do not show this. Neither is there any anecdotal information from European scientists suggesting that their fleets encountered concentrations of cod of sufficient magnitude to account for a significant portion of the observed decline. Also, in September 1991, Canada conducted a deepwater trawling survey for Greenland halibut in depths of 750-1500 m from Flemish Cap to Cape Chidley. No cod were encountered during this survey.

Predation by seals is also a possible explanation of the decline. The seal population has increased in recent years, although there has not been an 'explosion' as is often reported. The current population is estimated to be 2.7-3.5 million animals. Data from stomach samples collected over many years suggests that cod comprise only a small fraction of seal diet (<4%) but these data are from inshore areas only, and in winter seals inshore do not overlap to any large extent with cod distribution. The percentage of cod found in the relatively few offshore stomach samples from 1991 and 1992 is much higher, in the range of 50%, although these samples were collected by the offshore trawlers directing for cod and may be biased because of this. Some samples obtained from the area of the Virgin Rocks contained primarily capelin and sand lance. The sampled group from the offshore (age 7+ males) represents only a small portion of the total population. It is unknown if this sample is representative of the body of seals offshore or if behavioural differences between age groups and sexes accounted for disproportionate sampling.

Given the available information, the Workshop accepted that predation on cod by seals probably increased during the early 1990's. The extent of this increase could not be determined. Important data are lacking from the offshore, and increased sampling of seals in the offshore areas is necessary to address this shortfall.

Even if the seals did not actually prey upon the cod, it is possible that they caused mortality through some other means. For example, if the fish were in a weakened condition for some reason, then perhaps being chased generated enough stress or depleted reserves such as to cause higher than normal mortality. This type of consideration leads into another completely different, and little explored field; that of cod physiology and stress.

There were a number of plausible hypotheses put forward as to the possible effects of stress on cod. Stress related death is a possible explanation for the observed decline, but it is not believed that this was necessarily caused as a direct and immediate result of starvation. Based on research on cod in the southern Gulf of St. Lawrence, it is possible, however, to create an energy deficit in cod that could accumulate over one or more years and eventually cause higher than normal mortalities. The volume of the cold intermediate layer (CIL) was about 40% higher than normal not only in 1991, but in 1990 as well, and if this caused a deficit through unavailability of prey, then higher than normal mortality might occur after spawning in the subsequent year. This would result in a disproportionate decline in larger fish in 1991, consistent with what was observed.

The above type of event would indicate a cumulative rather than immediate effect. Some type of accumulation of effects probably occurred. The extra-ordinary events of 1990 and 1991 were perhaps the 'straw that broke the camel's back.' It is also possible that the stress built up over a longer period. Indications are that many organisms can tolerate stress for long periods before finally succumbing to it. In this situation, the final cause of death may be only a small further change in a critical factor such as environment, and therefore difficult to detect.

# RECOMMENDATIONS

The following specific recommendations, arising from the Workshop, identify areas of research that, for the most part, rely on existing data sets. From these analyses should follow recommendations for further research. It is important that these activities take place in a co-ordinated fashion and that progress be monitored closely. Results of these studies must be examined in total before drawing any conclusions or inferences from them, or recommending further research activities. Because of this, priority must be assigned to the work activities, and consideration should be given to holding a follow-up meeting within a suitable period to collate results.

## TIMING

1. Because of the uncertainties whether the declines in biomass were abrupt or more gradual, it is ***recommended*** that a modelling exercise be carried out using the trawl survey data to test the rate of decline. Analysis should also consider data available on gear-type, various fisheries, and tagging returns to see if common patterns are indicated. The different divisions should be segregated to identify sequential and concurrent changes. Depending on the results of this work, further recommendations may follow pertaining to evaluations of the commercial fishery data.

2. Related to the above, and because there was an apparent shift to deeper water in recent years, it is ***recommended*** to analyze the SCANMAR data collected over the past number of years to determine if it is possible that trawl catchability is different in deeper water. It is also ***recommended*** that otter trawl catchabilities in each of the divisions be examined using commercial trawl data to determine if there are any differences between divisions.

3. As another approach to determining the timing and rate of decline, it is ***recommended*** that any catch/effort data from the Virgin Rocks gillnet fishery in Division 3L be examined, as well as length frequency data. Examination of length frequency data from the offshore fishery in Divisions 2J, 3K and 3L should also be examined as an aid to pinpointing the time of decline of larger fish. It is ***recommended*** that length frequencies from the Division 3L fisheries and research vessel surveys in 1990 should also be examined to ensure that the increased survey estimates for that year were not partially due to fish moving north from Divisions 3NO.

4. Information on the sizes of fish captured in different areas is also available from production records of the offshore companies (FPI and National Sea) as well as the Canadian Saltfish Corporation. It is ***recommended*** that these records be examined in as much detail as possible to obtain information on the sizes and

possibly condition of the fish caught in different areas over time.

5. During the assessment process, data from the inshore areas are usually grouped by gear and NAFO Division. This makes it difficult to determine if there have been systematic changes in the inshore fishery over time. To address the issue of timing and rate of decline as well as the matter of a north-south progression, it is ***recommended*** that spatial analysis of the inshore fishery data be examined. This should not only include evaluation of catches in the different areas, but also an examination of length frequencies from these areas if available. It would also be useful to examine length frequency data from the Divisions 3L gillnet fishery as well as length frequency data from 2J and 3K to see if movements between divisions can be detected.

6. An understanding of stock movements from division to division is critical in establishing the timing and rate of the decline. Movements, if they occurred, would provide a sequence of changes brought about by a sequence of causes. Stock mixing could also serve to mask real changes and misrepresent the timing or severity of the change. To segregate stocks by division, or smaller areas, it is ***recommended*** that year-class, length frequency, and genetic integrity be investigated from existing data sets or preserved samples. It was also ***recommended*** that all relevant tagging and morphometric data pertaining to fish migration patterns be compiled and reviewed.

7. Declines in the biomass of other species have also been noted. For cod, it appears that the larger animals are disappearing at a faster rate. It is ***recommended*** that information for other species be examined to determine whether their declines are age specific or not.

CAUSES

1. It was well recognised during the Workshop that knowledge of the physiology of cod is lacking. There is work underway in the Gulf Region and at MLI, and through OPEN so more information should be available in the literature over the next few years. There is also work going on in Europe, and some information is available in existing literature. It is ***recommended*** that a Workshop on Cod Physiology be held as soon as possible to identify ongoing research as well as areas where there are knowledge gaps, and to recommend areas of research necessary to address these gaps. Issues which should be addressed include the physiological response of cod to $O_2$ levels, cold, starvation and spawning both in the short and longer term, as well as ways these may be measured.

2. During the workshop there were many discussions on starvation as a stress factor. Traditional assessments of condition factor in fish are not the best

indicators of either stress or starvation. To better reflect these phenomena in cod, and other fish, it is ***recommended*** that indicators such as liver lipid content and muscle water content be determined. Some data sets, obtained in the 1980's, include lipid content, and these should be reviewed in this context. Other potential indicators of stress are post-mortem pH and genetic material (RNA/DNA ratios). Stress indicators in cod could be compared to those determined in other species, using the same methods, to investigate common responses to environmental factors. It was further ***recommended*** that fish samples be gathered on a monthly basis (particularly from Division 2J) to investigate stress on a seasonal basis.

3. One of the possible factors contributing to stress and/or mortality is the $O_2$ content of the water. A long time series of $O_2$ data is not available, but there are indications that it correlates with st (sigma-tee) 27 (a density gradient). It is ***recommended*** that this possible correlation be investigated to determine if st 27 could serve as representative of $O_2$ thus enabling an examination of $O_2$ for a longer period.

4. It is ***recommended*** that comprehensive mapping of such things as the shape/volume and intensity of the CIL, as well as examination of $O_2$, and oceanic currents be carried out in order to obtain clear indications of the extent of changes over time as well as the timing of their occurrence. It is also important to determine exactly what factors may have the greatest importance. For example, some of the acoustic work studying cod migration has indicated that temperature gradients are important.

5. Work on cod anti-freeze can yield information on whether the fish are in cold water, and if so, for how long. Sampling associated with this work is currently taking place but on a large geographic scale. It is ***recommended*** that this work be expanded to allow for analyses of smaller geographic units within Divisions 2J3KL to help determine how cod are relating to the cold water, and assist in determining if cold water stress may be a factor contributing to mortality.

6. Parasite loads may serve as indicators of stress. It is ***recommended*** that the substantial database of *Lernaeocera branchialis* infestation of cod in the 2J3KL area be analyzed to determine if any shifts have occurred which may indicate a change. Information on other types of parasites might be useful if this is available.

7. There is a recognised gap in seal feeding data from the offshore. It is ***recommended*** that every effort be made to collect increased numbers of samples from all parts of the offshore areas where seals are found during winter months. Some information suggests that seals are being found in poor condition as well. To confirm this, it is ***recommended*** that analyses of blubber

condition be carried out, and that this be related, if possible to stomach content data.

8. Brief reference was made to documentation of drastic or long term effects on fish populations, of natural or environmental catastrophes such as earthquakes or particularly virulent parasitic infestations. It was ***recommended*** that a review of these types of reports might provide insight into such affects on northern cod.

Other

1. It was quite clear from discussion during the Workshop that a closer link between the biologists and oceanographers is necessary. Steps in the right direction have occurred with the formation of CAFSACs Fisheries Oceanography Subcommittee in late 1991. These initiatives must continue and be strengthened. Close collaboration between the two groups is essential to understanding the ecosystem and solving many of the problems facing us. It is ***recommended*** that every effort be made to enhance the communication and collaboration between fisheries scientists and oceanographers.

2. Considerable discussion took place of the role of plankton/benthos both as an indicator of environmental change, and as a possible cause of change through the food web. Clearly our knowledge of this part of the marine biota is lacking but should be increased. It is ***recommended*** that mechanisms be put in place to facilitate the initiation of plankton/benthos research to address this gap in our knowledge base.

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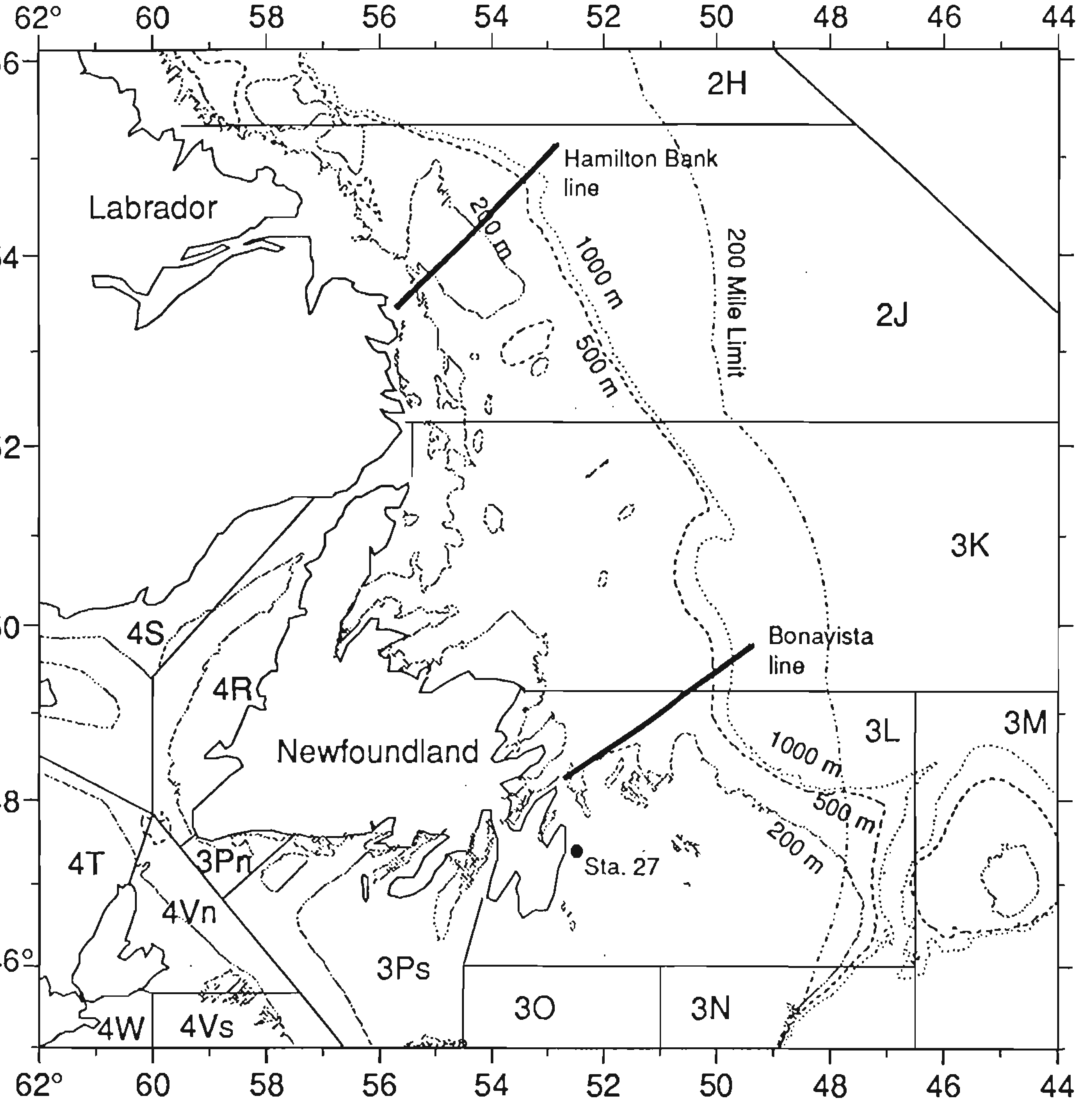


Figure 1: Map of stock area of northern cod.

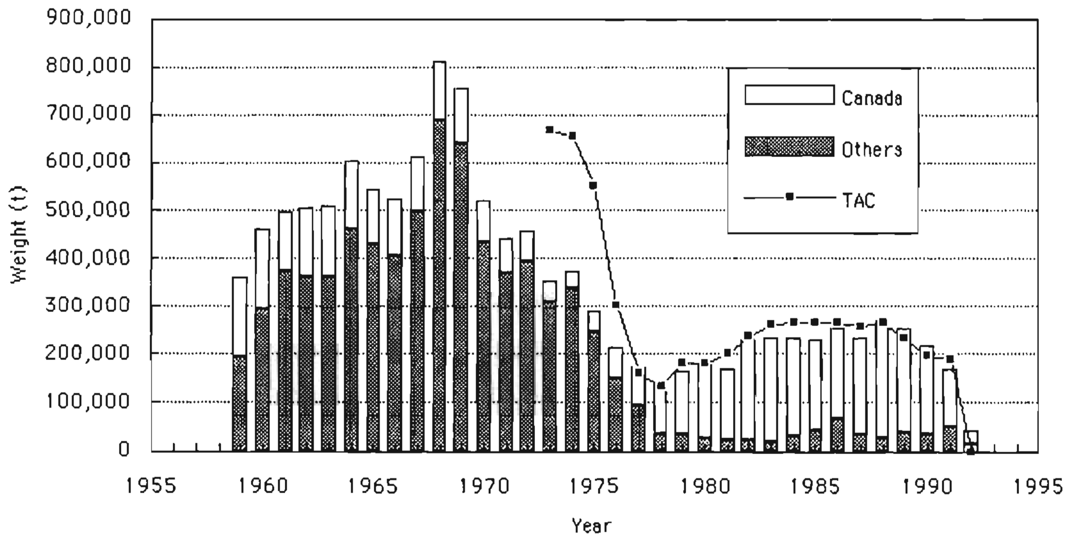


Figure 2: Catches and TACs of northern cod.

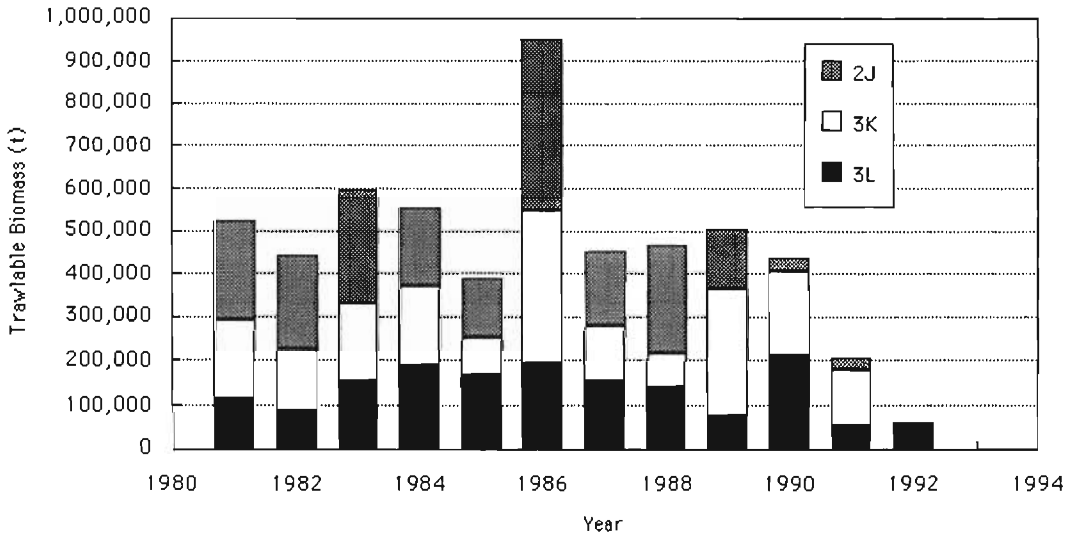


Figure 3: Estimates of trawlable biomass of northern cod from fall research surveys.

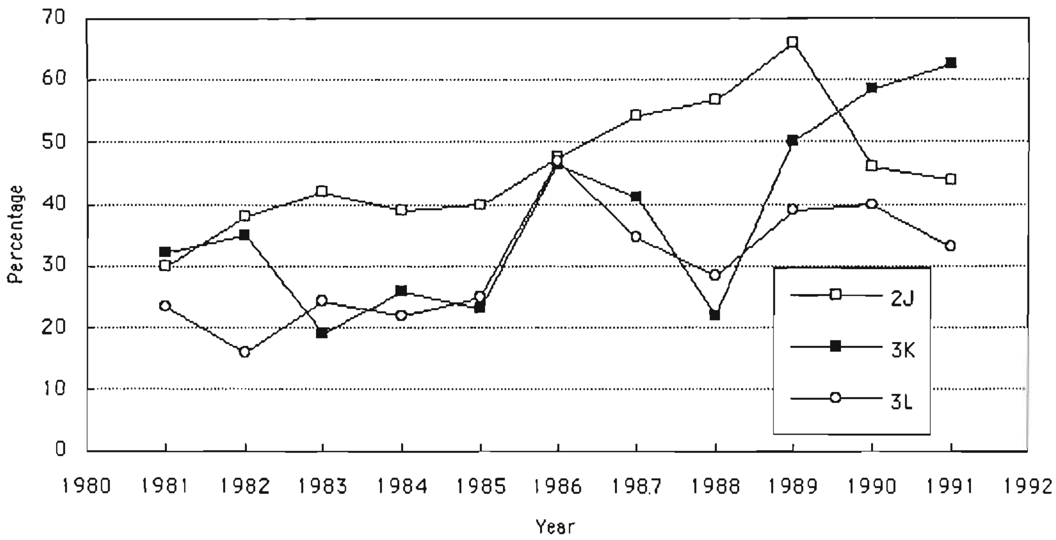


Figure 4: Cod as percentage of total trawlable groundfish biomass from RV surveys.

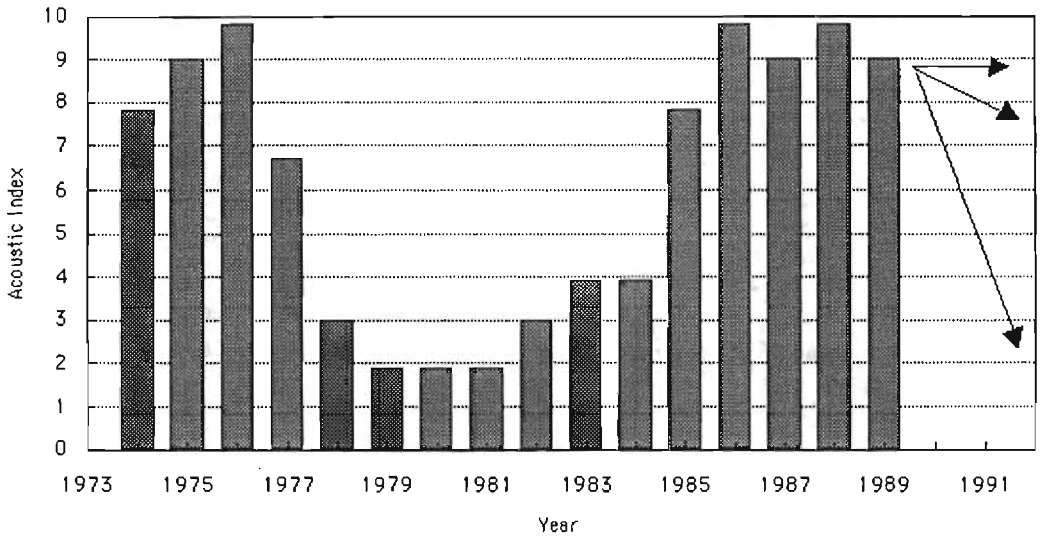


Figure 5: Index of relative offshore capelin abundance from acoustic surveys.

Mid 1970s . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . high abundance

Late 1970s - early 1980s . . . . . . . . . . . . . . . . . . . . . . . . . . . low abundance

Early 1980s - mid 1980s . . . . . . . . . . . . . . . . . . . . . . increasing abundance

Mid 1980s - late 1980s . . . . . . . . . . . . . . . . . . . . . . . . . . high abundance

Periods of high abundance the result of strong year-classes in 1973, 1983 and 1986.

Early 1990s evidence is contradictory:
- offshore survey results indicate dramatic decline
- inshore indices suggest no decline or not so severe

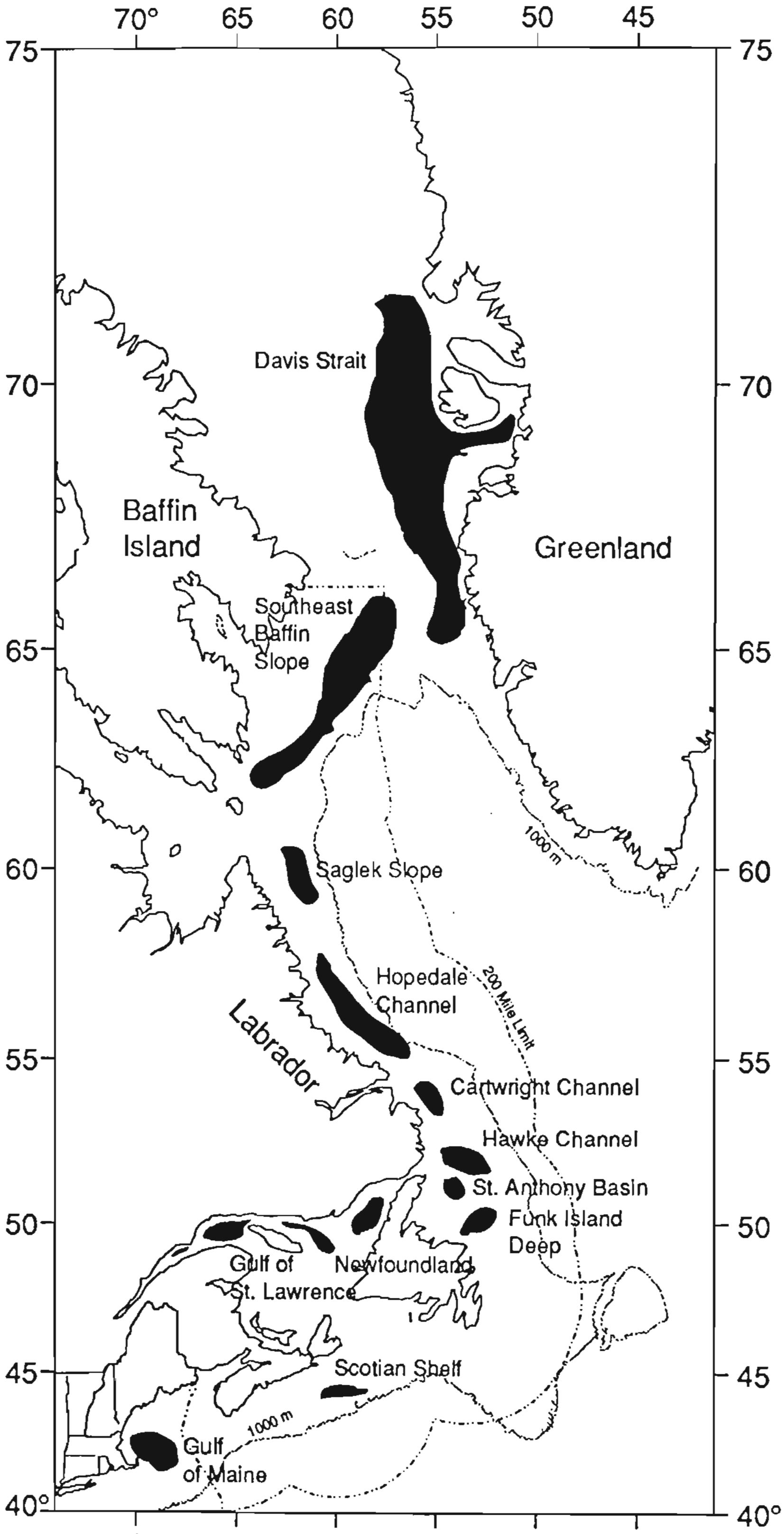


Figure 6: Major shrimp fishing grounds in Northwest Atlantic.

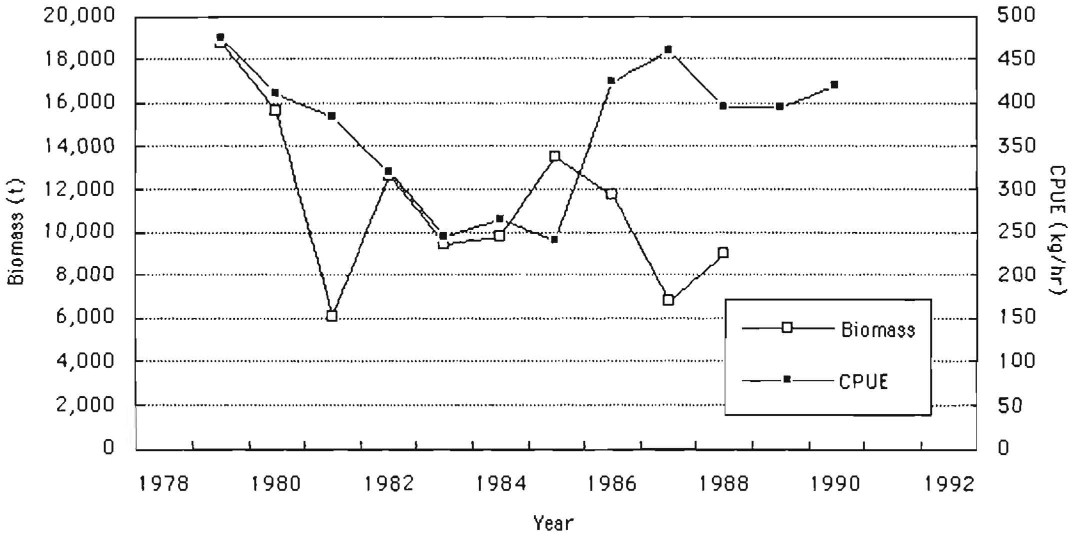


Figure 7: Shrimp CPUE (kg/hr) and RV biomass in Hopedale Channel.

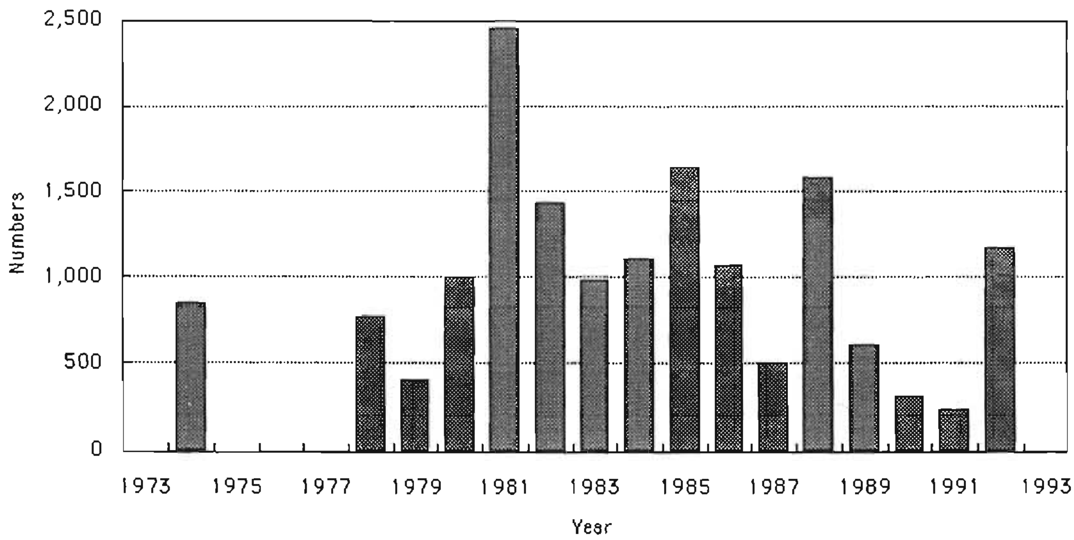


Figure 8: Grilse counts from Salmon Brook (Gander River).

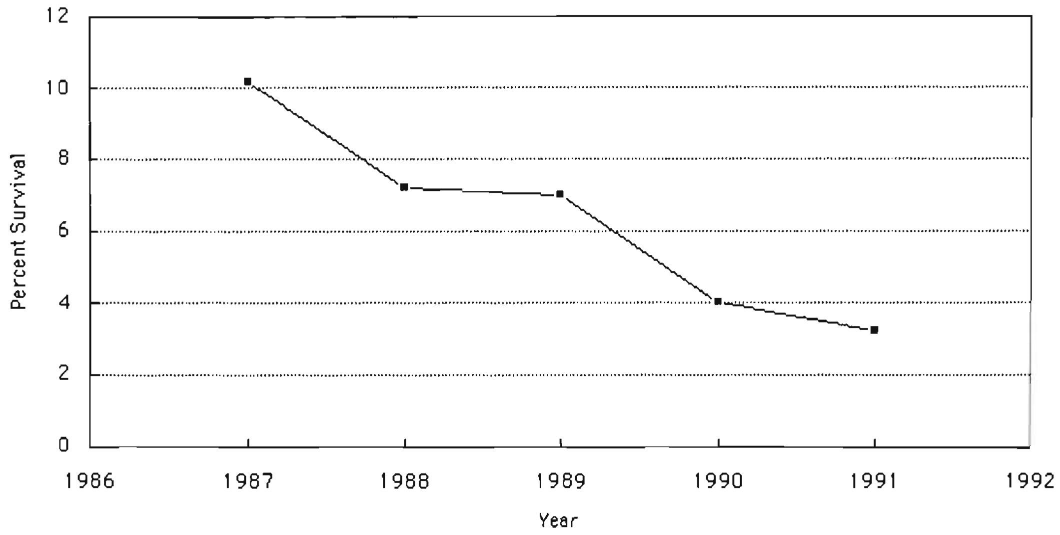


Figure 9: Sea survival from smolt to 1SW return in Conne River.

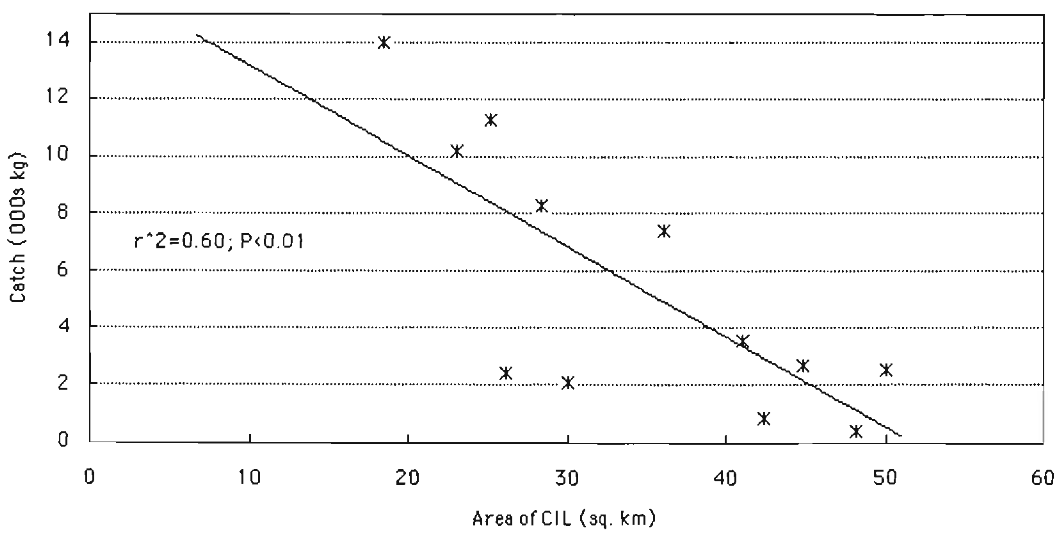


Figure 10: Relation between salmon catches in SFA 4 and CIL area along Bonavista line.

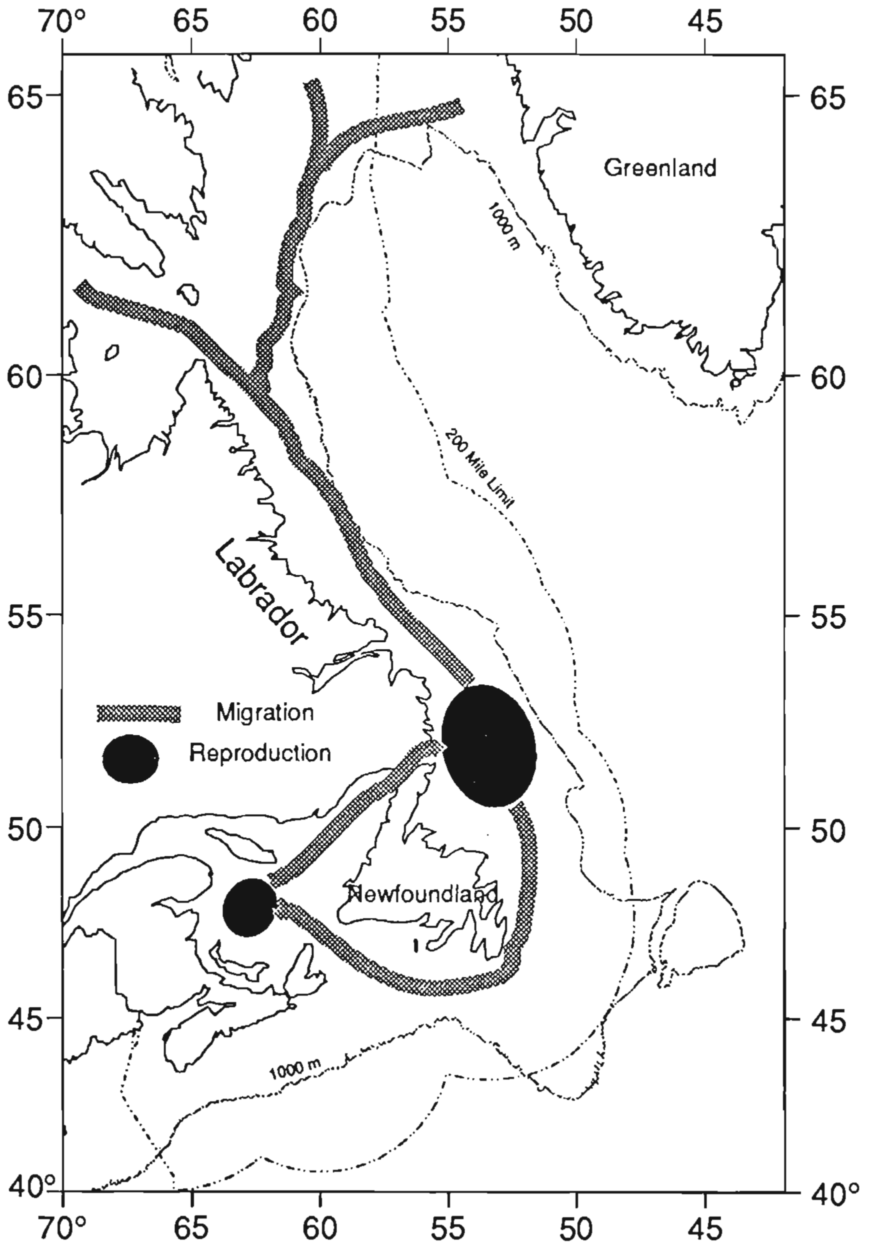


Figure 11: Migration routes and whelping areas for harp seals in the Northwest Atlantic.

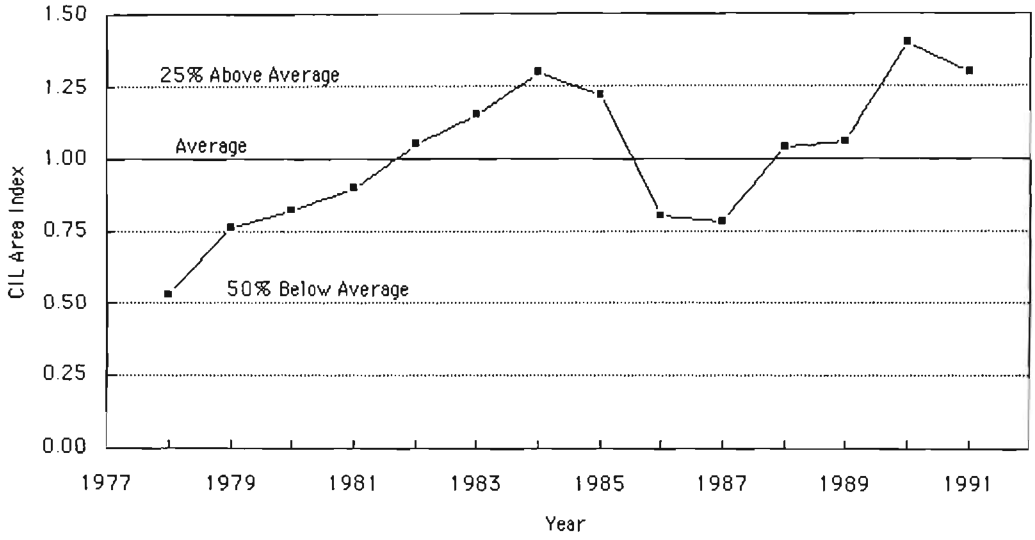


Figure 12: Index of Area of CIL based on hydrographic line data.

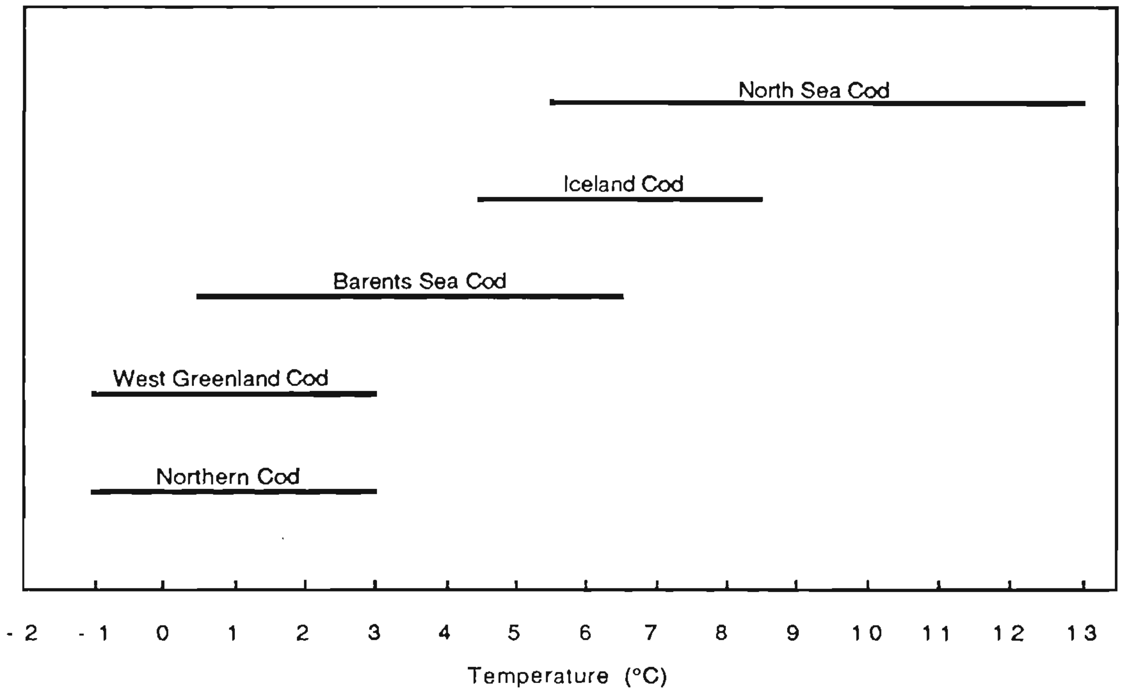


Figure 13: Temperature range of spawning for different North Atlantic cod stocks.

ANNEX I

# AGENDA OF THE NORTHERN COD WORKSHOP

January 27-29, 1993
Battery Hotel
St. John's, Newfoundland

## January 27

| | |
|---|---|
| • Introductory Remarks | L.W. Coady and W.G. Doubleday |
| • Biomass Trends & Discussion: | |
|   • Cod and Groundfish | J. Baird |
|   • Capelin, Shrimp, Crab | J. Carscadden |
|   • Atlantic Salmon | D. Reddin |
|   • Plankton | A. Longhurst |
|   • Marine Mammals | G. Stenson |
| • Physical Environment & Discussion | G. Mertz |
| • Enforcement & Discussion | L. Strowbridge |
| • Selection of Hypotheses | All |

## January 28

| | |
|---|---|
| • Summary of Previous Day's Session & Discussion | B. Atkinson |
| • Situation in Other Geographic Areas: | |
|   • Norway | K. Sunnana & S. Sundby |
|   • Iceland | S. Schopka |
|   • Greenland | H. Hovgaard |
|   • Alaska | T. Royer |
| • Hypotheses Discussions | All |

January 29

| | |
|---|---|
| • Summary of Previous Day's Session & Discussion | B. Atkinson |
| • Hypotheses/Research Discussions | |
| • Concluding Remarks | W.G. Doubleday |

ANNEX II

LIST OF PARTICIPANTS

| | |
|---|---|
| Anderson, J.T. | DFO, Science Branch, Newfoundland Region |
| Anthony, M. | |
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| Bowering, W.R. | DFO, Science Branch, Newfoundland Region |
| Brattey, J. | DFO, Science Branch, Newfoundland Region |
| Brodie, W.B. | DFO, Science Branch, Newfoundland Region |
| Bruce, W.J. | DFO, Enforcement Branch, Newfoundland Region |
| Campbell, J.S. | DFO, Science Branch, Newfoundland Region |
| Carscadden, J.E. | DFO, Science Branch, Newfoundland Region |
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| Davis, M.B. | DFO, Science Branch, Newfoundland Region |
| deYoung, B. | Memorial University of Newfoundland |
| Doubleday, W.G | DFO, Fisheries Science, Ottawa (Chairperson) |
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| Frank, K. | DFO, Science Branch, Scotia-Fundy Region |
| Gascon, D. | DFO, Science Branch, Quebec Region |
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| Holland, G. | DFO, Oceans Science, Ottawa |
| Hovgaard, H. | Greenland Fisheries Research Institute, Denmark |
| Jackson, L. | DFO, Communications Branch, Newfoundland Region |
| Kiceniuk, J.W. | DFO, Science Branch, Newfoundland Region |
| Lefaivre, D. | DFO, Science Branch, Quebec Region |
| Lilly, G.R. | DFO, Science Branch, Newfoundland Region |
| Loch, J. | DFO, Science Branch, Gulf Region |

| | |
|---|---|
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| Myers, R.E. | DFO, Science Branch, Newfoundland Region |
| Narayanan, S. | DFO, Science Branch, Newfoundland Region |
| Paranjape, M. | DFO, Science Branch, Newfoundland Region |
| Parsons, D.G. | DFO, Science Branch, Newfoundland Region |
| Parsons, L.S. | DFO, Science, Ottawa |
| Pepin, P. | DFO, Science Branch, Newfoundland Region |
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| Stenson, G.B. | DFO, Science Branch, Newfoundland Region |
| Strowbridge, L.A. | DFO, Enforcement Branch, Newfoundland Region |
| Sundby, S. | Institute of Marine Research, Norway |
| Sunnana, K. | Institute of Marine Research, Norway |
| Taggart, C. | DFO, Science Branch, Newfoundland Region |
| Ware, D. | DFO, Science Branch, Pacific Region |
| Warren, W.G. | DFO, Science Branch, Newfoundland Region |
| Whalen, C.A. | DFO, Fisheries and Habitat Management, NF Region |
| Winters, G.H. | DFO, Science Branch, Newfoundland Region |
| Wroblewski, J. | Memorial University of Newfoundland |